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QCD STUDIES OF HADRONIC DECAYS OF Z^0 BOSONS BY SLD[†]

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presented by

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Abstract

Z^0 bosons have been produced by collisions of longitudinally polarized electrons with unpolarized positrons at the SLAC Linear Collider and their decays have been recorded by the SLD experiment. We present preliminary QCD results based on the first 6000 such decays. We find good agreement between the inclusive properties of these data and the predictions of perturbative QCD plus fragmentation models. The strong coupling, α_s, has been measured by three methods: jet rates yield $\alpha_s(M_Z) = 0.119 \pm 0.002$ (*stat.*) ± 0.003 (*exp. syst.*) ± 0.014 (*theor.*); energy-energy correlations yield $\alpha_s(M_Z) = 0.121 \pm 0.002 \pm 0.004 \pm^{0.016}_{0.009}$; and the energy-energy correlation asymmetry gives $\alpha_s(M_Z) = 0.108 \pm 0.003 \pm 0.005 \pm^{0.008}_{0.003}$.

INTRODUCTION

The SLAC Linear Collider (SLC) produces electron-positron annihilation events at the Z^0 resonance which are recorded by the SLC Large Detector (SLD)[1]. The first physics run began in February 1992. SLC performance continued to improve during the run, routinely achieving Z^0 production rates of 10-20 per hour. By the end of August, about 12,000 Z^0s had been accumulated. Approximately 6000 hadronic Z^0 decays were used in the analysis presented here.

A major achievement of the 1992 run was the delivery of an intense beam of longitudinally polarized electrons. Details of the polarization program and a preliminary measurement of the left-right cross section asymmetry were contributed separately to this conference[2]. In this paper we study in detail the structure of hadronic Z^0 decays, compare with the predictions of perturbative QCD plus fragmentation models, and measure the strong coupling, α_s, by three established techniques.

THE SLD AND EVENT SELECTION

The detector is described in detail elsewhere[1]. The micro-vertex and Cherenkov Ring Imaging Detectors were not used in this analysis, but are described in separate contributions to this conference[3].

Charged particles were tracked in the Central Drift Chamber (CDC), which consists of 80 layers of axial or stereo sense wires, contained in a 0.6T axial magnetic field. Particle energies were measured in the Liquid Argon Calorimeter (LAC) and Warm Iron Calorimeter, which are segmented into approximately 40,000 projective towers.

Two triggers were used for hadronic events, one requiring a total LAC energy greater than 8 GeV, the other requiring at least two well-separated tracks in the CDC. Events were then required to pass two loose selections of hadronic events, one based on the topology of energy deposition in the LAC, the other on the number and topology of charged tracks in the CDC.

The analysis presented here used charged tracks measured in the CDC. A set of cuts was applied to select well-measured tracks and events well-contained within the detector accep-

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tance. Tracks were required to have:

- a fit quality of $\sqrt{2\chi^2} - \sqrt{2N_{df} - 1} < 15$,
- a closest approach to the beam axis within 10 cm, and within 20 cm along the axis of the nominal interaction point,
- a polar angle, θ, with respect to the beam axis within $|\cos\theta| < 0.8$, and
- a minimum momentum transverse to the beam axis of $p_\perp > 150$ MeV/c.

Events were required to have:

- a minimum of five such tracks,
- no track with measured momentum, $p > 100$ GeV/c,
- a thrust axis with polar angle, θ_T, with respect to the beam within $|\cos\theta_T| < 0.71$, and
- a minimum charged visible energy, $E_{vis} > 0.2 M_Z$, where all tracks were assigned the charged pion mass.

A total of 3837 events survived these cuts. The background is dominated by an estimated contribution of < 0.5% from tau pair events.

HADRONIC EVENT PROPERTIES

We have studied global event variables, including thrust, oblateness, sphericity and aplanarity, as well as inclusive track variables, such as rapidity, momentum, and transverse momentum in and out of the event plane. In addition, we have selected a sample of 3-jet events using a y_{cut} (see below) of 0.02, in order to examine the scaled jet energies and the polar angles of the most energetic jet and the event plane, as well as the Ellis-Karliner angle[4].

For each of these quantities, we compared the distributions from the data with the predictions of two perturbative QCD plus fragmentation Monte Carlo programs, JETSET 6.3[5] and HERWIG 5.3[6]. For JETSET, we used a parameter set tuned by TASSO[7] at $\sqrt{s} = 35$ GeV. For HERWIG, we used the default parameters. For each model, 10,000 events were generated and passed through a detailed simulation of the SLD and the same reconstruction, event selection, and analysis as the data.

For all variables studied, both models give a good description of the data. The distributions of thrust, oblateness, and transverse momentum in and out of the event plane are shown in Fig. 1 as examples. These results confirm predictions[8] of the JETSET simulation made before data at the Z^0 were available, and are in agreement with results from experiments at LEP[9].

JET RATES AND α_S

The measurement of jet production rates provides an intuitive way to determine the strong coupling, α_s, since in first order perturbative QCD the rate of three-jet events is directly proportional to this coupling. Jets are often reconstructed using the "JADE algorithm"[10], in which the lowest mass pair of particles is iteratively clustered together until all $m_{ij}^2 > y_{cut} E_{vis}^2$. The number of clusters remaining is defined to be the jet multiplicity of the event. We have used the E, E0 and p clustering schemes[11], as well as the recently-introduced "Durham" or $k_\perp$ scheme[12].

Jet multiplicity rates were calculated from our data as a function of the resolution parameter, y_{cut}, and from the simulations described above, which were found to reproduce the data. The data were therefore corrected to the parton level using the JETSET simulation, and compared with theoretical calculations. Figure 2 shows the quantity $D_2(y_{cut})$, which is the distribution of the value of y_{cut} for which the event changes from a two-jet event to a three-jet event, for the Durham scheme. Also shown are two fits to the data of a calculation by Kunszt and Nason[13]. The calculation has two parameters, $\Lambda_{\overline{MS}}$, which is related to α_s, and the QCD renormalization scale, μ, the choice of which is not theoretically well-defined. In one fit (dashed line) μ was fixed to the Z^0 mass. In the second (solid line) it was a free parameter. Both fits are able to describe the data, however the $\Lambda_{\overline{MS}}$ values are quite different and the fitted value of μ is very small.

Figure 3 shows the value of $\alpha_s(M_Z)$ calculated from the fitted $\Lambda_{\overline{MS}}$ with fixed μ, as a function of μ for each of the schemes studied. There is substantial variation between the four schemes for any fixed μ, and the schemes show

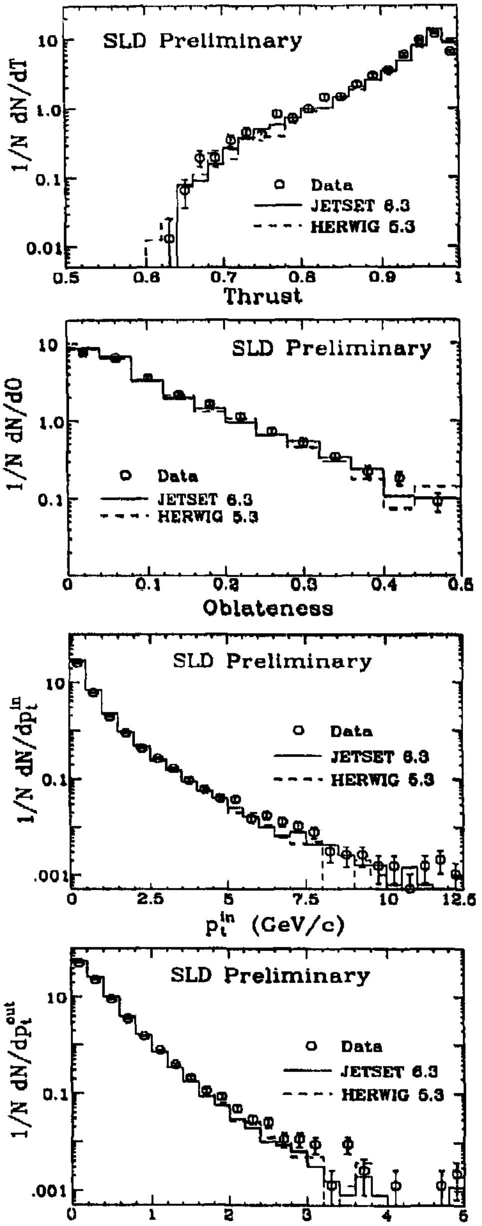

Figure 1. Comparison of (a) thrust, (b) oblateness, (c) p_t^{in} and (d) p_t^{out} distributions from our data (points with error bars) with predictions of the JETSET (solid line) and HERWIG (dashed line) simulations.

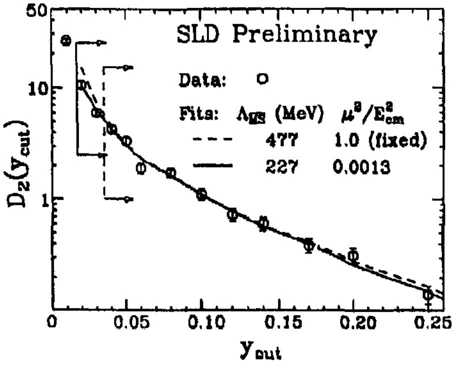

Figure 2. The corrected differential two-jet rate in the Durham scheme. The calculations of Kunszt and Nason have been fitted to the data with the renormalization scale fixed (dashed) and free (solid). The fit ranges[14] are indicated by the arrows.

strong and different μ dependences, although low fitted values of μ are obtained in each case. In order to quote a result, we first averaged the α_s values from the two fits (μ free and $\mu = M_Z$) for each scheme, then averaged over the four schemes. Our preliminary result is $\alpha_s(M_Z) = 0.119 \pm 0.002 \pm 0.003 \pm 0.014$. The first error is statistical. The second error is experimental systematic, evaluated by varying the analysis cuts and detector simulation. The third error is theoretical and is dominated by the largest observed variation with μ, although it also includes contributions from varying hadronization simulations and the differences between the jet-finding schemes.

ENERGY-ENERGY CORRELATIONS

Another quantity sensitive to the strong coupling is the energy-weighted distribution of opening angles, χ, between particle pairs, or energy-energy correlation[15], EEC(χ) ≡

$$\left\langle \frac{1}{2\Delta\chi} \int_{\chi - \frac{\Delta\chi}{2}}^{\chi + \frac{\Delta\chi}{2}} \sum_{ij} \frac{E_i E_j}{E_{vis}^2} \delta(\chi' - \chi_{ij})\, d\chi' \right\rangle ,$$

where the average is over all events in the sam-

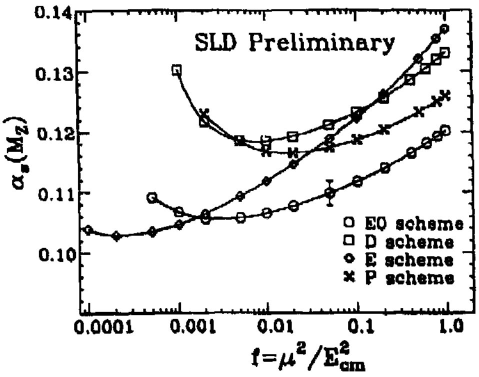

Figure 3. Renormalization scale dependence of the α_s measurement for the four clustering schemes. The size of the statistical error is indicated on one point.

ple. The region around $\chi \sim \pi/2$ is sensitive to hard gluon emission. Since the EEC uses tracks directly, this method is insensitive to ambiguities in jet finding. The asymmetry, $\mathrm{AEEC}(\chi) = \mathrm{EEC}(\pi-\chi) - \mathrm{EEC}(\chi)$, is also sensitive to α_s and is expected to be less sensitive to details of hadronization.

The EEC and AEEC were derived from our data and from the two Monte Carlo simulations. Both simulations reproduced the data, and the data were corrected to the parton level and compared with four theoretical calculations[13,16]. Figure 4 shows the corrected data along with fits to one calculation. Here also, there is considerable ambiguity in the choice of renormalization scale. Figure 5 shows the μ dependence of the fitted $\Lambda_{\overline{MS}}$ value for each calculation. All fits give adequate descriptions of the data. However, there is substantial variation between the calculations, and each calculation shows a strong dependence on the renormalization scale.

For the purpose of quoting a result, we took the fit from Kunzst and Nason at f=0.1 as our central $\Lambda_{\overline{MS}}$ value and calculated α_s. This yields $\alpha_s(M_Z) = 0.121 \pm 0.002 \pm 0.004 \pm^{0.016}_{0.009}$ for the EEC and $\alpha_s(M_Z) = 0.108 \pm 0.003 \pm 0.005 \pm^{0.008}_{0.003}$ for the AEEC. In both cases, the first error is statistical, the second experimental systematic and the third theoretical. The experimental systematic errors were evaluated by varying the analysis cuts and fit ranges. The theoretical error dominates and is due mostly to the renormalization scale dependence, but also takes into account hadronization and differences between the four calculations.

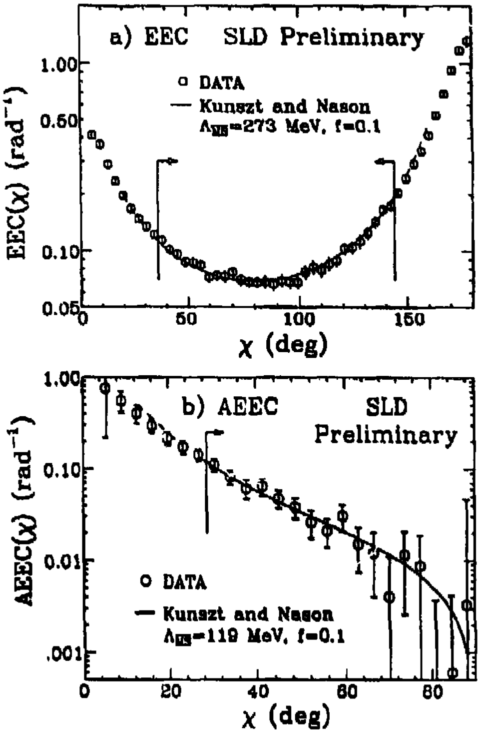

Figure 4. The measured (a) energy-energy correlation and (b) its asymmetry. The solid lines are fits using calculations of Kunszt and Nason over the regions indicated by the arrows.

SUMMARY AND CONCLUSIONS

Properties of hadronic decays of Z^0 bosons have been measured by the SLD at SLAC. These properties are reproduced by the perturbative QCD plus fragmentation Monte Carlo programs JETSET and HERWIG.

These events have been used to measure the strong coupling, α_s, by three methods, with the results $\alpha_s(M_Z)$ =

$$0.119 \pm 0.002 \pm 0.003 \pm 0.014 \quad \text{(Jet Rates)}$$

$$0.121 \pm 0.002 \pm 0.004 \pm^{0.016}_{0.009} \quad \text{(EEC)}$$

$$0.108 \pm 0.003 \pm 0.005 \pm^{0.008}_{0.003} \quad \text{(AEEC)}$$

In each case, the first error listed is statistical, the second is from experimental systematics, and the third is our estimate of the theoretical uncertainty. The theoretical errors are dominated by uncertainties in the choice of renormalization scale.

These results are all in agreement with results from experiments at LEP[17] within *experimental* errors. The AEEC gives a smaller value of α_s than the other two methods which is significant if only experimental errors are considered.

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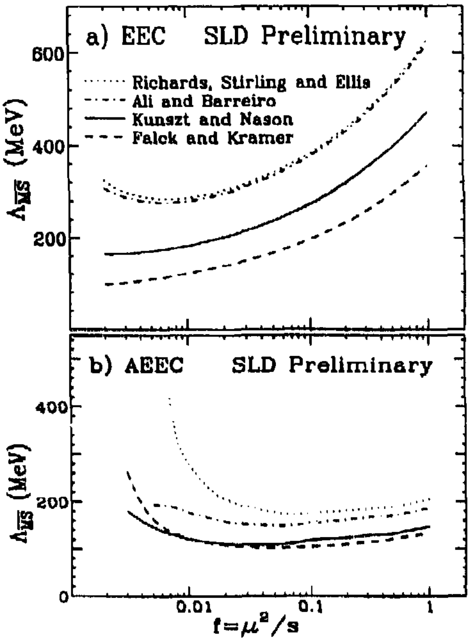

Figure 5. Variation of the fitted $\Lambda_{\overline{MS}}$ with the assumed renormalization scale in (a) EEC and (b) AEEC.

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