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A Study of the LEP and SLD Measurements of A_{b}

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Abstract

A systematic study is made of the data dependence of the parameter A_{b}, that, since 1995, has shown a deviation from the Standard Model prediction of between 2.4 and 3.1 standard deviations. Issues addressed include: the effect of particular measurements, values found by individual experiments, LEP/SLD comparison, and the treatment of systematic errors. The effect, currently at the 2.4σ level, is found to vary in the range from 1.7σ to 2.9σ by excluding marginal or particularly sensitive data. Since essentially the full LEP and SLD Z decay data sets are now analysed the meaning of the deviation, (new physics, or marginal statistical fluctuation) is unlikely to be given by the present generation of colliders.

1 Introduction

As has been recently pointed out in the literature [1-4], the analysis of the precision data on the decays $\mathrm{Z} \rightarrow \mathrm{f}\overline{\mathrm{f}}$ from LEP and SLD has shown good agreement with the predictions of the Standard Electroweak Model (SM) [5] with the exception of the parameter A_{b} defined as:

$$A_{\mathrm{b}} = \frac{2(\sqrt{1-4\mu_{\mathrm{b}}})\overline{r}_{\mathrm{b}}}{1-4\mu_{\mathrm{b}}+(1+2\mu_{\mathrm{b}})\overline{r}_{\mathrm{b}}^2} \tag{1.1}$$

where

$$\overline{r}_{\mathrm{b}} = \overline{v}_{\mathrm{b}}/\overline{a}_{\mathrm{b}}$$

Here $\overline{v}_{\mathrm{b}}$ and $\overline{a}_{\mathrm{b}}$ are the effective b quark coupling constants and $\mu_{\mathrm{b}} = (\overline{m}_{\mathrm{b}}(M_{\mathrm{Z}})/M_{\mathrm{Z}})^2 \simeq 1.0 \times 10^{-3}$ [6]. Since 1995, the LEP+SLD average value of A_{b} has differed from the SM prediction of 0.935 [1] by between 2.4 and 3.1 standard deviations. The evolution with time of the LEP+SLD average value of A_{b} is shown in Table 1 and Fig.1 [1,7-13]. It is important to note that, in the SM, the prediction for A_{b} is essentially a fixed number with no significant dependence on the values of the masses of of the top quark or the Higgs boson (see Figs 5-7 below). Combining the A_{b} measurement with that of R_{b}, which shows relatively good agreement with the SM, enables the effective b quark couplings $\overline{v}_{\mathrm{b}}$, $\overline{a}_{\mathrm{b}}$ or $\overline{g}_{\mathrm{b}}^L$, $\overline{g}_{\mathrm{b}}^R$ to be extracted [2-4]. When this is done, the largest deviation from the SM prediction is found to be in the right handed effective coupling $\overline{g}_{\mathrm{b}}^R$ which is about 40% and three standard deviations higher than the SM prediction.

The aim of the present note is a thorough study of the data dependence of the LEP+SLD average value of A_{b}. Important questions concern the consistency of individual measurements, and the effect of one or a few 'outlying' measurements on the average. At SLD the parameter A_{b} is measured directly from the forward/backward, left/right asymmetry of tagged b quarks. Three different types of measurement are made. The b quarks are tagged using a decay vertex and the jet charge, a semi-leptonic weak decay, or a $\mathrm{K}^{\pm}$ tag [12]. The LEP value of A_{b} is instead derived from the Z-pole forward/backward charge asymmetry, related to A_{b} by the expression:

$$A_{FB}^{0,\mathrm{b}} = \frac{3}{4} A_{\mathrm{e}} A_{\mathrm{b}} \tag{1.2}$$

where A_e is the parameter defined similarly to A_{b} (Eqn.(1.1)) for the electron. In general lepton universality i.e. $A_\ell = A_{\mathrm{e}} = A_\mu = A_\tau$, is assumed. Each of the four LEP experiments measures $A_{FB}^{0,\mathrm{b}}$ using either a lepton tag or the combination of decay vertex and jet charge measurements. Thus there are eight separate (though not completely uncorrelated) LEP measurements of $A_{FB}^{0,\mathrm{b}}$. Using the LEP+SLD average value of A_ℓ ($A_\ell = 0.1490 \pm 0.0017$) and Eqn.(1.2) the corresponding values of A_{b} for each LEP experiment and each analysis method may be calculated. These results are shown, together with the three direct SLD measurements, in Table 2 and Fig.2. The data shown are the most recent (Spring 1999) available at the time of writing. They are essentially the same as those presented at the 1998 Vancouver conference [12] except for the recent important update [13] of the SLD jet charge measurement which yields an SLD average value of A_{b} that is consistent, at the one standard deviation level, with the SM prediction.

Because the LEP value of A_{b} depends directly on the LEP+SLD average value of A_ℓ, it is of interest to compare the different measurements of this quantity. Each of the four LEP

Year	Reference	A_{b}	Deviation (σ) from SM
1993	[7]	0.925(56)	-0.18
1994	[8]	0.934(48)	-0.02
1995	[9]	0.871(27)	-2.4
1996	[1]	0.867(22)	-3.1
1997	[10]	0.877(23)	-2.5
1998	[11]	0.878(19)	-3.0
1999	[12,13]	0.894(17)	-2.4

Table 1: The time evolution of the LEP+SLD average values of A_{b}.

experiments measures A_ℓ either via the forward/backward leptonic charge asymmetry:

$$A_\ell = \sqrt{\frac{4A_{FB}^{0,\ell}}{3}}\ , \quad (l = \ell, \mu, \tau) \tag{1.3}$$

or by the analysis of τ-polarisation. The angular average of the τ-polarisation measures A_τ, whereas the angular distribution of the polarisation is also sensitive to A_e. Combining, for each LEP experiment, under the assumption of lepton universality, the measurements of A_τ and A_e, and including A_e as measured at SLD by the left/right electron beam polarisation asymmetry, leads to the nine independent measurements of A_ℓ shown in Table 3 and Fig.3.

Very good consistency can be seen in Table 2 and Fig.2 between the 11 different measurements of A_{b} ($\chi^2/dof = 4.5/10, CL = 92\%$ for consistency of the measurements with their weighted mean). The LEP and SLD average values agree within 0.2σ. As noted also for the 1996 data set [4], the mutual consistency of the different A_ℓ measurements is somewhat less satisfactory. Although the χ^2 test gives: $\chi^2/dof = 10.7/8, CL = 22\%$ which is acceptable, three measurements (OPAL $A_{FB}^{0,\ell}$ and the τ-polarisation measurements of DELPHI and OPAL) all show negative deviations of 1.5σ or more from the weighted average value. In contrast, all the positive deviations are $\leq 1\sigma$. The average value of A_ℓ, and hence the derived LEP value of A_{b} is thus sensitive to the inclusion or exclusion of these data, as will be discussed below. The situation concerning the consistency of the τ-polarisation measurements, both with each other, and with the other determinations of A_ℓ, discussed in detail for the 1996 data set in reference [4], has recently been improved by the new, more precise, ALEPH measurement (see Fig 3).

2 Effect of Individual Measurements on the Average Value of A_{b}

In this Section the sensitivity of the A_{b} value to the different data contributing to the world average is examined. The results of this study are presented in Table 4. The ALEPH jet charge A_{b} value is the only one that lies above the SM prediction. The probability

SLD	
Jet Ch	0.882 ± 0.020 ± 0.029 (0.035)
Lepton	0.924 ± 0.032 ± 0.026 (0.041)
$K^{\pm}$ tag	0.855 ± 0.088 ± 0.102 (0.134)
LEP	
A Lepton	0.908 ± 0.041 ± 0.020 (0.046)
D Lepton	0.904 ± 0.057 ± 0.026 (0.063)
L Lepton	0.869 ± 0.055 ± 0.030 (0.063)
O Lepton	0.851 ± 0.038 ± 0.021 (0.043)
A Jet Ch	0.953 ± 0.037 ± 0.029 (0.047)
D Jet Ch	0.898 ± 0.042 ± 0.021 (0.047)
L Jet Ch	0.806 ± 0.106 ± 0.051 (0.118)
O Jet Ch	0.898 ± 0.047 ± 0.037 (0.060)
WA SLD	0.908(27)
WA LEP	0.885(22)
WA LEP+SLD	0.894(17)

Table 2: The different LEP and SLD measurements of A_{b}. The first error quoted is statistical, the second systematic. The quadratic sum of these errors is given in parentheses. 'WA' denotes Weighted Average.

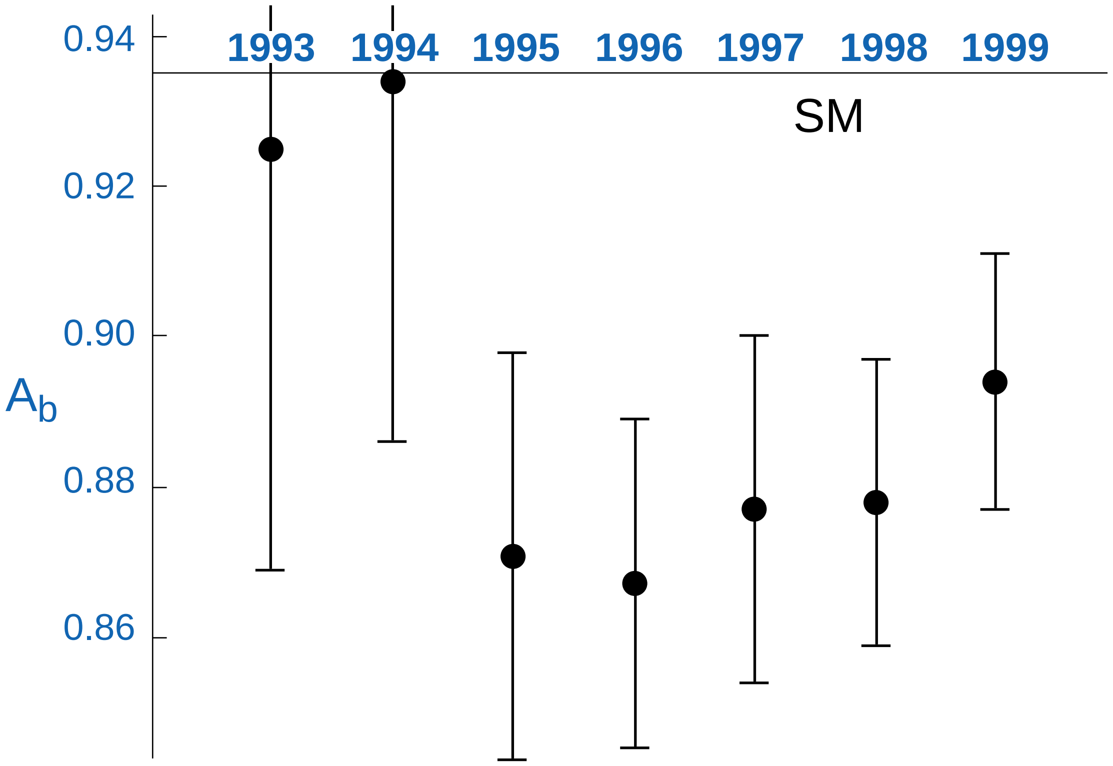

Figure 1: The time evolution of the LEP+SLD average value of A_{b}. The horizontal line shows the Standard Model prediction $A_{\mathrm{b}} = 0.935$.

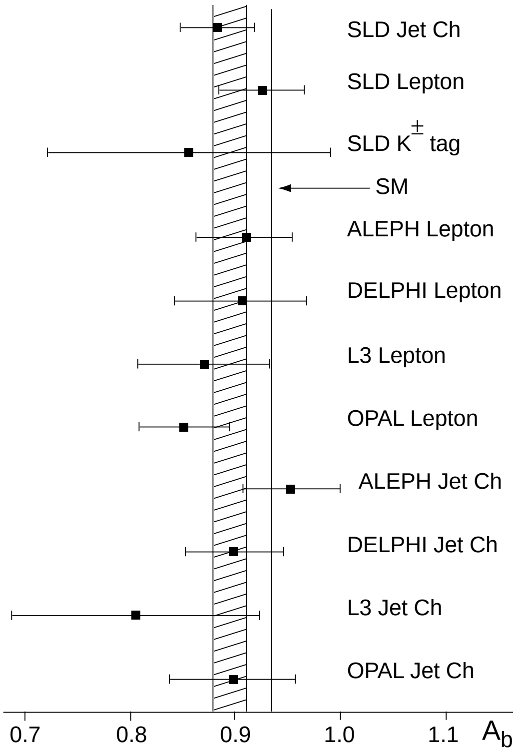

Figure 2: LEP and SLD measurements of A_{b}. The vertical line shows the Standard Model prediction $A_{\mathrm{b}} = 0.935$. The hatched vertical band shows the weighted average value $\pm 1\sigma$.

LEP $A_{FB}^{0,\ell}$	
ALEPH	0.1501(70)
DELPHI	0.1579(78)
L3	0.1579(106)
OPAL	0.1371(80)
LEP τ-polarisation	
ALEPH	0.1475(46)
DELPHI	0.1369(79)
L3	0.1558(83)
OPAL	0.1318(100)
SLD A_{LR}	
0.1504(23)	
WA LEP+SLD	
0.1490(17)	

Table 3: The different LEP and SLD measurements of A_ℓ. The errors (quoted in parentheses) are the quadratic sums of statistical and systematic errors.

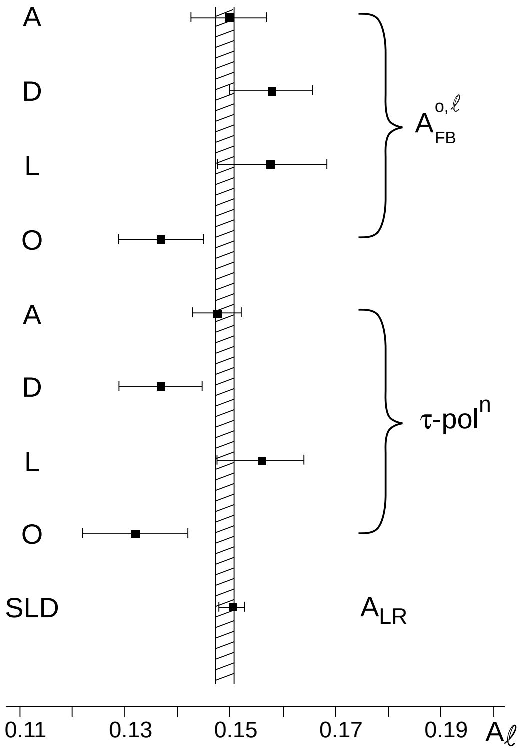

Figure 3: LEP and SLD measurements of A_ℓ. The hatched vertical band shows the weighted average value $\pm 1\sigma$.

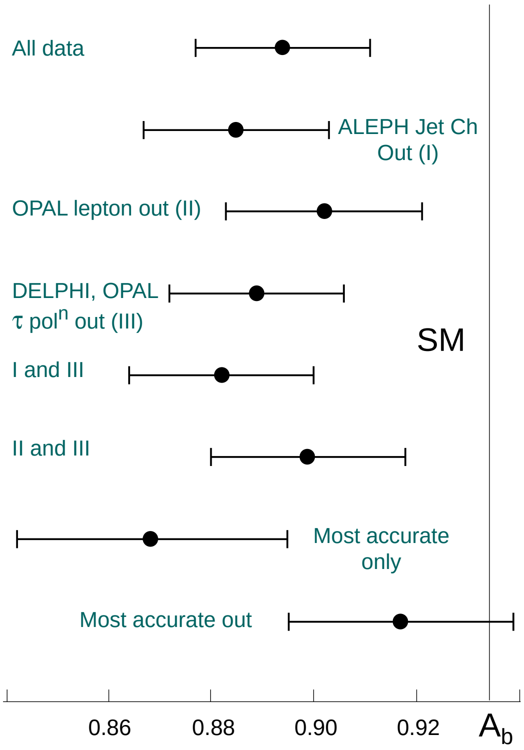

Figure 4: Data sensitivity of the A_{b} average. The vertical line shows the Standard Model prediction $A_{\mathrm{b}} = 0.935$.

Condition	A_{b}	Dev(σ) WA	Dev(σ) SM	CL SM(%)
All data	0.894(17)	0.0	-2.4	1.6
ALEPH Jet Ch out (I)	0.885(18)	-0.5	-2.8	0.51
OPAL lepton out (II)	0.902(19)	0.42	-1.7	9.0
DELPHI, OPAL τ pol^n out (III)	0.890(17)	-0.24	-2.6	0.93
I and III	0.882(18)	-0.67	-2.9	0.37
II and III	0.899(19)	0.26	-1.9	5.7
Most accurate measurements only	0.868(27)	-0.96	-2.5	1.2
Exclude most accurate measurements	0.917(22)	1.35	-0.82	41.3

Table 4: Data sensitivity of the A_{b} average. Deviations from the Weighted Average (WA) and the Standard Model (SM) are shown, as well as the Confidence Level (CL) for agreement with the SM.

that ten or more out of eleven measurements of a quantity all lie either above or below the expected value is 1.2%. Removing the ALEPH jet charge measurement increases the deviation from -2.4σ to -2.8σ. The $A_{FB}^{0,\mathrm{b}}$ measurement with the largest weight in reducing the average value of A_{b} is the OPAL lepton measurement. Excluding this datum gives $A_{\mathrm{b}} = 0.902(19)$ only 1.7σ below the SM prediction. This single measurement gives, therefore, a significant contribution to the overall deviation of A_{b}. As discussed in detail in Ref. [4], apparent inconsistencies exist between the τ-polarisation measurements of A_{ℓ} by the different LEP experiments. Currently two measurements (ALEPH and L3) show good agreement with the Weighted Average (WA) value, whereas the other two (OPAL and DELPHI) show rather large (1.5-2.0σ) deviations as shown in Fig.3 and Table 3. Removing the latter measurements gives a small increase of the deviation from the SM to -2.6σ. Removing both the ALEPH and the DELPHI τ-polarisation measurements and the ALEPH jet charge $A_{FB}^{0,b}$ result increases the deviation to -2.9σ, whereas removing the same τ-polarisation measurements and the OPAL lepton $A_{FB}^{0,\mathrm{b}}$ result reduces the deviation to -1.9σ. Thus exclusion of 'marginal' data results in a variation of the A_{b} deviation from -1.7σ to -2.9σ as compared to the all data deviation of -2.4σ. One may remark however that, in general, removal of the data with the largest deviations from the average values (OPAL for $A_{FB}^{0,l}$, DELPHI and OPAL τ-polarisation for A_{ℓ}; ALEPH jet charge for $A_{FB}^{0,\mathrm{b}}$) tends to increase, not decrease the deviation from the SM. As mentioned above, the single measurement with the largest weight in the deviation is the OPAL lepton measurement of $A_{FB}^{0,\mathrm{b}}$.

The average A_{b} value given by the LEP jet charge measurements, 0.913(28), shows good agreement with the SM prediction and is somewhat higher than the similar average of the lepton measurements, 0.880(26). However, the difference is mainly due to the high value of ALEPH measurement. Excluding this gives, for the jet charge average, 0.890(35), which agrees with the lepton average within 0.2σ.

	A_ℓ	$A_{FB}^{0,\mathrm{b}}$	A_b (WA A_ℓ)	Dev(σ) SM	A_b (own A_ℓ)	Dev(σ) SM
ALEPH	0.1483(38)	0.1040(35)	0.931(33)	-0.12	0.935(40)	0.0
DELPHI	0.1475(56)	0.1006(41)	0.900(38)	-0.92	0.909(50)	-0.52
L3	0.1566(65)	0.0956(62)	0.855(56)	-1.4	0.814(63)	-1.9
OPAL	0.1350(62)	0.0970(38)	0.868(35)	-1.9	0.958(58)	0.40
SLD	0.1504(23)	-	-	-	0.908(27)	-1.0
WA values	0.1490(17)	0.1002(21)	0.896(19)	-2.1	0.911(18)	-1.3

Table 5: A_ℓ and A_b results of individual experiments. The last row shows Weighted Average (WA) values calculated neglecting error correlations. The 'own A_ℓ' value for SLD refers to the direct measurement of A_b using the F/B-L/R asymmetry.

In the last two rows of Table 3 are shown the results of calculating A_b using either (i) only the measurements of each raw observable with the smallest total error, or (ii) the remaining data. The most accurate measurements are: ALEPH($A_{FB}^{0,\ell}$), ALEPH(τ-polarisation), SLD(A_{LR}), SLD jet charge (A_b) and OPAL lepton ($A_{FB}^{0,\mathrm{b}}$). Although the weighted average error of the average using only the 'most accurate' measurements is 70% larger than for all data, the resulting value of $A_\mathrm{b} = 0.868(27)$ still shows a -2.5σ deviation from the SM. On the other hand, the remaining data with a weighted error only 38% larger than that for all data, gives a deviation of only -0.82σ from the SM prediction. The poor consistency between these two sets of data evidently raises the question whether the systematic errors of some, or all, of the 'most accurate' measurements may have been under-estimated. If this is the case, the significance of the apparent deviation from the SM prediction may be much reduced.

3 The A_ℓ and A_b Measurements of the Different LEP and SLD Experiments

The values of A_ℓ and A_b as measured separately by the four LEP experiments, and by SLD are presented in Table 5. For each LEP experiment A_b is calculated in two different ways: (i) by use of the world average value of A_ℓ in Eqn.(1.2), or (ii) by use, instead, of the value of A_ℓ measured by the experiment itself. In each case the deviation of A_b from the SM prediction is shown. It may be noticed that, although ALEPH provides two out of the five 'most accurate' measurements, that together yield a -2.5σ deviation from the SM (see Table 4), the ALEPH measurement itself, for both cases (i) and (ii), is in good agreement with the SM. DELPHI shows small deviations of -0.92σ, -0.52σ in the cases (i) and (ii), whereas L3 shows a larger deviation for case (ii) (-1.9σ) than for case (i) (-1.4σ). An interesting case is OPAL, which shows the largest deviation of any experiment (-1.9σ) in case (i), but a value quite consistent with the SM (0.40σ deviation) in case (ii).

This is easy to understand from Figs 1 and 2. The OPAL lepton measurement gives, as mentioned above, the most significant deviation of $A_{\rm b}$ from the SM for the case (i) (see Fig 1). However, it can seen in Fig 2 that the OPAL values of A_ℓ, as determined from $A^{0,\ell}_{FB}$ and the τ-polarisation measurement lie well below the WA value. The combined effect is so large, that for the case (ii), the deviations of $A^{0,{\rm b}}_{FB}$ and A_ℓ cancel almost exactly, giving an $A_{\rm b}$ value, calculated via Eqn(1.2), in agreement with the SM prediction.

4 The LEP and SLD Measurements of $A_{\rm b}$

The separate LEP and SLD measurements of $A_{\rm b}$ are given in Table 2. They differ, respectively, from the SM prediction of 0.935 by -2.3σ and -1.0σ. The data are compared in more detail in Figs. 5, 6, 7 which show plots of the measured values of $A_{\rm b}$ and A_ℓ for LEP, SLD and LEP+SLD respectively. In Figs 5 and 7 the LEP average $A^{0,{\rm b}}_{FB}$ measurement is shown as a diagonal band. In each case results of fits to $A_{\rm b}$ and A_ℓ are shown, as well as the SM prediction for a range of values of m_t and m_H. In Figs 5 and 6 the dark square marked 'WA' shows the World Average best fit value: $A_{\rm b} = 0.894$, $A_\ell = 0.1487$.

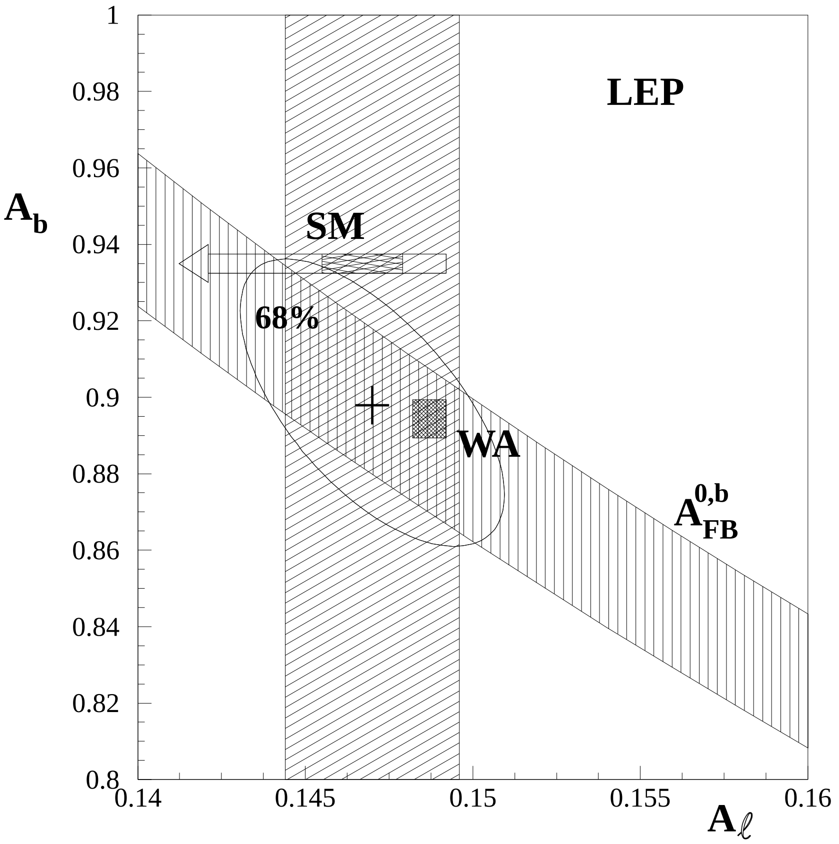

Figure 5: A_{b} versus A_ℓ plot for LEP data.The cross shows the best fit value $A_\ell = 0.1470$, $A_{\mathrm{b}} = 0.898$, while the solid square marked WA (World Average) shows the result of the fit to the combined LEP+SLD data. The Standard Model prediction is given by the arrow. The length of the shaft (moving towards the tip) corresponds to a variation of m_H from 50 to 300 GeV ($m_t = 174$GeV) whereas the shaded area corresponds to a variation of m_t from 169 to 179 GeV ($m_H = 100$GeV). The 68% CL contour of the fit is also shown.

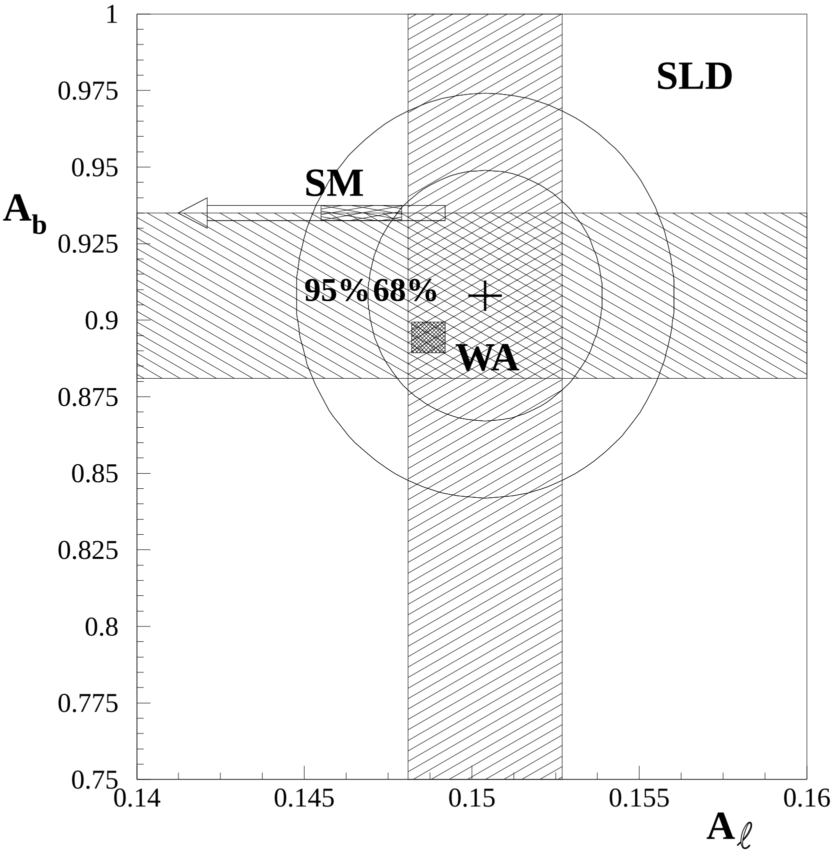

Figure 6: A_{b} versus A_ℓ plot for SLD data. The cross shows the best fit value $A_\ell = 0.1504$, $A_{\mathrm{b}} = 0.908$, WA and the SM arrow are defined as in Fig 5. The 68% and 95% CL contours of the fit are shown.

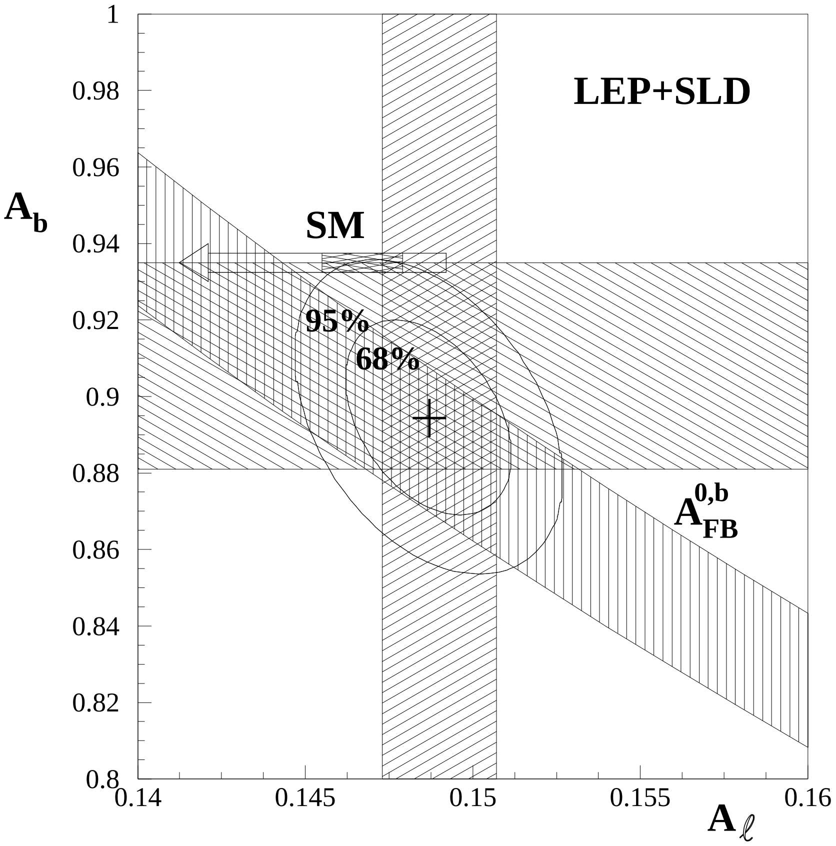

Figure 7: A_{b} versus A_ℓ plot for LEP+SLD data. The cross shows the best fit value $A_\ell = 0.1487$, $A_{\mathrm{b}} = 0.894$. WA and the SM arrow are defined as in Fig 5. The 68% and 95% CL contours of the fit are shown.

5 The Effect of Systematic Errors on the A_{b} Measurement

The different errors on the combined SLD and LEP measurements of A_{b} as estimated by the LEP/SLD Heavy Flavour Working Group are presented in Table 5 [14]. It can be seen that, even with the full LEP1 data set of all four experiments, the error on the LEP average value remains statistics dominated, and that the systematic error is about 50% correlated. In contrast, the SLD statistical and systematic errors are roughly equal and the correlated component of the systematic error is relatively small. Since the forward/backward b quark asymmetry measurements at SLD and LEP are very similar, and the systematic error related to the beam polarisation measurement gives only a small contribution, it is reasonable to hope for a considerable reduction in the SLD systematic error. Indeed, the smaller systematic error at LEP is largely due to the much larger statistics of Z-decays at LEP, permitting systematic effects related to quark fragmentation to be estimated from the data itself.

	SLD	LEP
σ_{stat}	0.017	0.019
σ_{syst}^{uncorr}	0.019	0.007
σ_{syst}^{corr}	0.0019	0.0061
σ_{tot}	0.0349	0.0211

Table 6: Statistical and systematic errors of the combined SLD and LEP measurements of $A_{\rm b}$.

Syst. Error Hypothesis	f %
Gaussian	1.211(5)
Uniform	1.188(5)
LEP×1.5	1.93(4)
LEP/1.5	0.98(3)
SLD/2.7	0.65(3)
(SLD/2.7,LEP)×1.5	1.35(4)
(SLD/2.7,LEP)/1.5	0.44(5)

Table 7: The effect of different hypotheses for systematic errors on the significance of the observed $A_{\rm b}$ deviation. f is the fraction of Monte Carlo ensembles of measurements with a simple average value of $A_{\rm b}$ less than the actual measured value (0.886).

Because of the large statistical weight of the LEP measurement, whose error is statistics dominated, the treatment of systematic errors is not expected to play a major rôle concerning the size of the $A_{\rm b}$ deviation. Even so, it is interesting to investigate the effect of different treatments of the systematic error on the $A_{\rm b}$ deviation. It must not be forgotten that the estimation of systematic errors is, perhaps, more of an art than a science, so that all confidence levels estimated on the assumption that the systematic errors are both correct and gaussian, should be taken *cum grano salis*. Here the effects are investigated of (i) using a uniform rather than a gaussian distribution for the systematic errors, (ii) an improvement in the systematic error of the SLD $A_{\rm b}$ measurement, (iii) optimism or conservatism in the assignement of systematic errors.

A simple Monte Carlo program was used to generate ensembles of $A_{\rm b}$ measurements distributed according to the statistical and systematic errors of the different LEP and SLD experiments as shown in Tables 2 and 6. The correlated and uncorrelated components of the different $A_{\rm b}$ and $A_{FB}^{0,{\rm b}}$ measurements were properly taken into account. In all cases except one (see below) the systematic errors were modeled according to gaussian functions with RMS equal to the quoted errors. The error on the LEP+SLD average value of A_ℓ used to extract the LEP values of $A_{\rm b}$ according to Eqn(1.2) was taken to be gaussian and 100% correlated between the different measurements. The Standard Model value of $A_{\rm b}$ (0.935) was assumed, and the fraction, f, of ensembles of measurements with a simple mean value of $A_{\rm b}$ less than that given by the data ($A_{\rm b} = 0.886$) was noted. In Table 6 the values of f (corresponding to a one-sided CL) are shown for several different hypotheses concerning the errors. The first row corresponds to the quoted errors and assumes gaussian distributions. In the second row, all systematic errors are chosen according to uniform distributions with RMS equal to the quoted errors. In the third (fourth) rows the effect is shown of increasing (decreasing) the systematic errors of all the LEP experiments by a factor 1.5. In the fifth row is shown the effect of reducing the systematic errors of the SLD experiments by a factor 2.7 so that the average systematic error becomes equal to the uncorrelated LEP systematic error. Finally, in the last two rows an additional scale factor of 1.5 or 1/1.5 is applied to the systematic errors of all experiments. As anticipated above, different scenarios for the systematic errors do not have a dramatic effect on the significance of the observed deviation. Use of a uniform distribution instead of a gaussian one (expected to reduce the tails of distribution) in fact only gives a 2% relative change in f. Assuming that the SLD systematic error is reduced to the same level as the current LEP one, overestimation (underestimation) of all systmatic errors by a factor 1.5 gives CLs of 0.44% (1.4%) that the observed fluctuation is purely statistical, to be compared with 1.2% for the nominal errors.

It may finally be remarked that a previous study [4] of Z decay measurements showed a clear tendency to overestimate point-to-point systematic errors and to underestimate correlated ones. Correcting for the first effect would increase the significance of any deviation, while correcting for the second would tend to decrease it. Unfortunately, there are insufficient independent measurements to perform a similar analysis in the present case.

6 Summary and Outlook

This paper has studied, in detail, the data dependence of the parameter $A_{\rm b}$. The individual measurements of both $A_{\rm b}$ and the related (for LEP) parameter A_ℓ show quite good internal consistency. For $A_{\rm b}$ the largest positive deviation from the WA is given by the ALEPH jet charge measurement. Removing this increases the $A_{\rm b}$ deviation from -2.4σ to -2.8σ. The single measurement with the largest weight tending to increase the size of the deviation is the OPAL lepton $A_{FB}^{0,{\rm b}}$ measurement. Removing this reduces the $A_{\rm b}$ deviation to -1.7σ. For A_ℓ it may be noted that the $A_{FB}^{0,\ell}$ measurement of OPAL and the τ-polarisation measurements of DELPHI and OPAL all lie about 2σ below the WA. Excluding these measurements slightly increases the $A_{\rm b}$ deviation to -2.6σ . The deviation observed is much larger (-2.5σ) if only the most accurate measurements of each raw observable are used, than for all the remaining measurements (-0.82σ). This is a possible hint that the systematic errors of the 'most accurate' measurements may be underestimated, leading to an overestimation of the deviation from the SM for these data. The independent measurements of $A_{\rm b}$ for each LEP experiment give smaller deviations for all experiments, except L3, than when the world average value of A_ℓ is used to extract $A_{\rm b}$. The naive WA (neglecting error correlations) of the individual measurements of $A_{\rm b}$ of the four LEP experiments and SLD shows only a -1.3σ deviation. Using the world average value of A_ℓ to extract $A_{\rm b}$ from the LEP experiments yields a deviation of -2.1σ to be compared with -1.0σ for the combined SLD experiments. A study of the modelling and the degree of optimism/conservatism in the estimation of systematic errors shows essentially identical results for gaussian or uniform distributions and values for the CL for agreement with the SM that varies from 0.44% to 1.9%, as compared to the nominal value of 1.2%.

In the future, some improvement may be expected in the SLD values of A_ℓ and $A_{\rm b}$, mainly due to an improved understanding of systematic errors [15]. On the other hand, no significant improvement is to be expected from the LEP results which, although many are still ‘preliminary’, are almost entirely based on the full LEP1 statistics. It may be noted that a recent summary of the SLD data [15] found slightly different values for the LEP,SLD average values of $A_{\rm b}$ of 0.877(21), 0.898(29) respectively (compare with the values given in Table 2). The small differences from the values used above do not affect any of the conclusions of this study.

This paper is based on the precision electroweak data available in Spring 1999. In the Summer 1999 update [16], the values 0.881(20), 0.905(26) were given for the LEP, SLD average values, respectively, of $A_{\rm b}$. A fit to the combined LEP+SLD data for A_ℓ and $A_{\rm b}$, similar to those shown if Figs.(5-7) of this paper, yielded the values; $A_\ell = 0.1493(16)$, $A_{\rm b} = 0.889(16)$. Thus, in the most recent data, the significance of the $A_{\rm b}$ deviation has increased to 2.9σ.

Finally, the deviation in $A_{\rm b}$ although interesting, and possibly suggestive of new physics [17, 18, 19] is still of only marginal statistical significance. If there is no fresh data from SLD it may be some decades before it is known for sure if the effective couplings of the b quarks are, or are not, in agreement with the SM predictions!

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