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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 α_s 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 leading and next-to-leading logarithm approximation. The study includes event shapes, jet rates, and particle correlations. We checked the consistency between α_s extracted from these different measures and found the dominant uncertainty on α_s to be from uncalculated higher order contributions.

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Various observables have been introduced to measure α_s in the process $e^+e^- \rightarrow$ hadrons. We studied fifteen observables which can be calculated exactly up to $\mathcal{O}(\alpha_s^2)$ in QCD perturbation theory.[1,2] The observables comprise six event shapes, i.e., thrust ($\tau = 1 - T$), heavy jet mass ($\rho = M_H^2/E_{vis}^2$), total jet broadening (B_T), wide jet broadening(B_W),[3] 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)[4]; energy-energy correlations (EEC) and their asymmetry ($AEEC$), and the jet cone energy fraction ($JCEF$).[5] Further discussion of the definitions and properties of these observables can be found elsewhere.[6] The strong coupling α_s can be derived by fitting the QCD calculations to the distributions from the experimental data.

In this comprehensive analysis we used the combined 1992 and 1993 data samples collected by the SLD/SLC; 37226 events passed our hadronic event selection criteria.[7,8] We applied bin-by-bin correction factors to the experimental distributions to account for the effects of the detector acceptance and hadronization. Each corrected distribution was fitted by minimizing χ^2 with respect to $\Lambda_{\overline{MS}}$ at selected values of the *renormalization scale* $f \equiv \mu^2/s$, where $\sqrt{s} = M_{Z^0}$. For the jet rates analysis, the lower bound on y_{cut} was chosen such that the 4-jet rate, R_4, is less than 1 %. For the event shapes, EEC, $AEEC$, and $JCEF$, the fit ranges were set by the kinematic limit for 3-parton production at $\mathcal{O}(\alpha_s)$, and by the empirical approach of extending the fit range toward the back-to-back region as long as the χ^2_{dof} of the fit with $f = 1$ remained less than 5. In addition, we required the size of the deviation from 1 for the hadronization correction factors to be smaller than 40 % and the uncertainties of the hadronization and detector correction to be smaller than 30 % for all observables.

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.[9] We therefore considered for each observable the f range bounded below by the criterion $\chi^2_{dof} < 5$, and placed an upper bound of $f = 4$ corresponding to a reasonable physical limit.

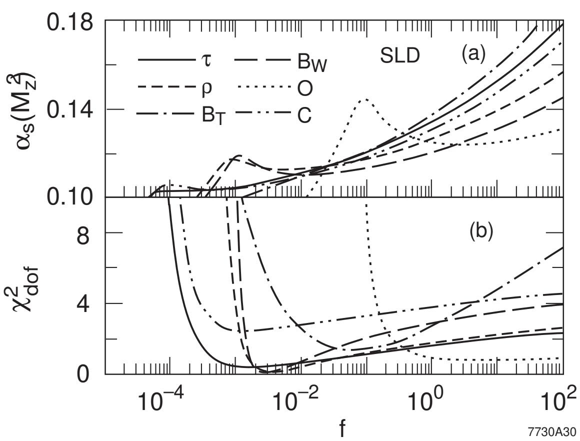

Fig. 1. (a) $\alpha_s(M_Z^2)$ and (b) χ^2_{dof} from the $\mathcal{O}(\alpha_s^2)$ fits for event shapes.

For each observable we took the central value of α_s as defined by the midpoint between the extrema in this f range, and the scale uncertainties as defined by the difference between the central value and the extrema. The hadronization uncertainty on α_s was estimated by adding in quadrature the uncertainties from the Q_0 cutoff value (0.5-2.0 GeV) in JETSET 7.3[10] and half of the difference between the α_s values using

JETSET 7.3 and HERWIG 5.5.[11] We took the average value of α_s using JETSET 7.3 and HERWIG 5.5 hadronization corrections as the final α_s result from each observable.

Experimental systematic errors were estimated by varying the cuts applied to the data and changing parameters in the simulation of the detector. We found the experimental systematic errors were at the level of 2-3 % of α_s.

We combined the results from all fifteen observables using an unweighted average of the α_s values, experimental systematic, and theoretical uncertainties to obtain $\alpha_s(M_Z^2) = 0.121 \pm 0.003(\text{exp.}) \pm 0.011(\text{theor.})$. The theoretical error is dominated by the scale uncertainty (± 0.011).

We next measured α_s by comparing matched $NLL + \mathcal{O}(\alpha_s^2)$ calculations with the data. These calculations combine a resummation[12] of the leading and next-to-leading logarithmic terms to all orders in α_s with the second order calculations. These calculations are applicable to τ, ρ, B_T, B_W, D_2(D-algorithm), and EEC. We considered four matching schemes.[13,14,16] The differences between these matching schemes are at $\mathcal{O}(\alpha_s^3)$. The fit ranges were chosen to be the same as for the $\mathcal{O}(\alpha_s^2)$ fits except for EEC where the $NLL + \mathcal{O}(\alpha_s^2)$ calculation is applicable only above 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 $NLL+\mathcal{O}(\alpha_s^2)$ 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 to obtain a value of α_s for each observable, and considered the matching ambiguity, defined as the maximum deviation from the average, as an additional theoretical uncertainty. We did not consider *R-matching* for B_T and B_W because we found the fit qualities were poor for all f. By averaging over the six α_s values we obtained $\alpha_s(M_Z^2) = 0.119 \pm 0.003(\text{exp.}) \pm 0.007(\text{theor.})$, where the theoretical error is the sum in quadrature of the hadronization (± 0.002) and scale and matching uncertainties (± 0.007). The theoretical uncertainty, which reflects a lack of higher order terms in the calculations, is reduced by a factor of 1.5 relative to the $\mathcal{O}(\alpha_s^2)$ analysis. However, this uncertainty still dominates the error on the measurement of α_s.

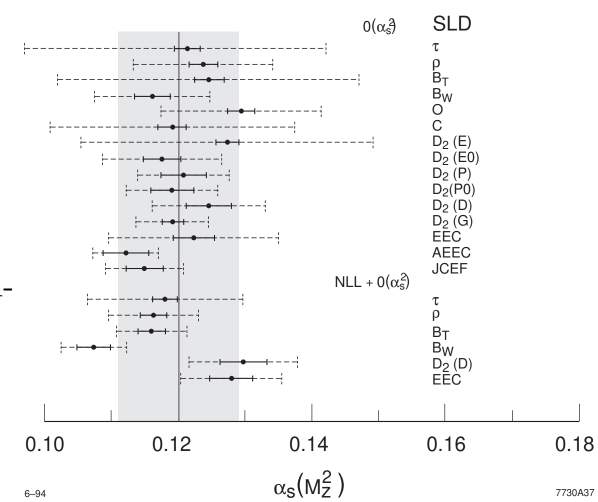

Fig. 2. Compilation of $\alpha_s(M_Z^2)$. The vertical line and the shaded region represent the average value of α_s and its error.

Figure 2 summarizes the measured α_s values from the fifteen observables using $\mathcal{O}(\alpha_s^2)$ calculations and the six observables using the $NLL+\mathcal{O}(\alpha_s^2)$ calculations. 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 $NLL + \mathcal{O}(\alpha_s^2)$ calculations by taking an unweighted average of the α_s values and experimental and theoretical errors, obtaining

$$\alpha_s(M_Z^2) = 0.120 \pm 0.003(\text{exp.}) \pm 0.009(\text{theor.}).$$

This result is consistent with our previous results[7,8] and with the experiments at LEP.[13–16]

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