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Final input parameters for the LEP/SLD heavy flavour analyses

The LEP/SLD Heavy Flavour Working Group *

Abstract

This note describes the common input parameters for the LEP/SLD heavy flavour analyses that are used from the summer 2001 conferences onward and in the final electroweak publication.

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1 Introduction

All the measurements contributing to the electroweak fit require some input from simulated events. Quantities derived from the simulation are affected by uncertainties related to the modelling of the detector response, as well as by the limited knowledge of the physics processes that are simulated. These latter sources are common to all experiments, and they have to be treated as correlated when averaging individual results. Furthermore, in order to produce consistent averages, the input physics parameters or models used in the simulation must be the same for all analyses in all experiments.

The choice of the input physics parameters and models relevant for electroweak heavy flavour analyses is discussed below. Whenever possible measurements at LEP/SLD or at lower energies are used to constrain the models used in the simulations.

This note presents the set of input parameters that are used from the summer-2001 conferences onwards and in the final publication of the combined LEP/SLD electroweak results. In most cases the latest published results have been used. For the results taken from the Particle Data Group the ones of the 1998 edition [1] have been kept. It has been checked that the changes in the heavy flavour results using the 2000 edition [2] are completely insignificant so that it was felt safer not to update all the input tables for these small changes.

2 The heavy quark fragmentation

The process of hadron production is modelled as the convolution of a perturbative part (hard gluon radiation), and a non perturbative part, called fragmentation, described with phenomenological models.

In the JETSET [3] simulation the fragmentation model by Peterson *et al.* [4] is used, which describes the process in terms of the variable $z = (E + p_{\parallel})_{\mathrm{hadron}}/(E + p_{\parallel})_{\mathrm{quark}}$, where $p_{\parallel}$ is the momentum component in the direction of the fragmenting quark. The model contains one free parameter, ε_{Q}, which is tuned to reproduce a given value of the mean energy of the heavy hadrons produced. Such tuning depends on the cut-off used for the transition between the perturbative and the non-perturbative part, therefore ε_{Q} can not be given an absolute meaning. The energy spectrum is more conveniently described in terms of the variable x_Q, defined as the energy of the weakly-decaying hadron containing the heavy quark Q normalised to the beam energy.

The analyses quoted in Reference [5–9], which provide a value for the mean energy of b hadrons, are averaged obtaining:

$$\langle x_{\mathrm{b}} \rangle = 0.702 \pm 0.008 \tag{1}$$

where the error includes the uncertainty due to the modelling of the fragmentation function. This uncertainty is estimated by using the functional forms proposed by Collins and Spiller [10], and by Kartvelishvili *et al.* [11] as alternatives to Peterson *et al.* when extracting $\langle x_{\mathrm{b}} \rangle$.

The energy of charmed hadrons is measured in analyses which make use of lepton tags or inclusive reconstruction of $\mathrm{D^0/D^+}$-mesons [12, 13], and in analyses with full reconstruction of $\mathrm{D^{*+}}$-mesons [14–16]. The former have a larger dependence on the modelling of the spectrum, while the latter need an additional correction to obtain the energy of the weakly-decaying hadron. In all cases the contribution from charmed hadrons produced by hard gluons splitting to heavy quarks is removed.

The average energy of weakly-decaying c-hadrons is found to be

$$\langle x_{\mathrm{c}} \rangle = 0.484 \pm 0.008 \tag{2}$$

which again includes the estimated uncertainty from the modelling of the spectrum.

3 Heavy quarks from gluon splitting

Hard gluons can occasionally split to heavy quark pairs. In several analyses these contributions need to be subtracted. In particular the uncertainty on the rate of gluons splitting to $\mathrm{b\overline{b}}$ pairs is the single largest contribution to the systematic error on the R_{b} world average.

The rates $g_{\mathrm{c\bar{c}}}$ and $g_{\mathrm{b\bar{b}}}$ are defined as the number of hadronic Z decays containing a hard gluon splitting to a $\mathrm{c\overline{c}}$ or $\mathrm{b\overline{b}}$ pair, normalised to the total number of hadronic Z decays.

Measurements of $g_{\mathrm{b\bar{b}}}$ rely on an inclusive lifetime-based tag applied to the jets reconstructed in the event [17–21], while measurements of $g_{\mathrm{c\bar{c}}}$ make use of exclusive D^* reconstruction, final states containing leptons, or are based on the combination of event shape variables [22–24].

Averaging published results yields:

$$\begin{aligned} g_{\mathrm{c\bar{c}}} &= 0.0296 \pm 0.0038\,, \\ g_{\mathrm{b\bar{b}}} &= 0.00254 \pm 0.00051\,, \end{aligned} \tag{3}$$

with only a very small correlation between the two values.

4 Multiplicities in heavy flavour decays

Many analyses make use of inclusive b tagging methods which exploit the long lifetimes of b hadrons. The discrimination is based on the presence, in a jet, or a hemisphere, or the whole event, of charged tracks with significant impact parameter from the primary vertex of the events. Therefore the tagging efficiency is directly affected by the number of charged tracks produced in the long-lived hadron decay.

In R_{b} measurements the tag is applied to hemispheres, and the b efficiency is measured directly in the data from the fraction of events with both hemispheres tagged. The b charged multiplicity only enters through the hemisphere correlation, which is computed with the simulation. Measurements of the average b charged multiplicity performed at LEP are used. Results from lower energy experiments cannot be used because of the different b-hadron mixture.

However, the charm selection efficiency is taken from the simulation, at least for the samples with highest purity. It is therefore crucial to propagate correctly the uncertainty due to the decay charged multiplicities of the various charmed hadrons. This is done separately for each hadron species due to the significant differences in lifetimes.

The charm selection efficiency also depends on the number of neutral particles accompanying the charged particles in a given topological decay channel. The size of this effect depends on how invariant mass cuts are implemented and might vary substantially in different analyses. The uncertainty is evaluated varying the K^0 and π^0 production rates in charmed hadron decays.

4.1 Average charged multiplicity in b hadron decays

Inclusive measurements of the mean b-hadron charged multiplicity at LEP [25–27] are combined to obtain:

$$\langle n_b^{ch} \rangle = 4.955 \pm 0.062 \ . \tag{4}$$

Particles coming from the decay of $B^{\star\star}$ or other possible excited b states are excluded; the result is also corrected to exclude charged particles originating from the decay of K^0 and Λ.

4.2 Charged multiplicities of c hadron decays

Inclusive topological branching fractions have been measured for D^0, D^+ and $\mathrm{D_s}$ [28]. For each species, each channel is varied within its uncertainty, except for the channel with the highest rate, which is used to compensate the variation. The resulting errors are combined using the corresponding correlation coefficients.

The values f_i of the branching fractions for the decays into i charged particles, the corresponding errors σ_i and correlation coefficients C_{ij} are given in Table 1.

D^0	$f_0 = 0.054$	$f_2 = 0.634$	$f_4 = 0.293$	$f_6 = 0.019$
	$\sigma_0 = 0.011$		$\sigma_4 = 0.023$	$\sigma_6 = 0.009$
	$C_{04} = 0.07$	$C_{46} = -0.46$	$C_{06} = 0$	
D^+	$f_1 = 0.384$	$f_3 = 0.541$	$f_5 = 0.075$	
	$\sigma_1 = 0.023$		$\sigma_5 = 0.015$	
	$C_{15} = -0.33$			
$\mathrm{D_s}$	$f_1 = 0.37$	$f_3 = 0.42$	$f_5 = 0.21$	
	$\sigma_1 = 0.10$		$\sigma_5 = 0.11$	
	$C_{15} = -0.02$			

Table 1: Topological rates for the different charm-meson species, with estimated errors and correlation coefficients. The subscripts indicate the number of charged particles produced.

4.3 Neutral particle production in c hadron decays

The procedure to estimate the residual dependence of the lifetime tag efficiency on the average rate of neutral particles produced in charm decays is tailored, case by case, on the specific properties of the tag and based on the measurements available [1].[1] Although the procedures differ somewhat between experiments, the resulting estimated uncertainties are taken as fully correlated.

5 Heavy flavour lifetimes

The lifetimes of heavy hadrons are relevant to many analyses, in particular all those which make use of lifetime-based b tagging methods. As for the charged multiplicity, in the case of the R_b analyses charm lifetimes enter directly in the estimate of the charm contamination in high purity samples, whereas b hadron lifetimes only affect the estimate of the hemisphere correlations.

[1] In all cases it has been checked that using the 2000 edition of RPP is not changing the results or the errors.

5.1 Average b hadron lifetime

The average lifetime of b hadrons is taken to be [1]

$$\tau_b = 1.576 \pm 0.016 \text{ ps} , \tag{5}$$

which is obtained from analyses of fully inclusive b final states. The lifetime difference between b species has in general little impact in all analyses. It is considered as a source of uncertainty in the R_b analyses either by using the individual lifetimes [1] or by enlarging the error to 0.05 ps.

5.2 Lifetimes of c hadrons

The lifetimes of the different c hadron species are considered as individual sources of uncertainties. The values and errors are [1]

$$\begin{aligned} \tau(D^0) &= 0.415 \pm 0.004 \text{ ps} , \\ \tau(D^+) &= 1.057 \pm 0.015 \text{ ps} , \\ \tau(D_s) &= 0.467 \pm 0.017 \text{ ps} , \\ \tau(\Lambda_c) &= 0.206 \pm 0.012 \text{ ps} . \end{aligned} \tag{6}$$

6 Charmed hadron decays to exclusive final states

Charm counting measurements determine the production rates of individual c-hadron species by tagging exclusive final states, using the branching fraction for the appropriate decay mode as input. The values and errors used are [1, 29]:

$$\begin{aligned} \mathrm{BR}(D^0 \to K^-\pi^+) &= 0.0385 \pm 0.0009 , \\ \mathrm{BR}(D^+ \to K^-\pi^+\pi^+) &= 0.090 \pm 0.006 , \\ \mathrm{BR}(D_s^+ \to \phi\pi^+) &= 0.036 \pm 0.009 , \\ \frac{\mathrm{BR}(D_s^+ \to \bar{K}^{\star 0}K^+)}{\mathrm{BR}(D_s^+ \to \phi\pi^+)} &= 0.92 \pm 0.09 , \\ \mathrm{BR}(\Lambda_c \to pK^-\pi^+) &= 0.050 \pm 0.013 . \end{aligned} \tag{7}$$

7 Heavy flavour leptonic decays

Many analyses rely on semileptonic final states in order to tag the presence of heavy hadrons and possibly their charge. Assessing the performance of such tags involves estimating the rates of the different sources of lepton candidates in hadronic events, and modelling the kinematics of the leptons produced in the decay of heavy hadrons.

The rates for the major sources (direct b and c decays $\mathrm{b} \to \ell^-$ and $\mathrm{c} \to \ell^+$, cascade b decays $\mathrm{b} \to \mathrm{c} \to \ell^+$) are measured at LEP, and included as fitted parameters. The modelling of the decay kinematics is a common source of systematic uncertainty. The rates for the other sources are taken from external measurements.

7.1 Modelling of direct semileptonic b decays

For the semileptonic decays of B^0- and B^+-mesons the CLEO collaboration has compared decay models to their data and measured the free parameters of the models. Based on the CLEO fits [30], the LEP experiments quote results for three different models.

- The model proposed by Altarelli *et al.* [31], is an extension of the free quark model which attempts to account for non-perturbative effects kinematically. The two free parameters of the model, the Fermi momentum of the constituent quarks inside the heavy meson and the mass of the final quark, are determined from CLEO data to be $p_{\mathrm{F}} = 298$ MeV/c, $m_c = 1673$ MeV/c^2.
- The form-factor model proposed by Isgur *et al.* [32], with the model prediction that 11% of semileptonic B-meson decays result in an L=1 charm-meson, $D^{\star\star}$.
- The same model with the rate of $D^{\star\star}$-mesons increased to 32%, as preferred by the CLEO data [30, 32].

The model of Altarelli *et al.* is used to derive the central values of the analyses, while the two others, which give respectively harder and softer lepton spectra, are used to give an estimate of the associated uncertainty.

Reweighting functions are constructed to adjust the lepton spectrum of semileptonic B^0 and B^+ decays in the LEP Monte Carlo samples to the three models based on CLEO data. For use in Z decays, the same reweighting functions have been assumed to be valid for the B_s-meson and b-baryons. This would be correct in the simplest spectator model, and is thought more generally to be adequate for the B_s. The baryons contribution is only about 10%, and no additional systematic error is assigned.

7.2 Modelling of direct semileptonic c decays

The measurements of DELCO [33] and MARK III [34] for D^0 and D^+ semileptonic decays have been combined and parameterised using the model of Altarelli *et al.* as a convenient functional form. The D boost and the experimental resolution are taken into account in the fit to the data. Based on this fit [35], the model parameters are fixed to $p_{\mathrm{F}} = 0.467$ GeV/c, $m_s = 0.001$ GeV/c^2 and they are varied to $p_{\mathrm{F}} = 0.353$ GeV/c, $m_s = 0.001$ GeV/c^2 and $p_{\mathrm{F}} = 0.467$ GeV/c, $m_s = 0.153$ GeV/c^2 to derive an estimate of the associated uncertainty. The reweighting functions derived from D^0 and D^+ decays are assumed to be valid for all charm hadrons.

7.3 Modelling of cascade semileptonic b decays

For the cascade decays, $\mathrm{b} \to \mathrm{c} \to \ell^+$, the three models used for $\mathrm{c} \to \ell^+$ decays are combined with the measured $\mathrm{b} \to \mathrm{D}$ spectrum from CLEO [36] to generate three models for the lepton momentum spectrum in the rest frame of the b hadron. The CLEO $\mathrm{b} \to \mathrm{D}$ spectrum can be conveniently modelled by a Peterson function [4] with free parameter $\varepsilon = 0.42 \pm 0.07$. The effect of this $\mathrm{b} \to \mathrm{D}$ model uncertainty on the $\mathrm{b} \to \mathrm{c} \to \ell^+$ spectrum is negligible compared to the uncertainty from the $\mathrm{c} \to \ell^+$ models.

7.4 The rate of $\mathrm{b} \to \overline{\mathrm{c}} \to \ell^-$ transitions

Several quantities related to the rate of leptons from c hadrons produced from the "upper vertex" in b-hadron decays have been measured. An estimate of this rate is therefore possible, based upon experimental results.

The inclusive and flavour-specific $\mathrm{B} \to \mathrm{D}$ and $\mathrm{B} \to \Lambda_c^+$ rates measured at CLEO [37–39] are combined with the $\mathrm{B} \to \mathrm{DD(X)}$ rates measured in ALEPH [40] to extract the probabilities of producing the different c-hadrons from the upper vertex in b decays. These are combined with the c-hadron semileptonic branching fractions to obtain a value for the $\mathrm{BR}(\mathrm{b} \to \overline{\mathrm{c}} \to \ell^-)$.

The estimate obtained is

$$\mathrm{BR}(\mathrm{b} \to \overline{\mathrm{c}} \to \ell^-) = 0.0162\,^{+0.0044}_{-0.0036}\,. \tag{8}$$

7.5 Other semileptonic decays

The rate for $\mathrm{b} \to \tau^- \to \ell^-$ decaysis derived from existing measurements of $\mathrm{BR}(\mathrm{b} \to \tau)$ [41–44] combined with the τ leptonic branching fraction [1]. The procedure yields:

$$\mathrm{BR}(\mathrm{b} \to \tau^- \to \ell^-) = 0.00419 \pm 0.00055\ . \tag{9}$$

The rate for $\mathrm{b} \to (J/\psi, \psi') \to \ell\ell$ decaysis calculated from the production rate of J/ψ and ψ' in $Z \to b\bar{b}$ decays, and the J/ψ and ψ' leptonic branching fractions [1], yielding

$$\mathrm{BR}(\mathrm{b} \to (J/\psi, \psi') \to \ell\ell) = 0.00072 \pm 0.00006\ . \tag{10}$$

8 Hemisphere correlations in double-tag methods

In analyses where a b-tagging algorithm is applied in one hemisphere, the tagging efficiency can be measured from the data by comparing the fraction of hemispheres that are tagged and the fraction of events with both hemispheres tagged. However, the correlation between the tagging efficiencies in the two hemispheres must then be estimated from simulation. This is particularly crucial for the precise R_b double tag measurements.

There are basically three physics sources for such a correlation:

- detector inhomogeneities,
- the use of a common primary vertex.
- kinematic correlations, mainly due to gluon radiation,

Detector effects are easily controllable from the data by measuring the tagging rate as a function of jet direction and then folding the two hemispheres in an event. This error source is clearly uncorrelated between the experiments.

The second of these sources is relatively small for algorithms based on the reconstruction of the b decay length, since this is dominated by the uncertainty on the position of the secondary vertex.

However, it is a major issue for tags based on track impact parameters, and it is particularly difficult to control since it heavily influences the other sources. Therefore in the R_{b} analyses the primary vertex is generally reconstructed independently in the two hemispheres, rendering this source of correlation negligible.

The kinematic correlations are correlated between the experiments. They mainly arise from the fact that the tagging efficiency depends on the b-hadron momentum and that a gluon emitted at a large angle reduces the energy of both quarks.

If the efficiency is proportional to the b-hadron momentum the efficiency correlation is directly given by the momentum correlation. Analytic $\mathcal{O}(\alpha_{\mathrm{s}})$ QCD calculations predicts effects of about 1.4% [45] for the correlation between the two b-quark momenta. At the parton level, fragmentation models agree to the 0.2% level with this number. At the hadron level HERWIG [46] gives an up to 0.8% larger correlation than the other models.

Since the proportionality between the B-momentum and the tagging efficiency is only approximate, in practice the experiments have derived test quantities that are sensitive to the kinematical correlations and the systematic uncertainties are derived from data/Monte Carlo comparisons. As an example the momentum of the fastest jet assuming a three jet topology can be calculated and the tagging rate for the hemisphere containing this jet and the opposite one is measured. Although these errors have a large statistical component, they are conservatively taken as fully correlated between the experiments.

Events where the radiated gluon is so hard that the two b-hadrons are in the same hemisphere are particularly relevant for the estimate of the correlation. The rate of such events (about 1% of all $\mathrm{Z} \rightarrow \mathrm{b\bar{b}}$ events) is varied by 30%, motivated by a comparison of matrix element and parton shower models.

Furthermore, the hemisphere correlation also depends on b hadron production and decay properties. Such a dependence is a small second order effect for analyses which reconstruct the primary vertex independently in the two hemispheres, but can be substantial if a common primary vertex is used, due to the inclusion of tracks from b-hadrons into the primary vertex determination. The sources of uncertainty considered are:

- average charged track multiplicity in b-hadron decay,
- b fragmentation,
- b hadron lifetimes,

and the errors are evaluated according to the prescription in this section.

9 Light quark background in lifetime tagged samples

The amount of light quark background in lifetime-tagged samples is mainly determined by the rate of long-lived light hadrons, namely K^0_s and Λ, produced in the fragmentation. This is only a significant source of uncertainty for the precise R_{b} measurements. In the case of forward-backward asymmetry measurements, other details of light quark fragmentation are relevant in the extraction of the asymmetry from the measured charge flow.

9.1 The rate of long-lived light hadrons

All experiments have measured the rates of long-lived light hadrons and tuned their fragmentation model accordingly. Variations of 10% around the central value are used to estimate the uncertainty.

9.2 The fragmentation of light quarks

The JETSET model contains many free parameters, several of which influence the charge flow predictions. These parameters have been tuned individually by the experiments and it is not possible to define a common procedure to evaluate the errors due to light quark fragmentation. Fortunately these errors turn out to be relatively small, and they are assumed to be fully correlated even if the procedures to evaluate them vary slightly between the experiments.

10 Corrections to the measured electroweak parameters

10.1 Corrections to R_{b}, R_{c}

Small corrections have to be applied to the measurements performed by the experiments. The R_{b} and R_{c} analyses measure the ratio of productions cross sections $R_{\mathrm{q}} = \sigma_{\mathrm{q\bar{q}}}/\sigma_{\mathrm{had}}$. To obtain the ratios of partial widths $R^0_{\mathrm{q}} = \Gamma_{\mathrm{q\bar{q}}}/\Gamma_{\mathrm{had}}$, small corrections for photon exchange and $\gamma - $Z-interference have to be applied. These corrections are typically $+0.0002$ for R_{b} and -0.0002 for R_{c}, and are applied by the experiments before the combination as their size depends slightly on the invariant mass cutoff of the $\mathrm{q\bar{q}}$-system imposed in the analysis.

10.2 QCD corrections to the heavy flavour forward-backward asymmetries

The measured forward backward asymmetries do not correspond to the underlying quark asymmetries due to QCD effects. The dominant corrections are due to radiation of gluons from the final state quarks. The QCD corrections do not depend on the beam polarisation and are thus identical for the unpolarised forward-backward asymmetry and the left-right-forward-backward asymmetries.

Theoretical calculations use either the quark direction or the thrust direction to define the axis relative to which the asymmetry is computed. Since the reconstructed thrust axis is generally used as the heavy quark direction estimator in experimental measurements, calculations based on the thrust axis are considered.

The effect on the asymmetry at the scale $\mu^2 = m^2_{\mathrm{Z}}$ is parametrised as [47]:

$$\begin{aligned} \left(A^{\mathrm{q\bar{q}}}_{\mathrm{FB}}\right)_{\mathrm{meas}} &= (1 - C_{\mathrm{QCD}})\left(A^{\mathrm{q\bar{q}}}_{\mathrm{FB}}\right)_{\mathrm{no\,QCD}} \\ &= \left(1 - \frac{\alpha_s(m^2_{\mathrm{Z}})}{\pi}c_1 - \left(\frac{\alpha_s(m^2_{\mathrm{Z}})}{\pi}\right)^2 c_2\right)\left(A^{\mathrm{q\bar{q}}}_{\mathrm{FB}}\right)_{\mathrm{no\,QCD}} . \end{aligned} \tag{11}$$

The first-order corrections are known including mass effects [48]. Taking the thrust axis as the direction and using the pole mass, they are $c_1 = 0.77$ for $A^{\mathrm{b\bar{b}}}_{\mathrm{FB}}$ and $c_1 = 0.86$ for $A^{\mathrm{c\bar{c}}}_{\mathrm{FB}}$.

The second order corrections have recently been recalculated [49, 50] and found to be in disagreement with previous results [48]. The calculation of [50] is strictly massless and also neglects the corrections from triangle diagrams involving top quarks, given in [48]: corrections arising from diagrams which lead to two-parton final states are the largest, and they can be added to the results of [50], as they apply in the same way to calculations based either on the thrust or and the quark direction.

The second order coefficients used are $c_2 = 5.93$ for $A_{\rm FB}^{\rm b\overline{b}}$ and $c_2 = 8.5$ for $A_{\rm FB}^{\rm c\overline{c}}$. The final QCD correction coefficients, including fragmentation effects and using the thrust axis as reference direction ($C_{\rm QCD}^{\rm had,T}$), are $C_{\rm QCD}^{\rm had,T} = 0.0354 \pm 0.0063$ for $A_{\rm FB}^{\rm b\overline{b}}$ and $C_{\rm QCD}^{\rm had,T} = 0.0413 \pm 0.0063$ for $A_{\rm FB}^{\rm c\overline{c}}$. The breakdown of the errors is given in Table 2.

Error on $C_{\rm QCD}^{\rm had,T}$		$\rm b\overline{b}$	$\rm c\overline{c}$
Higher orders	[50]	0.0025	0.0046
Mass effects	[47]	0.0015	0.0008
Higher order mass	[50]	0.005	0.002
$\alpha_s = 0.119 \pm 0.003$		0.0012	0.0015
Hadronisation	[47]	0.0023	0.0035
Total		0.0063	0.0063

Table 2: Error sources for the QCD corrections to the forward-backward asymmetries.

The procedure to implement QCD corrections in the experimental analyses is non-trivial. It is described in detail in [47] and briefly summarised in the following.

The corrections provided by theoretical calculations are not directly applicable to experimental measurements for two main reasons. First, the thrust axis used in theoretical calculations is defined using partons; a further smearing is caused by the hadronisation of partons into physical particles. This effect, typically ten times smaller than the correction itself, is taken from the simulation using the JETSET model, and its full size is taken as an additional uncertainty. Second, and much more important, the experimental selection and analysis method can introduce a bias in the topology of the events used, or intrinsically correct for the effects. This analysis bias is calculated using the full detector simulation with JETSET for event-generation, where it has been verified, that JETSET reproduces the analytical calculations very well for full acceptance. It turns out that analyses based on semileptonic decays typically need between 50% and 70% of the full correction. In the jetcharge analyses the QCD corrections are largely hidden in the hemisphere correlations which are corrected for internally. The remaining corrections are very small.

Because of the analysis dependence of the QCD corrections all asymmetries quoted in the notes of the LEP Electroweak Working Group are corrected for QCD effects.

The uncertainty on the theoretical calculation of the corrections, as well as on the additional effect due to hadronisation, are taken as fully correlated between the different measurements. The "scaling factor" applied for each individual analysis to account for the experimental bias is instead evaluated case by case together with its associated uncertainty, and these errors are taken as uncorrelated.

10.3 Other corrections to the asymmetries

The forward backward asymmetries at LEP vary strongly as a function of the centre of mass energy because of $\gamma-$Z-interference. Since the mean energies at the different points vary slightly with time, the mean energies of the results of the different analyses are also not completely identical. The experiments quote the mean centre of mass energy for each asymmetry measurement. In a first fit the asymmetries are corrected to the closest of the three energies $\sqrt{s} = 89.55\mathrm{GeV}(-2),\ 91.26\mathrm{GeV}(\mathrm{pk}),\ 92.94\mathrm{GeV}(+2)$ assuming Standard Model energy dependence.

The slope of the asymmetries depends only on the well known fermion charges and axial couplings while the asymmetry value on the Z-pole is sensitive to the effective weak mixing angle. Once it is verified in the first fit that the energy dependence is indeed consistent with that expected in the Standard Model, in a second fit all asymmetries are corrected to the peak energy (91.26 GeV) before fitting.

To obtain the pole asymmetry, $A_{\mathrm{FB}}^{0,\mathrm{q}}$, which is defined as the asymmetry at the Z-mass for pure Z-exchange, the fitted asymmetries at the peak energy, denoted as $A_{\mathrm{FB}}^{\mathrm{q\overline{q}}}(\mathrm{pk})$ need to be corrected further as summarised in Table 3. These corrections are due to the energy shift from 91.26 GeV to m_{Z}, initial state radiation, γ exchange and γ-Z interference. A very small correction due to the nonzero value of the b quark mass is included in the correction called γ-Z interference. All corrections are calculated using ZFITTER.

Source	$\delta A_{\mathrm{FB}}^{\mathrm{b\overline{b}}}$	$\delta A_{\mathrm{FB}}^{\mathrm{c\overline{c}}}$
$\sqrt{s} = m_{\mathrm{Z}}$	-0.0013	-0.0034
QED corrections	$+0.0041$	$+0.0104$
γ, γ-Z, mass	-0.0003	-0.0008
Total	$+0.0025$	$+0.0062$

Table 3: Corrections to be applied to the quark asymmetries as $A_{\mathrm{FB}}^{0,\mathrm{q}} = A_{\mathrm{FB}}^{\mathrm{q\overline{q}}}(\mathrm{pk}) + \delta A_{\mathrm{FB}}$.

Similar corrections have to be applied to the left-right-forward-backward asymmetries. However they are directly presented in terms of $\mathcal{A}_{\mathrm{b}}$ and $\mathcal{A}_{\mathrm{c}}$ by SLD.

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