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Electroweak Experimental Results at LEP

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Abstract

Recent data on precision tests of the standard model at LEP are presented and compared with the theoretical expectations. These results are obtained by a preliminary analysis of all the data collected at LEP between 1990 and 1995.

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1 Introduction

The results presented here are based on the analysis of $\sim$ 16 million Z decays, collected by the four LEP experiments during the years 1990-1995. The data consist of the hadronic and leptonic cross sections, the leptonic forward-backward asymmetries, the τ polarization asymmetries, the $\mathrm{b\bar{b}}$ and $\mathrm{c\bar{c}}$ partial widths and forward -backward asymmetries and the $\mathrm{q\bar{q}}$ charge asymmetry [1]. Information on the individual results and a detailed list of references can be found in [2]. Some of the electroweak results from SLD and the TEVATRON are also included.

2 Z lineshape and LEP energy calibration

The parameters m_Z and Γ_Z are extracted by a scan of the Z resonance [3], i.e. by measuring the cross sections $e^+e^- \rightarrow f\bar{f}$ for hadronic ($q\bar{q}$) and leptonic ($\ell^+\ell^-$) final states as a function of $\sqrt{s} \sim m_Z$. The number of selected events and the systematic errors on the event selections are shown in Table 1.

The theoretical error for the calculation of the small angle Bhabha cross section of 0.11% represents the accuracy of the Monte Carlo generator BHLUMI [4] and has been treated as common to all experiments (ALEPH still uses the theoretical error of 0.16% associated to the previous BHLUMI version). This theoretical uncertainty on the luminosity normalization improves with respect to previous calculations from 0.16% to 0.11% [5], reflecting into a more accurate determination of the hadronic cross section.

The LEP energy uncertainty [6] has an important impact on the determination of m_Z and Γ_Z: the error on the mass is in fact dominated by the calibration error, while the error on the width due to calibration uncertainties is almost as large as the statistical one.

For the 1995 scan [7], the LEP instrumentation was improved by installing two new NMR probes in the LEP tunnel. Furthermore, for six fills resonant depolarisation [8] measurements were performed at both the beginning and end of fills. Both the tunnel NMRs and

		ALEPH	DELPHI	L3	OPAL
Number of events	$q\bar{q}$	4164K	3556K	3358K	3357K
	$\ell^+\ell^-$	485K	376K	317K	454K
Syst. error	$q\bar{q}$	0.07%	0.1%	0.05%	0.15%
	e^+e^-	0.48%	0.50%	0.25%	0.25%
	$\mu^+\mu^-$	0.25%	0.30%	0.30%	0.15%
	$\tau^+\tau^-$	0.35%	0.60%	0.65%	0.46%
Experimental syst. error on luminosity		0.07%	0.09%	0.09%	0.08%
Common theory error		0.16%	0.11%	0.11%	0.11%

Table 1: Number of selected events and systematic errors of the event selection used for the analysis of the Z line shape. The data sample corresponds to an integrated luminosity of $\sim$140 pb^{-1} collected between 1990 and 1995 by each LEP experiment.

the six calibration experiments indicated a significant rise of the LEP beam energy during a fill. This raise has been associated to parasitic currents on the LEP beam pipe induced by the passage of trains on the nearby railway. As a consequence, this new effect has been included in the modeling of the mean beam energy in 1995.

The 1993 and 1994 energies have also been revised, since the same effect was almost certainly present in those years as well. Although the description of the energy rise for earlier years strongly depends on observations made in 1995, there are calibration experiments performed in 1993 and 1994 which support the present analysis.

The measurements of the LEP 1993-1995 beam energies and the associated uncertainties are still preliminary and might still improve as a result of future data. In particular, the installation of 14 additional NMR probes in the LEP tunnel will allow a better testing of the modeling of the energy rise in a fill.

Another point worth being recalled is that the 1995 energy scan required the control of a new effect associated with the bunch-train bumps. These bumps induce opposite sign vertical dispersion at the interaction points, and, if the beam collide with an offset (δ_y), a shift in the centre of mass energy proportional to δ_y is produced. This effect represented a potentially major source of systematic uncertainty which had called into question the feasibility of the 1995 scan. It was controlled by performing Vernier scans for each off-peak fill, hence reducing δ_y as much as possible. As a result, the systematic uncertainties arising from the dispersion corrections are small, inducing an error of ~ 0.3 MeV on m_Z and of ~ 0.25 MeV on Γ_Z.

Finally, the systematic error on Γ_Z resulting from the uncertainty of the centre-of-mass energy spread [7] is now reduced to ~ 0.2 MeV, while it used to be ~ 1 MeV in the past.

There are nine independent parameters to be fitted: m_Z, Γ_Z, σ_h^0, R_e, R_μ, R_τ, $A_{FB}^{0,e}$, $A_{FB}^{0,\mu}$, $A_{FB}^{0,\tau}$ [3]. The parameter σ_h^0 is the hadronic cross section after deconvolution of initial state radiation, which, at the peak, takes the form:

$$\sigma_h^0 \equiv \frac{12\pi}{m_Z^2}\frac{\Gamma_{ee}\Gamma_{had}}{\Gamma_Z^2}.$$

The pole asymmetry $A_{FB}^{0,f}$ can be expressed directly in terms of the ratio of the vector (g_v^f) and axial vector (g_a^f) coupling constants of the neutral current to fermion f:

$$A_{FB}^{0,f} \equiv \frac{3}{4}\mathcal{A}_e\mathcal{A}_f \quad (1)$$

with:

$$\mathcal{A}_f \equiv \frac{2g_{Vf}g_{Af}}{g_{Vf}^2 + g_{Af}^2}. \quad (2)$$

The parameter R_ℓ gives, for each lepton species, the ratio of the hadronic and the leptonic partial widths.

These parameters are chosen because they are most directly related to the experimental quantities and are weakly correlated. The number of fitted quantities is reduced to five when lepton universality is assumed. Tables 2 and 3 show the results obtained when combining the data of the four collaborations for the nine and five parameter fit,

Parameter	Average Value
m_Z(GeV)	91.1863±0.0020
Γ_Z(GeV)	2.4946±0.0027
σ_h^0(nb)	41.508±0.056
R_e	20.754±0.057
R_μ	20.796±0.040
R_τ	20.814±0.055
$A_{FB}^{0,e}$	0.0160±0.0024
$A_{FB}^{0,\mu}$	0.0162±0.0013
$A_{FB}^{0,\tau}$	0.0201±0.0018

Table 2: Average line shape and asymmetry parameters from the data of the four LEP experiments, without the assumption of lepton universality.

Parameter	Average Value
m_Z(GeV)	91.1863±0.0020
Γ_Z(GeV)	2.4946±0.0027
σ_h^0(nb)	41.508±0.056
R_ℓ	20.778±0.029
$A_{FB}^{0,\ell}$	0.0174±0.0010

Table 3: Average line shape and asymmetry parameters from the results of the four LEP experiments, assuming lepton universality.

	m_Z	Γ_Z	σ_h^0	R_ℓ	$A_{FB}^{0,\ell}$
m_Z	1.00	0.09	−0.01	−0.01	0.08
Γ_Z	0.09	1.00	−0.14	−0.01	0.00
σ_h^0	−0.01	−0.14	1.00	0.15	0.01
R_ℓ	−0.01	−0.01	0.15	1.00	0.01
$A_{FB}^{0,\ell}$	0.08	0.00	0.01	0.01	1.00

Table 4: The correlation matrix for the set of parameters given in Table 3.

Without Lepton Universality:	
Γ_{ee} (MeV)	83.96±0.15
$\Gamma_{\mu\mu}$ (MeV)	83.79±0.22
$\Gamma_{\tau\tau}$ (MeV)	83.72±0.26

With Lepton Universality:	
$\Gamma_{\ell\ell}$ (MeV)	83.91±0.11
$\Gamma_{\rm had}$ (MeV)	1743.6±2.5
$\Gamma_{\rm inv}$ (MeV)	499.5±2.0

Table 5: Partial decay widths of the Z boson, derived from the results of the 9 and 5-parameter fit.

respectively. The average correlation coefficients for the five parameter fit are given in Table 4.

Starting from these primary measurements one can derive important additional quantities as, for example, $\Gamma_{\ell\ell}$, $\Gamma_{\rm had}$ and $\Gamma_{\rm inv}$, which are shown in Table 5.

Using the results of Table 5 on the ratio $\Gamma_{\rm inv}/\Gamma_{\ell\ell}$ and taking the standard model prediction for $\Gamma_{\nu\nu}/\Gamma_{\ell\ell}$ (1.991 ± 0.001), the number of light neutrino species can be derived:

$$N_\nu \;=\; 2.989 \pm 0.012\,.$$

From the ratio R_ℓ of the hadronic and the leptonic partial widths one can extract a measurement of α_s. For $m_Z = 91.1863$ GeV, and imposing $m_t = 175 \pm 6$ GeV [9–11] as a constraint, $\alpha_s = 0.124 \pm 0.004 \pm 0.002$ is obtained, where the second error accounts for the variation of the result when varying m_H in the range 60 GeV $\leq m_H \leq$ 1000 GeV.

The line shape results presented here are not only preliminary, but also not complete. At present, only ALEPH, DELPHI and L3 have produced cross sections for the '95 data. The measurement of Γ_Z should therefore still improve with the inclusion of the complete set of data and of the final LEP energy calibration results.

3 The hadronic γZ interference term

As an alternative approach, cross sections and lepton forward-backward asymmetries can be described in a more model independent way along the lines of [12], the so-called S-matrix approach. In the fitting procedure described in the previous section, the interference between the continuum and the Z resonance amplitude was fixed to the value predicted by the standard model. However, this assumption can be tested by measuring the interference term directly from the data.

Measurements of the hadronic cross section at centre-of-mass energies far away from the Z pole are especially sensitive to the parameters describing the interference between photon and Z-boson exchange $j^{\rm tot}_{\rm had}$. The results presented here [13] include the data collected at LEP in 1995 at $\sqrt{s}$ from 130 GeV to 140 GeV.

The combination of results from the four LEP experiments gives a value for $j^{\rm tot}_{\rm had}$ of -0.21 ± 0.20, to be compared with the standard model prediction of 0.22. This discrepancy of about 2.2 standard deviations is due to the large negative value for $j^{\rm tot}_{\rm had}$ obtained by three experiments. The precision on the hadronic interference can be improved by including low energy data. The fit to the LEP and TOPAZ [14] cross sections gives $j^{\rm tot}_{\rm had} = -0.07 \pm 0.16$, in better agreement with theory.

4 τ polarization

The τ polarization is determined by measuring the longitudinal polarization of τ pairs produced in Z decays. It is defined as [3]

$$\mathcal{P}_\tau \equiv \frac{\sigma_R - \sigma_L}{\sigma_R + \sigma_L}, \qquad (3)$$

where σ_R and σ_L are the τ-pair cross sections for the production of a right-handed and left-handed τ^-, respectively. The angular dependence of P_τ as a function of the angle θ between the e^- and the τ^- is given by:

$$\mathcal{P}_\tau(\cos\theta) = -\frac{\mathcal{A}_\tau(1+\cos^2\theta) + 2\mathcal{A}_e\cos\theta}{1+\cos^2\theta + 2\mathcal{A}_\tau\mathcal{A}_e\cos\theta}, \qquad (4)$$

with $\mathcal{A}_e$ and $\mathcal{A}_\tau$ as defined in Equation (2).

When averaged on all production angles P_τ is a measurement of $\mathcal{A}_\tau$, while as a function of $cos\theta$, $\mathcal{P}_\tau$ provides nearly independent determinations of $\mathcal{A}_\tau$ and $\mathcal{A}_e$, allowing thus to test universality of the couplings of the Z to e and τ. When combining the results from the four LEP experiments, the average values for $\mathcal{A}_\tau$ and $\mathcal{A}_e$ are:

$$\mathcal{A}_\tau = 0.1401 \pm 0.0067 \tag{5}$$

$$\mathcal{A}_e = 0.1382 \pm 0.0076 . \tag{6}$$

The measurements included in the above averages do not yet make use of the full LEP1 statistics. Some improvements in the results can therefore be expected, especially for $\mathcal{A}_e$, a quantity still dominated by statistical errors.

5 $A_{\rm FB}^{0,\rm b}$ and $A_{\rm FB}^{0,\rm c}$

The new LEP average results for the b and c forward-backward asymmetries are:

$$\begin{aligned} A_{\rm FB}^{0,\rm b} &= 0.0979 \pm 0.0023 \\ A_{\rm FB}^{0,\rm c} &= 0.0733 \pm 0.0049 , \end{aligned}$$

where all corrections due to the energy shift to $\sqrt{s} = m_{\rm Z}$, initial state radiation and QCD effects are already taken into account.

The central value of $A_{\rm FB}^{0,\rm b}$ has decreased by 0.0023 with respect to the result shown at the winter conferences and the associated uncertainty is now ∼20% smaller. These changes are due to some newly analysed data and to an improved treatment of QCD corrections. Now, in fact, in the analyses of $A_{\rm FB}^{0,\rm b}$ using a lepton or $\rm D^*$ tag, the QCD corrections take into account the bias introduced by the experimental cuts, which considerably reduce the QCD effects with respect to their theoretical expectations [15,16]. For example, for the DELPHI analysis of $A_{\rm FB}^{0,\rm b}$ using a lepton tag, this reduction amounts to about 50% and is mainly associated to the selection of a high momentum lepton [17].

6 $\langle Q_{FB} \rangle$

One can take advantage of the large hadron statistics and measure the average quark charge asymmetry for all hadronic events. To infer the original quark charge, one relies on the fact that the leading particles in a jet carry information on their primary charge.

The present value of $\sin^2\theta_{\rm eff}^{\rm lept}$ from inclusive hadronic charge asymmetries at LEP (unchanged with respect to the winter conferences) is:

$$\sin^2\theta_{\rm eff}^{\rm lept} = 0.2320 \pm 0.0010\,.$$

7 $\sin^2\theta_{\rm eff}^{\rm lept}$

The effective electroweak mixing parameter $\sin^2\theta_{\rm eff}^{\rm lept}$ is defined from the expression [3]:

$$\sin^2\theta_{\rm eff}^{\rm lept} \equiv \frac{1}{4}(1 - g_{V\ell}/g_{A\ell})\,, \tag{7}$$

and, in the standard model, can be extracted from the combined LEP measurements for the various asymmetries. The results of the determinations of $\sin^2\theta_{\rm eff}^{\rm lept}$ are shown in Figure 1.

The uncertainty associated to the value of the fine structure constant $\alpha(m_Z^2)$ induces an error on the standard model prediction of $\sin^2\theta_{\rm eff}^{\rm lept}$ as large as the present experimental uncertainty. If the value $\alpha(m_Z^2) = 1/(128.896 \pm 0.090)$ [18] is used, this translates into an uncertainty on the standard model prediction of 0.00023, to be compared with an experimental error of 0.00024.

8 Heavy quark couplings

The measurements of the b and c forward-backward asymmetries determine the products $A_{\rm FB}^{0,{\rm f}} = \frac{3}{4}\mathcal{A}_{\rm e}\mathcal{A}_{\rm f}$ (Equation (1)). One can therefore extract $\mathcal{A}_{\rm f}$, once $\mathcal{A}_{\rm e}$ is known. By combining the value of $A_{\rm FB}^{0,\ell}$

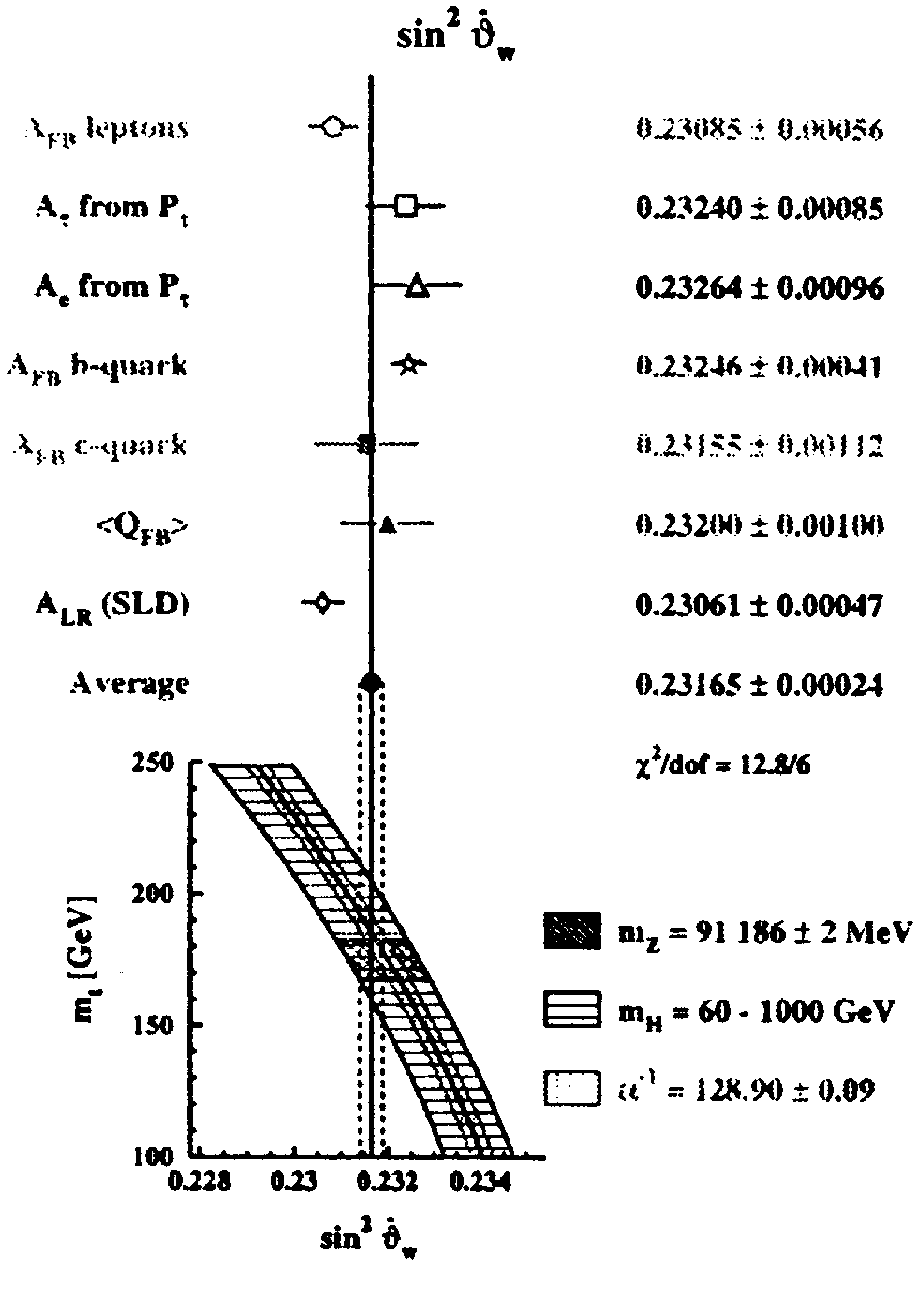

Figure 1: Comparison among different determinations of $\sin^2\theta_{\rm eff}^{\rm lept}$.

(0.1523 ± 0.0044) with the $\mathcal{P}_\tau(\cos\theta)$ measurements of Equations 5 and 6 (0.1393 ± 0.0050), one obtains $\mathcal{A}_e = 0.1466 \pm 0.0033$ and hence

$$\begin{aligned} \mathcal{A}_b &= 0.890 \pm 0.029 \\ \mathcal{A}_c &= 0.667 \pm 0.047 \end{aligned} \tag{8}$$

These results can be combined with the direct determinations of $\mathcal{A}_b$ and $\mathcal{A}_c$ obtained from the measurements of the left-right forward-backward asymmetries for b and c quarks at SLD [19]. In this case one gets the following averages:

$$\begin{aligned} \mathcal{A}_b &= 0.883 \pm 0.025 \\ \mathcal{A}_c &= 0.657 \pm 0.041 \end{aligned} \tag{9}$$

If the left-right asymmetry A_{LR} measured at SLAC [20] is also combined with the LEP measurements of $A_{FB}^{0,\ell}$ and $\mathcal{P}_\tau(\cos\theta)$ to extract $\mathcal{A}_e$ ($\mathcal{A}_e = 0.1500 \pm 0.0025$), the results for the heavy quark couplings become:

$$\begin{aligned} \mathcal{A}_b &= 0.867 \pm 0.022 \\ \mathcal{A}_c &= 0.646 \pm 0.040 \end{aligned} \tag{10}$$

In all three cases, the results for $\mathcal{A}_b$ deviate slightly from the standard model prediction $\mathcal{A}_{b_{SM}} = 0.863 \pm 0.049$. These deviations amount to about 1.6, 2.1 and 3.1 standard deviations for Equations 8, 9 and 10, respectively.

9 R_b

The measurement of the b partial width is particularly important due to the additional quadratic m_t dependence present in the Z$\rightarrow$ b$\overline{\text{b}}$ vertex. The LEP and SLD experimental results are shown in Figure 2. The lifetime/mass double tag measurements are the most precise measurements [21,22]. In particular, the very precise preliminary measurement presented by ALEPH [22] is based on the data obtained during the period 1992 to 1995 (i.e. 3.8 million Z decays). It makes use of a

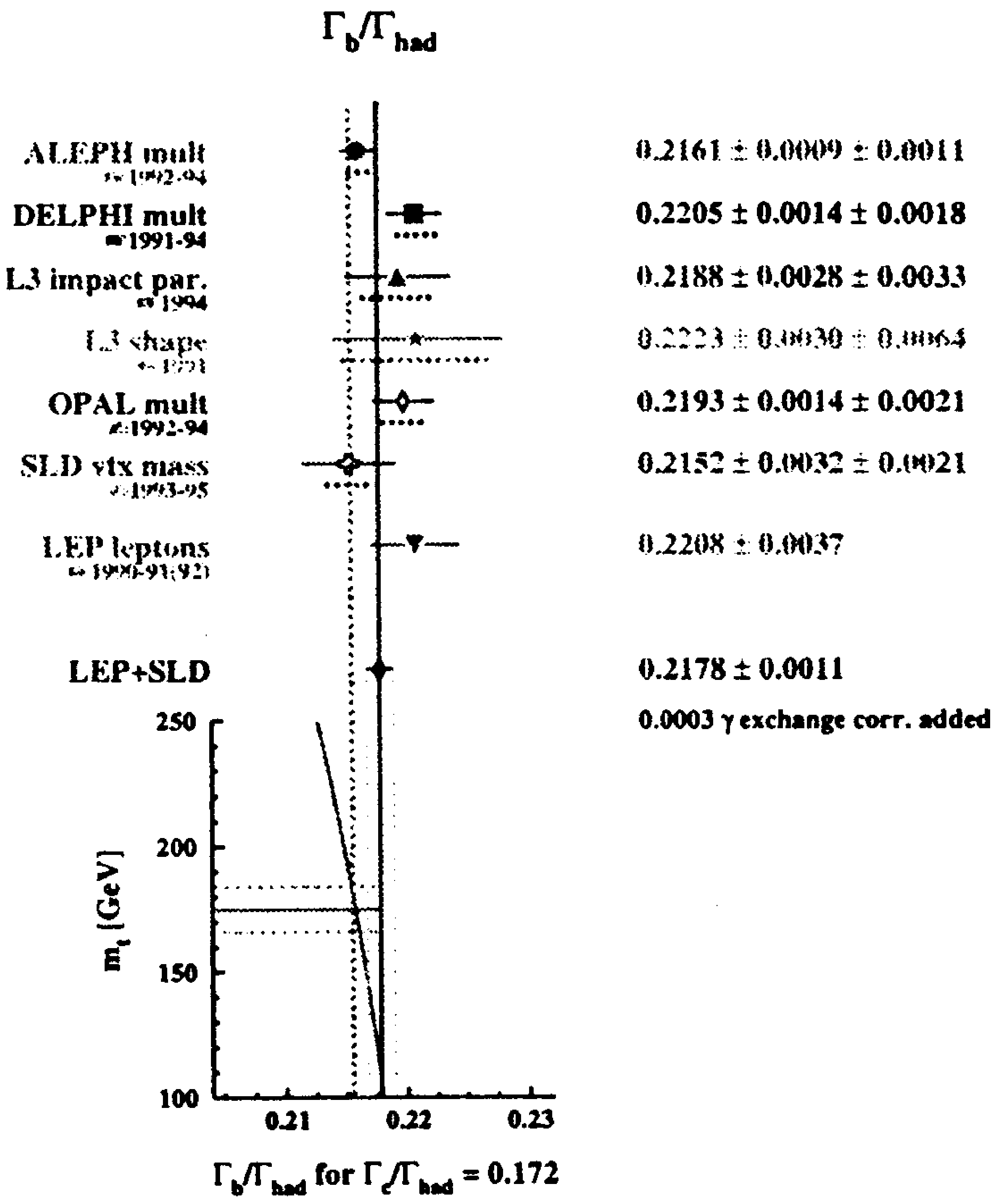

Figure 2: Ratio of b and hadronic partial widths. Here a correction of 0.0003 is applied to the experimental results to take into account the effect of γ exchange. The theoretical prediction in the standard model is also shown. This prediction is practically independent on $m_{\rm H}$ and nearly insensitive to α_s.

hemisphere b tag based on lifetime as well as mass information, complemented by four other mutually exclusive tags, using lifetime and event shapes.

If a high purity b tag is applied to each event hemisphere, by measuring the number of single and double tagged hemispheres, one can extract R_b and the b efficiency ε_b. The charm and light quark efficiencies ε_c, ε_{uds} and the correlation in tagging efficiency between b hemispheres ρ_b must be taken from a Monte Carlo simulation and represent a major source of systematic errors. It is therefore crucial to be able to keep the correlation and the light quark background as small as possible.

There are several identified sources of hemisphere-hemisphere correlations:

- geometrical effects induce a positive correlation (if a b-hadron is on the edge of the vertex detector angular acceptance, so is the other, since they tend to be back to back).
- Gluon emission induces a positive correlation by lowering the momenta of both b-hadrons.
- Correlations are also possible through the sharing of a common primary vertex. For example if one b hadron has a long decay length, it will be probably tagged. The resolution on the primary vertex will however degrade due to the lower track multiplicity, making the tag of the second b hadron less likely.

This last source of correlation is the dominant one ($\sim$ -10%). Its impact was drastically reduced (down to $\sim$ -0.5%) by reconstructing a primary vertex for each hemisphere separately, using tracks from that hemisphere only.

The introduction of a tag based not only on lifetime but also on mass, as pioneered by the SLD collaboration [21], allows to reduce the u,d,s,c background by exploiting the difference in mass between b and c hadrons. The invariant mass of tracks originating from a secondary vertex is in fact generally lower than 1.8 GeV (the approximate mass of a c hadron) for u,d,s and c quarks, while it extends to higher values for b quarks. The performance of the combined lifetime/mass tag,

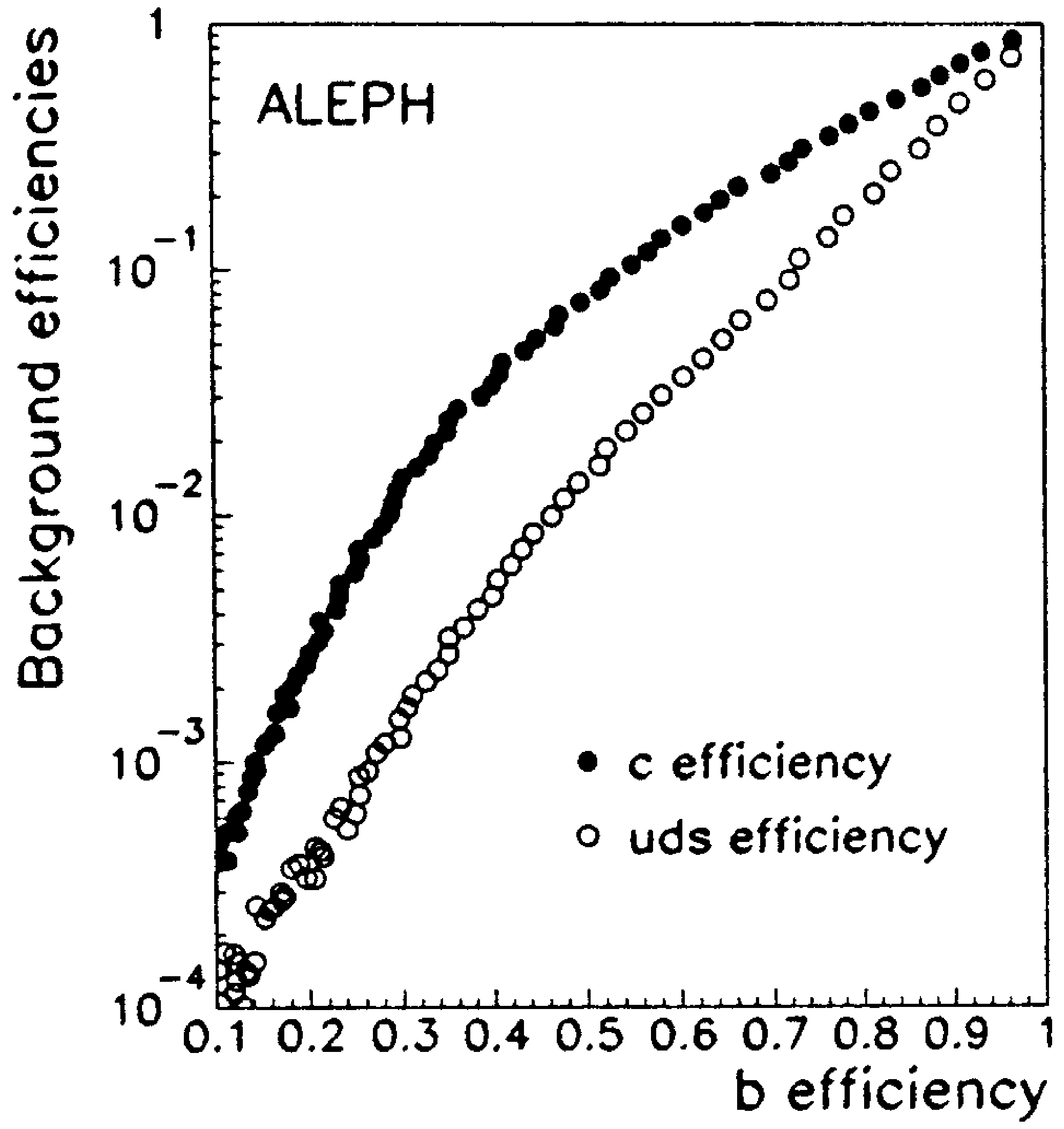

Figure 3: Hemisphere tagging efficiency for the mass-lifetime tag.

when using separate primary vertices in each hemisphere, is shown in Fig.3. For a b efficiency ε_b=22.66%, one has that ε_c=0.43% and ε_{uds}=0.05%. The b efficiency is approximately 44% higher than the one obtained with a tag only based on lifetime at the same purity.

The idea behind the multiple tag method is that the overall b tag efficiency can be increased by using other b tags, which make use for example of event shapes or of leptons from semileptonic b decays. The disadvantage is that these additional tags suffer from a large uds and c background. To overcome this difficulty, two new tags are introduced, one for c (based on lifetime and rapidity) and one for uds (anti-lifetime tag), which allow to measure the uds and c background from data. Table 6 shows the results of the efficiency for the different tags obtained from a Monte Carlo simulation. The fact of having three tags increases the statistical power by almost 50% with respect to the case when only the lifetime/mass tag is used.

By measuring 5 single tags and 15 double tags rates only the uds

		$\varepsilon_b(\%)$	$\varepsilon_c(\%)$	$\varepsilon_{uds}(\%)$
Lifetime/mass	(b)	19.55	0.20	0.03
Event shape	(b)	17.57	1.40	0.20
Leptons	(b)	4.25	0.69	0.16
Lifetime/rapidity	(c)	2.59	16.20	7.93
Anti-lifetime	(uds)	0.23	3.96	11.69

Table 6: Monte Carlo results for the efficiencies of the five tags.

and c efficiency for the lifetime/mass tag (which are very small numbers) and the hemisphere correlations need to be taken from simulation. The remaining 13 efficiencies and R_b are fitted to the data.

It should also be pointed out that in the present R_b combination the c-hadron production rates are no longer based on ARGUS and CLEO data, assuming that they are valid at $\sqrt{s} = m_Z$. Instead, they are available from LEP data. In addition, the gluon splitting rate $g \to c\bar{c}$ is also taken from data [23] and extrapolated to $g \to b\bar{b}$.

The average combined preliminary LEP+SLD value $R_b = 0.2178 \pm 0.0011$ is still slightly higher (by 1.8 standard deviations) than the standard model prediction, however the newest, precise measurements based on lifetime/mass tags by ALEPH and SLD are in very good agreement with the standard model.

10 R_c

The experimental results for R_c are shown in Figure 4. There are three classes of R_c measurements:

- single charm counting, based on the measurements of the production rates of D^0, D^+, D_s and Λ_c.
- Charm double tag, based either on the exclusive reconstruction of D or D^* mesons or on an inclusive slow pion from the decay $D^{*+} \to \pi^+ D^0$.

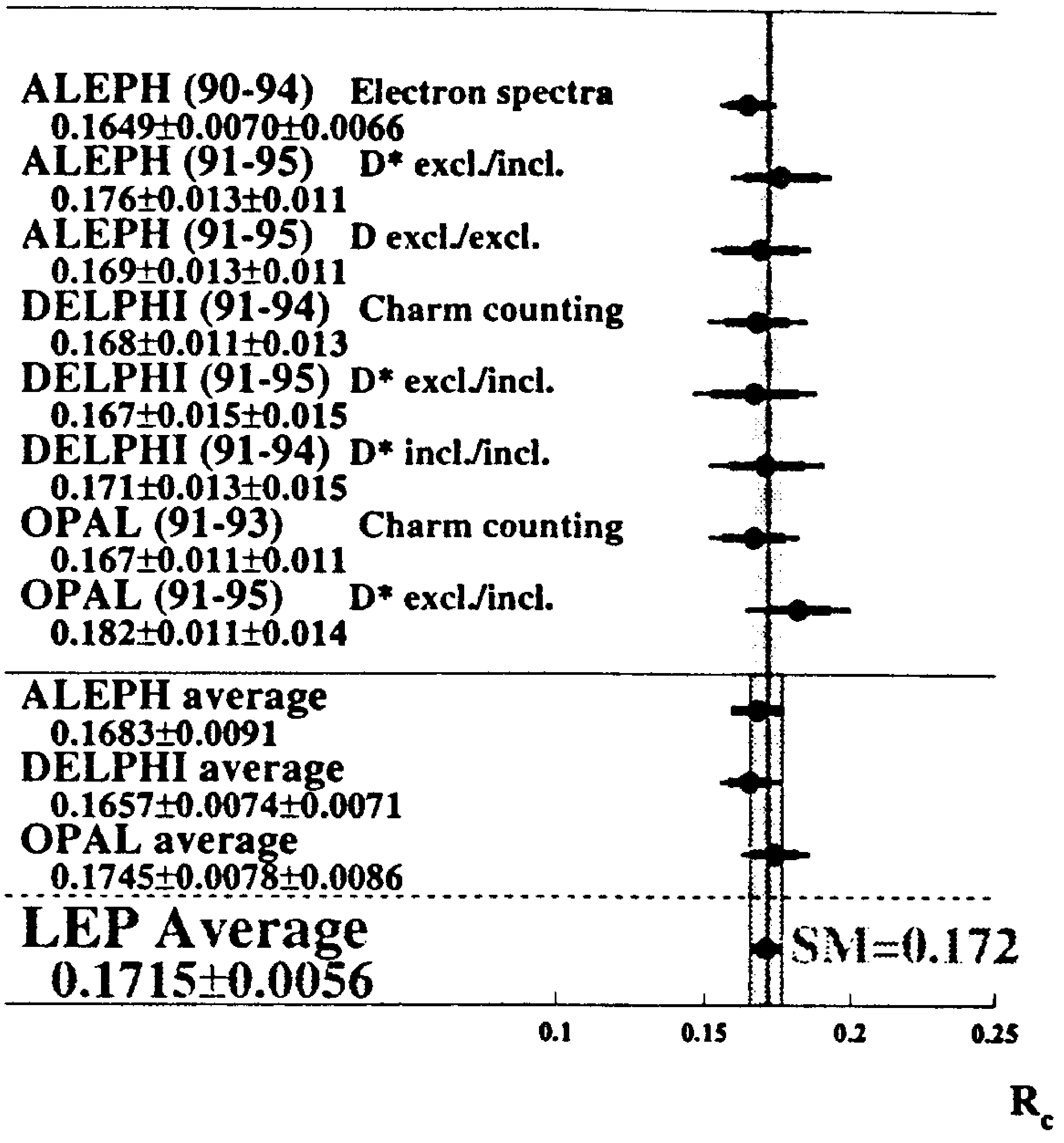

Figure 4: Ratio of c and hadronic partial widths. The theoretical prediction in the standard model is also shown.

- Measurements based on the detection of leptons from charm semileptonic decays.

The present R_c result ($R_c = 0.1715 \pm 0.0056$) is in very good agreement with the standard model prediction (0.172).

There are several important reasons for this change in the R_c central value. First of all, all the analyses used in the present combination are either new, or have been updated with respect to what was shown at the last winter conferences. Secondly, the measurement of the production rate of the D* mesons, which is an input value for some of the double tag analyses, is now measured at LEP: $P(c \rightarrow D^{*+}) \times BR(D^{*+} \rightarrow \pi^+ D^0) = 0.163 \pm 0.007$. This result is consistent within errors with the low energy measurent of 0.178 ± 0.013

used up to now. However, due to the large negative correlation of -60% between $P(c \rightarrow D^{*+}) \times BR(D^{*+} \rightarrow \pi^+ D^0)$ and R_c, the central value for R_c is now pulled up.

11 Standard model fits

All the results described in the previous sections can be compared with the standard model predictions. These results, with other precision electroweak measurements obtained outside LEP, are summarized in Table 7.

The main goal is to extract information on the unknown parameters of the theory, in particular on m_H.

Table 8 shows the result of the standard model fit to the LEP data alone and to all data of Table 7, including the TEVATRON measurement of the top mass [9–11]. These fits make use of the electroweak libraries described in [25]. Note that the Higgs mass is not held fixed but is also fitted.

As one can see, the LEP data favour a light top and a light Higgs. However, if the R_b measurement is excluded from the fit, this tendency disappears (and one obtains that $m_t = 171^{+38}_{-22}$ GeV).

From the fit to all data, an indirect measurement of m_W can also be derived:

$$m_W = 80.352 \pm 0.034\,\text{GeV}.$$

When the precision on m_W from direct measurements will match that obtained from the radiative corrections, this will provide an additional powerful test of the theory, in complete analogy with the top case. At the moment, this is not yet the case. The combination of preliminary results from the four LEP experiments on the W^+W^- cross section and the W mass at $\sqrt{s} = 161.3 \pm 0.2$ GeV [26] gives

$$\begin{aligned} \sigma_{WW} &= 3.57 \pm 0.46 \quad \text{pb} \\ m_W &= 80.4 \pm 0.2 \pm 0.1\,\text{GeV}. \end{aligned} \tag{11}$$

The errors on the results shown in Table 8 do not include theoretical uncertainties in the standard model predictions such as those

	Measurement with total error	Standard model	Pull
a) LEP			
m_Z [GeV]	91.1863 ± 0.0020	91.1861	0.1
Γ_Z [GeV]	2.4946 ± 0.0027	2.4960	−0.5
σ_h^0 [nb]	41.508 ± 0.056	41.465	0.8
R_ℓ	20.778 ± 0.029	20.757	0.7
$A_{FB}^{0,\ell}$	0.0174 ± 0.0010	0.0159	1.4
$\mathcal{A}_\tau$	0.1401 ± 0.0067	0.1458	−0.9
$\mathcal{A}_e$	0.1382 ± 0.0076	0.1458	−1.0
R_b	0.2179 ± 0.0012	0.2158	1.8
R_c	0.1715 ± 0.0056	0.1723	−0.1
$A_{FB}^{0,b}$	0.0979 ± 0.0023	0.1022	−1.8
$A_{FB}^{0,c}$	0.0733 ± 0.0049	0.0730	0.1
$\sin^2\theta_{eff}^{lept}$ $(\langle Q_{FB} \rangle)$	0.2320 ± 0.0010	0.23167	0.3
b) SLD			
$\sin^2\theta_{eff}^{lept}$ (A_{LR} [20])	0.23061 ± 0.00047	0.23167	−2.2
R_b [21]	0.2149 ± 0.0038	0.2158	−0.2
$\mathcal{A}_b$ [19]	0.863 ± 0.049	0.935	−1.4
$\mathcal{A}_c$ [19]	0.625 ± 0.084	0.667	−0.5
c) $p\bar{p}$			
m_W [GeV] ($p\bar{p}$ [24])	80.356 ± 0.125	80.353	0.3
m_t [GeV] ($p\bar{p}$ [9–11])	175 ± 6	172	0.5

Table 7: Electroweak measurements for the 1996 summer conferences. The results shown in columns 3 and 4 derive from a fit to the standard model parameters including all data with the Higgs mass treated as a free parameter.

	LEP	LEP +SLD + $p\bar{p}$ data + m_t
m_t [GeV]	155^{+18}_{-13}	172 ± 6
m_H [GeV]	86^{+202}_{-51}	149^{+148}_{-82}
$\log(m_H)$	$1.93^{+0.52}_{-0.39}$	$2.17^{+0.30}_{-0.35}$
$\alpha_s(m_Z^2)$	0.121 ± 0.003	0.120 ± 0.003
χ^2/d.o.f.	9/8	19/14

Table 8: Results of the fits to LEP data alone and to all data including the measurement of the mass of the top.

due to missing higher order corrections, as studied in the workshop on 'Precision calculations for the Z resonance' [27]. If these uncertainties are also taken into account, one obtains a 95% confidence level upper limit on m_H of approximately 550 GeV.

12 Outlook and conclusion

At present, at the end of the LEP1 program, the data continue to support the standard model in a remarkable way. The measurement of R_b is still 1.8 standard deviations higher w.r.t. the standard model prediction, however the newest analyses using improved techniques are in perfect agreement with the standard theory.

The LEP1 program of precision tests of the standard model is close to its end. However some improvements can still be expected:

- the lineshape analysis is not yet complete. At present, only three of the experiments have preliminary analyses of the cross sections using the 1995 data and the measurements of the LEP beam energies are still preliminary.
- New revised R_b measurements employing improved techniques, as already done by ALEPH and SLD, should be available in the near future from the other experiments.

- The uncertainty on observables such as the τ polarization asymmetry, which is still statistics dominated, will reduce, since not all the data have been analyzed yet.

Moreover, some improvement can still be expected on the determination of $\sin^2\theta_{\rm eff}^{\rm lept}$ from $A_{\rm LR}$ at SLAC. From LEP2 and the TEVATRON we expect an accurate determination of the W mass, and hopefully, some signs of new physics.

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