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MEASUREMENT OF α_s FROM HADRONIC EVENT OBSERVABLES AT THE Z^0 RESONANCE

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Abstract

We have measured the strong coupling $\alpha_s(M_Z^2)$ using hadronic decays of Z^0 bosons collected by the SLD experiment at SLAC. The data were compared with QCD predictions both at fixed order $\mathcal{O}(\alpha_s^2)$ and including resummed analytic formulae based on the next-to-leading logarithm approximation. We have performed a comprehensive analysis using event shapes, jet rates, particle correlations, and angular energy flows, and have checked the consistency between $\alpha_s(M_Z^2)$ values extracted from these different measures. Combining these results we obtain $\alpha_s(M_Z^2) = 0.1200 \pm 0.0025(\text{exp.}) \pm 0.0078(\text{theor.})$, where the dominant uncertainty is from uncalculated higher order contributions. We have also compared a recent calculation by Clay and Ellis of energy-energy correlations (EEC) and the asymmetry ($AEEC$) with our data. We find that the $\alpha_s(M_Z^2)$ value obtained for the EEC is significantly lower than that obtained from comparable fits using the $\mathcal{O}(\alpha_s^2)$ calculation of Kunszt and Nason.

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Various observables have been introduced to characterize event shapes in the process $e^+e^- \rightarrow$hadrons. We have studied fifteen observables which can be calculated exactly up to $\mathcal{O}(\alpha_s^2)$ in QCD perturbation theory [1, 10]. The observables comprise six event shapes: thrust ($\tau = 1 - T$), heavy jet mass ($\rho = M_H^2/E_{vis}^2$), total jet broadening (B_T), wide jet broadening(B_W), oblateness (O), and C-parameter (C); differential 2-jet rates (D_2) defined by six different jet resolution/recombination schemes (E, E0, P, P0, D, and G); energy-energy correlations (EEC) and their asymmetry ($AEEC$), and the jet cone energy fraction ($JCEF$). The definitions of these observables can be found elsewhere [2]. The strong coupling α_s can be derived by fitting the QCD calculations to the measured distributions.

In this analysis we used the 1992 and 1993 data samples collected by the SLD/SLC; 37226 events passed our hadronic event selection criteria [2, 3]. We applied bin-by-bin correction factors to the experimental distributions to account for detector effects and hadronization. Each corrected distribution was fitted by minimizing χ^2 with respect to variation of $\Lambda_{\overline{MS}}$ at selected values of the *renormalization scale* $f \equiv \mu^2/M_Z^2$. Fit ranges were chosen as described in ref. [2].

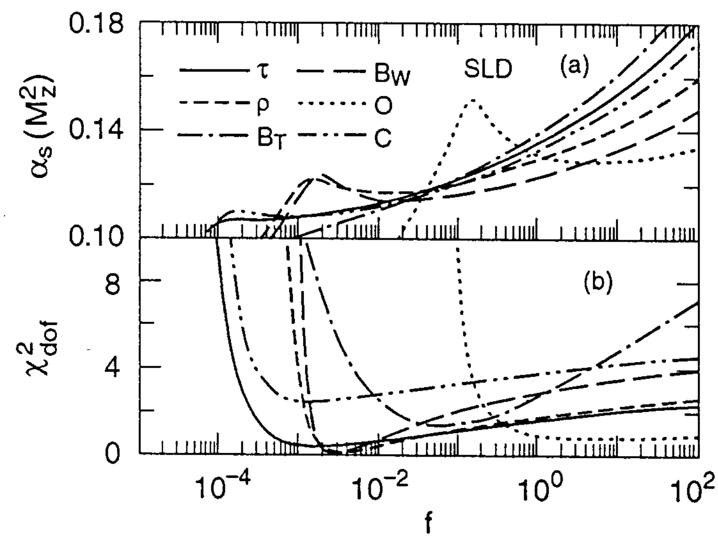

Figure 1: (a) $\alpha_s(M_Z^2)$ and (b) χ^2_{dof} from the $\mathcal{O}(\alpha_s^2)$ fits for event shapes.

Figure 1 shows (a) $\alpha_s(M_Z^2)$ and (b) the corresponding χ^2_{dof} respectively, derived from fits at different values of f for the event shapes. Results from other observables are similar. Several features are common to each observable: $\alpha_s(M_Z^2)$ depends strongly on f; the fit quality is good over a wide range in f, typically $f \geq 2 \times 10^{-3}$, and there is no preference for a particular scale for most of the observables. The poor fit quality at low f has been shown to be due to poor convergence of the $\mathcal{O}(\alpha_s^2)$ calculations [4]. We therefore considered for each observable the f range such that $\chi^2_{dof} < 5$ and $f \leq 4$, the latter corresponding to a reasonable physical limit. For each observable the central value of $\alpha_s(M_Z^2)$ was defined as the midpoint between the extrema in this f range, and the scale uncertainty was defined as the difference between the central value and the extrema. We combined the results from all fifteen observables using an unweighted average of the α_s values, experimental systematic, and theoretical uncertainties to obtain $\alpha_s(M_Z^2) = 0.1226 \pm 0.0026(\text{exp.}) \pm 0.0109(\text{theor.})$. The theoretical uncertainty is dominated by the scale ambiguity (± 0.0106).

We next determined α_s by comparing matched resummed+$\mathcal{O}(\alpha_s^2)$ calculations with the data. These calculations, which combined a resummation [5] of the leading and next-to-leading logarithmic terms to all orders in α_s with the second order calculations, have been performed for τ, ρ, B_T, B_W, D_2(D-algorithm), and EEC. We considered four matching schemes which differ at $\mathcal{O}(\alpha_s^3)$[2]. The fit ranges were chosen to be the same as for the $\mathcal{O}(\alpha_s^2)$ fits except for EEC where the resummed calculation is applicable only above $\chi^2 = 90°$. We applied the same analysis as for the $\mathcal{O}(\alpha_s^2)$ calculations to each combination of matching scheme and observable. We found the resummed+$\mathcal{O}(\alpha_s^2)$ calculations were able to fit the data in much reduced ranges of f and yielded a reduced scale dependence of α_s. We averaged over matching schemes[2] to obtain $\alpha_s(M_Z^2)$ for each observable, and considered the matching ambiguity, defined as the maximum deviation from the average, as an additional theoretical uncertainty. By averaging over the six α_s values we obtained $\alpha_s(M_Z^2) = 0.1192 \pm 0.0025(\text{exp.}) \pm 0.0070(\text{theor.})$, where the theoretical error is the sum in quadrature of the hadronization (± 0.0016) and scale and matching uncertainties (± 0.0065). This uncertainty, which reflects missing higher order terms in the calculations, is reduced by a factor of 1.5 relative to the $\mathcal{O}(\alpha_s^2)$ analysis but still dominates the error on the measurement of α_s.

Figure 2 summarizes our results. The solid error bars denote experimental errors, while the dotted error bars show the total errors, including experimental and theoretical errors added in quadrature. We combine the results from the $\mathcal{O}(\alpha_s^2)$ and resummed+$\mathcal{O}(\alpha_s^2)$ calculations by taking an unweighted average of the α_s values and experimental and theoretical errors, obtaining[2] $\alpha_s(M_Z^2) = 0.1200 \pm 0.0025(\text{exp.}) \pm 0.0078(\text{theor.})$, consistent with our previous results [3] and with results from LEP [6, 7, 8, 9].

The measurements described above use the QCD calculations of Kunszt and Nason (KN) [10]. Recently, Clay and Ellis (CE) have performed a new $\mathcal{O}(\alpha_s^2)$ QCD calculation of the EEC and $AEEC$ [11]. Applying the procedures described above, we find that the CE calculation describes the data well, and the CE and KN fits are practically indistinguishable. The extracted values of $\alpha_s(M_Z^2)$ for the $AEEC$ are in reasonable agreement for the two calculations. For EEC the CE $\alpha_s(M_Z^2)$ were systematically lower by between 0.005 and 0.009 in the range $f > 10^{-3}$, where perturbation theory can be applied reliably [4]. For the CE calculation we obtain a central value[12] $\alpha_s(M_Z^2) = 0.1184$ which is significantly lower than that for the KN calculation: $\alpha_s(M_Z^2) = 0.1240$.

The CE EEC result does not appear to be consistent with the claim of Ref. [13] that the KN EEC calculation has been demonstrated to be correct, and the data do not favor either calculation over the other. As the KN calculations of the EEC, $AEEC$, and other event shapes have been used universally in $\alpha_s(M_Z^2)$ determinations at SLC/LEP, it is imperative that the differences between these two calculations be resolved.

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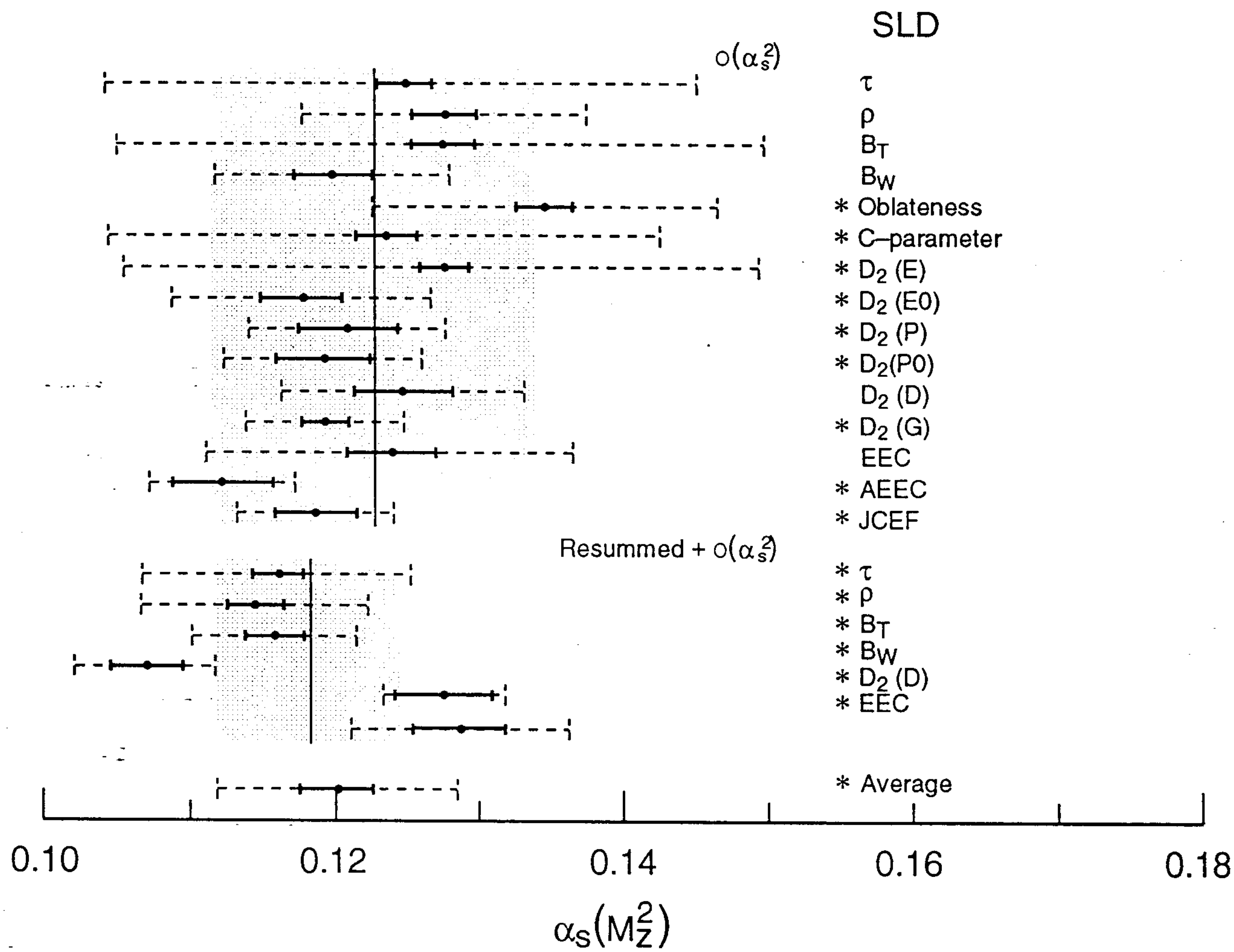

Figure 2: Compilation of $\alpha_s(M_Z^2)$. The vertical line and the shaded region represent the average value of α_s and its error.

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