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A TEST OF THE FLAVOR INDEPENDENCE
OF STRONG INTERACTIONS*

THE SLD COLLABORATION*

represented by

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ABSTRACT

We present a comparison of the strong couplings of b , c , and light (u , d , and s) quarks derived from multi-jet rates in flavor-tagged samples of hadronic Z^0 decays recorded with the SLC Large Detector at the SLAC Linear Collider. By comparing the rates of 3-jet events in these three samples we have extracted (Preliminary) values of: $\alpha_s(uds)/\alpha_s(all) = 0.96 \pm 0.03(\text{stat.}) \pm 0.04(\text{syst.}) \pm 0.02(\text{theory})$, $\alpha_s(c)/\alpha_s(all) = 1.16 \pm 0.11(\text{stat.}) \pm 0.10(\text{syst.}) \pm 0.07(\text{theory})$, $\alpha_s(b)/\alpha_s(all) = 0.98 \pm 0.04(\text{stat.}) \pm 0.08(\text{syst.}) \pm 0.02(\text{theory})$.

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One of the fundamental assumptions of the theory of strong interactions, Quantum Chromodynamics (QCD), is that the strong coupling α_s is independent of quark flavor. This assertion can be tested by selecting events of the type $e^+e^- \rightarrow q\bar{q}(g)$ for specific quark flavors q , and measuring the strong coupling in these selected samples. Although an absolute determination of α_s for each quark flavor would have large errors, it is possible to test the flavor-independence of QCD precisely by measuring ratios of couplings in which most experimental and theoretical errors are expected to cancel. Previous measurements¹ using this technique have verified the flavor-independence of strong interactions to a precision of a few percent for b quarks, and to 15% for other flavors, but typically suffer from large errors due to inefficient flavor tagging and large corrections for biases due to preferential selection of events without hard gluon radiation. However, with the advent of precision vertex detectors at e^+e^- colliders it has become possible to select enriched samples of particular quark flavors with high efficiency in a relatively unbiased manner. Comparison of the rates of multi-jet production in these samples allows one to derive the ratio of the strong coupling α_s for the selected quark flavor relative to that for the global sample of all flavors.

In this paper, we present an analysis based on the 1993 run of the SLC Large Detector (SLD) at the SLAC Linear Collider (SLC), during which approximately $2 pb^{-1}$ of electron-positron annihilation data were collected at a mean center-of-mass energy of $\sqrt{s} = 91.26$ GeV. The triggers and selection for hadronic events are described elsewhere^{3,4}. From our 1993 data sample, 28036 events were selected.

The analysis presented below used as a basis for the quark flavor tags the number of quality tracks n_{sig} whose impact parameter measured in the plane transverse to the beam axis was more than 3σ from the interaction point. The event sample was divided into three parts: those events with $n_{sig} = 0$ were defined as the uds -tagged sample; those with $1 \leq n_{sig} \leq 3$ were defined as the c -tagged sample; and those with $n_{sig} \geq 4$ were defined as the b -tagged sample. The efficiencies ε for selecting an event of the desired type after event cuts and the purities Π of the tagged samples relative to all events passing cuts are as follows: $(\varepsilon, \Pi) = 77\%, 86\%$ (uds); $(\varepsilon, \Pi) = 59\%, 38\%$ (c); and $(\varepsilon, \Pi) = 46\%, 94\%$ (b).

Jets were then reconstructed using iterative clustering algorithms. We have used the JADE algorithm⁵ and its ‘E’, ‘E0’, ‘P’, and ‘P0’ variations, as well as the ‘Durham’ algorithm.⁶ For each algorithm, y_c was chosen to maximize the rate of 3-jet event production R_3 , subject to the constraint that the measured rate of 4-jet events R_4 was smaller than 1%.

The three-jet rate R_3 for each of the tagged quark types (uds , c , and b) was extracted from a fit to the number of two- and three-jet events in each tagged sample, using tagging efficiency matrices calculated from Monte Carlo simulations of hadronic Z^0 decays⁷ combined with a simulation of the SLD detector.² The bias towards selecting two-jet over three-jet events in the tags is low. If we define the tag bias B^i as the ratio of the efficiency for tagging two-jet events of a desired flavor to that for tagging three-jet events, we find for the three tags: $B^{uds} = 1.060$, $B^c = 1.032$, $B^b = 1.224$.

In order to obtain the proper value for α_s in heavy quark events, a correction to the three jet rate of magnitude $\sim 5\%$ must be made to account for the reduced phase-space for gluon emission due to the heavy quark mass^{9,10}.

To $O(\alpha_s^2)$ in perturbative QCD, the three-jet rates R_3 have the general form⁸: $R_3 = A(y_c)\alpha_s + B(y_c)\alpha_s^2$. Hence, the ratio of the strong coupling in a sample of quark type j to that of all hadronic Z^0 boson decays can be extracted from the ratio of the three-jet rates by

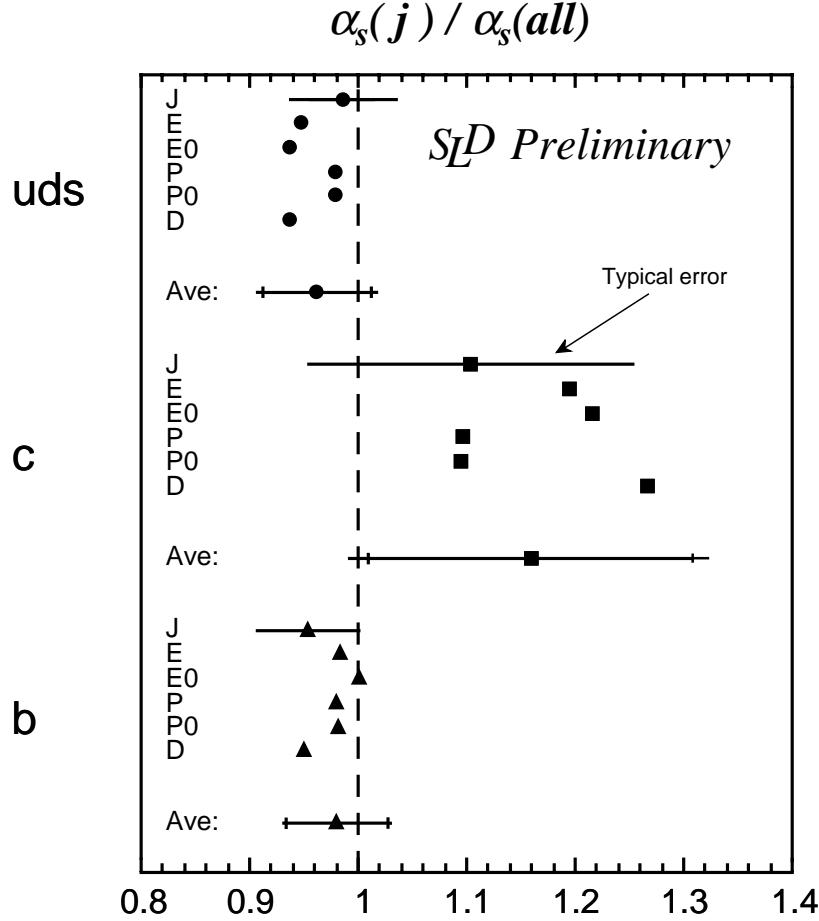


Fig. 1. The results from correcting the R_3 values to obtain $\alpha_s(j)/\alpha_s(\text{all})$, derived for each of the jet algorithms used in the analysis for each of the quark flavors. Typical statistical + systematic errors are shown on the points representing the JADE algorithm. The error bars on the average values include the r.m.s. variation of the values from the different algorithms and the statistical and systematic errors.

inverting the following equation:

$$\frac{R_3^j}{R_3^{\text{all}}} = \frac{A\alpha_s(j) + B\alpha_s^2(j)}{A\alpha_s(\text{all}) + B\alpha_s^2(\text{all})} . \quad (1)$$

After applying the phase space correction, equation 1 was inverted for all jet algorithms, the results of which are shown in Fig. 1. The results were averaged to obtain the ratio of the strong couplings, giving (preliminary) values of:

$$\begin{aligned} \frac{\alpha_s(\text{uds})}{\alpha_s(\text{all})} &= 0.96 \pm 0.03(\text{stat.}) \pm 0.04(\text{syst.}) \pm 0.02(\text{theory}) \\ \frac{\alpha_s(c)}{\alpha_s(\text{all})} &= 1.16 \pm 0.11(\text{stat.}) \pm 0.10(\text{syst.}) \pm 0.07(\text{theory}) \\ \frac{\alpha_s(b)}{\alpha_s(\text{all})} &= 0.98 \pm 0.04(\text{stat.}) \pm 0.08(\text{syst.}) \pm 0.02(\text{theory}) . \end{aligned} \quad (2)$$

The largest systematic error contributions are from the uncertainty in tag efficiencies resulting from our limited knowledge of the heavy quark fragmentation functions. The theory error includes an overall theoretical error⁴ on α_s (all) of ± 0.01 and the r.m.s. of the spread in values when the analysis is repeated with each of the 6 jet algorithms, which dominates the error. The correlation coefficients from the fit are: $uds - c : -0.79$, $uds - b : 0.26$, $c - b : -0.51$. We see that, within errors, there is no evidence of a flavor dependence of α_s .

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