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A STUDY OF JET RATES AND MEASUREMENT OF α_s AT THE Z^0 RESONANCE*

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ABSTRACT

We present jet rates in hadronic decays of Z^0 bosons measured by the SLD experiment at SLAC. The data are analysed in terms of the JADE and recently proposed Durham algorithms, and are found to be in agreement with the predictions of perturbative QCD plus fragmentation Monte Carlo models of hadron production. Corrected 2, 3 and 4-jet rates are well described by $\mathcal{O}(\alpha_s^2)$ perturbative QCD calculations. From fits to the differential 2-jet distribution the strong coupling $\alpha_s(M_Z)$ is measured to be $\alpha_s(M_Z) = 0.119 \pm 0.002(\text{stat.}) \pm 0.003(\text{exp.syst.}) \pm 0.014(\text{theory})$ (preliminary). The largest contribution to the error arises from the theoretical uncertainty in choosing the QCD renormalisation scale.

Event Selection and Measurement

The SLAC Linear Collider (SLC) produces electron-positron annihilation events at the Z^0 resonance which are recorded by the SLC Large Detector (SLD). In the first physics run from February to September 1992, a sample of about 12000 Z^0 decays was accumulated by the SLD. 9000 are used in this analysis.

The analysis presented here used charged tracks measured in the central drift chamber (CDC). A set of cuts was applied to select well-measured tracks and events well-contained within the detector acceptance.[1] 5500 events survived these cuts. The total background was estimated to be at the level of 0.3%.

We reconstructed jets using the Durham (D)[2] jet-finding algorithm as well as with the E, E0 and p schemes which are variations of the JADE algorithm.[3] The n-jet rates $R_n(y_{cut})$ reconstructed from the SLD data with the D algorithm are shown in Fig. 1 for the cases $n = 2,3,4,\geq 5$. The data were corrected by standard procedures[1] for the effects of initial state radiation, detector acceptance and resolution, analysis cuts, unmeasured neutral particles, decays of unstable particles and hadronization. Also shown in Fig. 1 are the predictions of the JETSET 6.3 and HERWIG 5.3 perturbative QCD plus fragmentation Monte Carlo programs, which are seen to be in agreement with the data.

$R_3(y_{cut})$ and $R_4(y_{cut})$ have been calculated to next-to-leading and leading order, respectively, in QCD perturbation theory.[4,5] $R_2(y_{cut})$ is derived by applying the

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unitarity constraint $R_2 = 1 - R_3 - R_4$. The free parameters in the calculations are the QCD interaction scale $\Lambda_{\overline{MS}}$ and the renormalization scale factor $f = \mu^2/E^2_{cm}$.

To avoid the correlations between adjacent points in Fig. 1 it is customary to fit the QCD calculations to the differential 2-jet rate $D_2(y_{cut})$ defined as: $D_2(y_{cut}) \equiv [R_2(y_{cut}) - R_2(y_{cut} - \Delta y_{cut})]/\Delta y_{cut}$. The SLD measurement of $D_2(y_{cut})$ is shown in Fig. 2, where each event enters the plot only once, along with are two fits of the

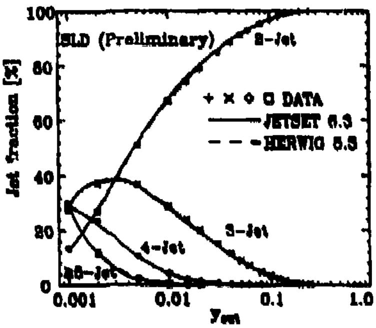

Fig. 1 Jet rates measured by SLD with the Durham algorithm

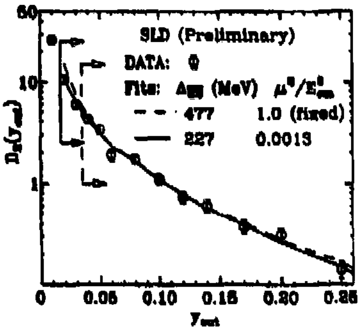

Fig. 2 Differential 2-Jet Rate and QCD fits to the data

$O(\alpha_s^2)$ calculation by Kunszt and Nason.[5] In the first fit (dashed line) the renormalisation scale factor f was fixed to unity and the single parameter $\Lambda_{\overline{MS}}$ was varied. In the second fit (solid line) both $\Lambda_{\overline{MS}}$ and f were varied. Since R_4 is only calculated to leading order and R_5 does not contribute to $O(\alpha_s^2)$, the fits were restricted to regions of y_{cut} where $R_4 < 1\%$ for $f = 1$ and $R_5 < 1\%$ for free f. The resulting values for $\Lambda_{\overline{MS}}$ can be translated into $\alpha_s(M_Z)$ using the renormalisation group equation, giving $\alpha_s(M_Z) = 0.133 \pm 0.002$ and 0.118 ± 0.002 respectively. A similar analysis was performed for the E0, E and p schemes. The results are shown in Table 1.

	(f = 1)		(f fitted)		
scheme	$\Lambda_{\overline{MS}}$ (MeV)	$\chi^2/d.o.f$	$\Lambda_{\overline{MS}}$ (MeV)	$f = \mu^2/E^2_{cm}$	$\chi^2/d.o.f$
D	477 ± 41	7/8	227 ± 18	0.0013 ± 0.0002	7/10
E0	258 ± 35	14/8	109 ± 12	0.0045 ± 0.0005	15/10
E	528 ± 50	9/4	89 ± 8	0.0001 ± 0.0001	7/6
P	326 ± 48	5/8	209 ± 13	0.023 ± 0.0012	8/10

Table 1 Results of fitting $O(\alpha_s^2)$ QCD calculations to SLD data, for fixed and variable renormalisation scales. The errors are statistical only.

For each jet-finding scheme the averaged results from the two fits are listed in Table 2. Also listed are the errors contributing to this measurement. The statistical error is $\leq 2\%$ and the experimental systematic error is $\leq 3\%$ for all algorithms; $\Delta\alpha_s(had.)$ is the error introduced by the modelling of the hadronization process, estimated by comparing results from two different fragmentation models in JETSET 6.3 and HERWIG 5.3; $\Delta\alpha_s(Q_0)$ is the uncertaintiy introduced by the choice of the lower cutoff for parton branching Q_0, estimated by varying Q_0 between 0.5 and 5.0 GeV. The largest error is introduced by the scale uncertainty, $\Delta\alpha_s(scale)$, estimated from the difference between the measured values of $\Lambda_{\overline{MS}}$ with $f = 1$ and with f as a free parameter. In Fig. 3 the behavior of α_s as a function of the renormalization scale f is shown. The fitted values of f lie very close to the minimum for each jet-finding algorithm. The scale uncertainty is taken to be the difference between the minimum of each curve and the value at $f = 1$. Uncertainties introduced by varying the fit range of y_{cut} were found to be negligible. These results agree within experimental errors with previous measurements from SLC and LEP[6] as well as with our own measurement of α_s from energy-energy correlations.[1]

Scheme	$\alpha_s(M_{Z^0})$	$\Delta\alpha_s(stat.)$	$\Delta\alpha_s(exp.)$	$\Delta\alpha_s(had.)$	$\Delta\alpha_s(Q_0)$	$\Delta\alpha_s(scale)$
D	0.125	±0.002	±0.003	±0.003	±0.004	±0.007
E0	0.112	±0.002	±0.003	±0.003	±0.002	±0.007
E	0.119	±0.002	±0.003	±0.003	±0.005	±0.013
P	0.120	±0.002	±0.003	±0.003	±0.005	±0.009

Table 2 Summary of results for α_s and from various sources. The values for α_s are the average of the results from the two fits.

Summary and Discussion

We have presented an analysis of jet rates from a data sample of 12000 hadronic Z^0's recorded by the SLD. We have determined the value of the strong coupling, $\alpha_s(M_{Z^0})$, using four different jet finding algorithms (E0,p,E and D). These measurements were compared with analytic calculations in complete second order perturbative QCD. The QCD parameter $\Lambda_{\overline{MS}}$, and thus $\alpha_s(M_{Z^0})$, was determined by fits of the QCD calculations to the corrected data distributions.

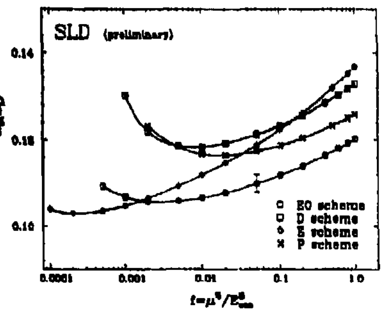

Fig.3 α_s as a function of the scale f

The average of the four results is

$$\alpha_s(M_Z) = \mathbf{0.119} \pm \mathbf{0.002}\ (\text{stat.}) \pm \mathbf{0.003}\ (\text{exp.syst.}) \pm \mathbf{0.014}\ (\text{theory}).$$

Experimental statistical and systematical uncertainties are at the level of $2-3\%$. The theoretical error is taken as the sum of $\Delta\alpha_s(had.)$, $\Delta\alpha_s(Q_0)$ and $\Delta\alpha_s(scale)$ added in quadrature, for the E scheme, which yields the largest uncertainties. We find that the largest error in this measurement is the theoretical error from varying the renormalization scale f. Our result is in good agreement with results from the LEP experiments.

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