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FIRST QCD RESULTS FROM SLD*

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Abstract

The first Z^0 data were recorded by the SLD experiment at SLAC during an engineering run in 1991. From the sample of a few hundred hadronic events collected, the strong coupling $\alpha_s(M_Z)$ has been measured from jet rates and energy-energy correlations (EEC). These (preliminary) results are presented here. From jet rates a second order perturbative QCD fit yields: $\alpha_s(M_Z) = 0.117 \pm 0.009$ (stat.) $\pm\ 0.006$ (exp. syst.) $^{+0.007}_{-0.009}$ (theory). Large systematic differences between α_s values derived from fits to the EEC distribution are observed for various second order QCD calculations, in addition to a significant dependence on the QCD renormalisation scale μ^2. For the Kunszt-Nason calculations at $\mu^2 = 0.1$, $\alpha_s(M_Z) = 0.123 \pm 0.004$ (stat.) $^{+0.003}_{-0.002}$ (exp. syst.) $^{+0.012}_{-0.008}$ (theory) is obtained. For both measurements the theoretical error is dominated by the uncertainty involved in choosing the scale μ^2.

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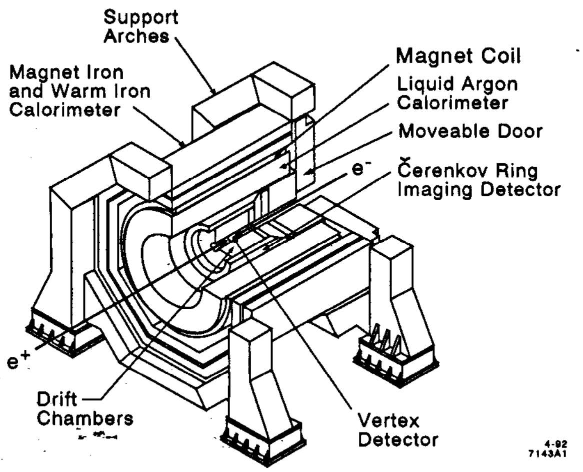

Figure 1. Isometric cutaway drawing of SLD.

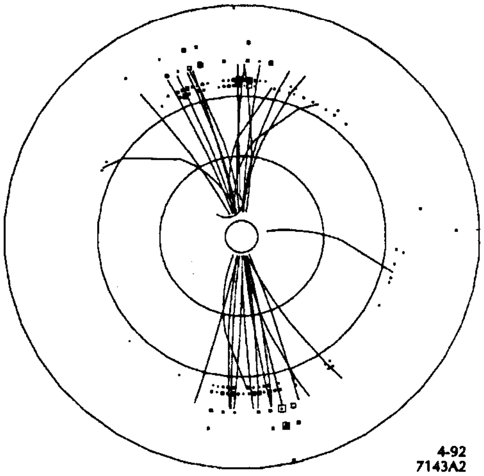

Figure 2. Display of a typical hadronic event showing charged tracks and LAC clusters.

1. STATUS OF THE SLD/SLC PROJECT

Construction of the SLAC Large Detector (SLD)[1] is now practically complete. The detector is shown schematically in Fig. 1 and is described briefly below.

Charged particles are tracked in the Central Drift Chamber (CDC) which contains 10 superlayers of axial and stereo sense wires. Tracking is extended to forward angles (10^0 from the beam axis) by endcap drift chambers. The mean drift distance resolution has been measured to be around 100μm. Momentum measurement is provided by a uniform axial magnetic field of 0.6T.

A micro-vertex detector (VXD) based on charge-coupled device (CCD) technology[2] is mounted on the beampipe. Sixty ladders of 8 CCD's are arranged in four layers at radii between 2.9 and 4.1 cm, extending a distance of 8 cm parallel to the beam axis. Each CCD is composed of square pixels of 22μm size, giving an intrinsic spatial resolution of 5μm.

Charged particle identification is provided by Čerenkov Ring Imaging Detectors (CRID),[3] which lie outside the drift chambers in both barrel and endcap sections. The CRID is designed to provide separation of charged pions, kaons and protons up to momenta of about 30 GeV.

Particle energies are measured in the Liquid Argon Calorimeter (LAC),[4] which contains both electromagnetic and hadronic sections, and in the Warm Iron Calorimeter[5] which forms the outer layer of the hadronic calorimetry, and also provides tracking for muons. Luminosity is measured from the rate of small-angle Bhabha events detected in forward silicon-tungsten calorimeters[6] mounted close to the beampipe.

Towards the end of the 1991 engineering run the SLAC Linear Collider (SLC), operating at a repetition rate of 60 Hz, delivered 4-5 Z^0/hour routinely, attaining a peak rate of 8 Z^0/hour. 332 hadronic events were logged with full readout of the CDC and calorimeters, enabling the triggering, data acquisition and offline analysis chain to be exercised. These data are used in the analysis described in this paper.

2. DATA SELECTION

Two triggers were used. The first, for hadronic and wide-angle Bhabha events, required a LAC energy sum in excess of 30 GeV. The second, for small-angle Bhabha events, required typically 7.5 GeV in both forward and backward luminosity monitors. Hadronic events were then selected by two independent methods, one based on the topology of energy depositions in the LAC, the other on the number of charged tracks measured in the CDC. Both samples were also scanned by eye. The overlap between the two samples was approximately 99%. Bhabha events were identified from their characteristic topology by a similar procedure. Comparison of the relative numbers of hadronic and Bhabha events found indicates that the trigger and selection efficiency was better than 90% for hadronic events. A typical hadronic event is shown in Fig. 2.

The analysis presented here uses only charged tracks measured in the CDC. A standard set of cuts was applied to the data to select well-measured tracks in terms of position and momentum and events well-contained within the detector acceptance. For the jet rates analysis, tracks were required to have a polar angle θ with respect to the beam axis within the range $|\cos\theta| < 0.80$, and to have a minimum transverse momentum perpendicular to this axis of $p_T > 150$ MeV/c^2. Events were required to contain a minimum of five such tracks, have a thrust axis orientation θ_T within $|\cos\theta_T| < 0.71$, and a minimum charged visible energy of 20 GeV. 229 events survived these cuts and were used in the subsequent analysis. A similar set of cuts was applied for the EEC analysis.

3. α_s FROM JET RATES

The 'JADE algorithm'[7,8] has been widely used as a standard procedure for defining jets in both experimentally-measured hadronic events and in perturbative QCD calculations at the parton level,[9,10] thereby allowing theory to be compared with experiment after taking account of hadronisation effects appropriately. The fraction, R_n, of events classified as being of n-jet topology depends upon an arbitrary parameter, y_c,[7] which sets the jet resolution scale. $R_n(y_c)$ reconstructed from the SLD data is shown in Fig. 3(a) for the cases $n = 2,3,4,\geq 5$. (The data were corrected by standard procedures (see *eg.*[8,11]) for the effects of initial state radiation, detector acceptance and resolution, analysis cuts, unmeasured neutral particles and decays of unstable particles.) Also shown in Fig. 3(a) are the predictions of the JETSET 6.3[12] and HERWIG 5.3[13] Monte Carlo programs, which are in good agreement with the data.

$R_3(y_c)$ and $R_4(y_c)$ have been calculated to next-to-leading and leading order, respectively, in second order QCD perturbation theory [9,10]. $R_2(y_c)$ is derived by applying the 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 so-called renormalisation scale $\mu^2 = Q^2/s$.

In Fig. 3(a) the data points at any value of y_c are strongly correlated with those at other y_c values, as the whole dataset is used in calculating the R_n at each y_c value. To avoid these correlations when fitting the QCD calculations to the data,

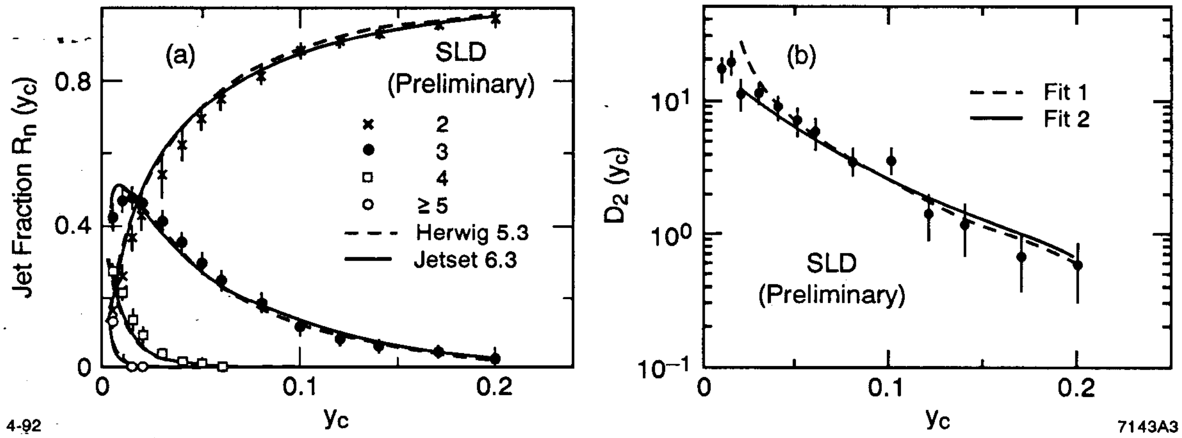

Figure 3. Corrected jet rates (a) and $D_2(y_c)$ (b) distributions. Also shown in (a) are Monte Carlo predictions, and in (b) the results of QCD fits to the data (see text).

it is conventional to fit to the D_2 distribution,[14,15] defined as the slope of the R_2 distribution: $D_2(y_c) \equiv (R_2(y_c) - R_2(y_c - \Delta y_c))/\Delta y_c$, where each event enters the distribution only once. $D_2(y_c)$ is shown in Fig. 3(b) for SLD data corrected, in addition, for hadronisation effects using the Lund string model.[12] Also shown are two fits of the calculation to $O(\alpha_s^2)$[10]: in the first case (fit 1) μ^2 was fixed to unity and the single parameter $\Lambda_{\overline{MS}}$ was fitted in the range $y_c \geq 0.04$, [14] yielding $\Lambda_{\overline{MS}} = 261 \pm 143$ MeV. In the second case (fit 2) a two-parameter fit to $\Lambda_{\overline{MS}}$ and μ^2 was performed in the range $y_c \geq 0.02$, yielding $\Lambda_{\overline{MS}} = 133 \pm 57$, $\mu^2 = 1.2 \pm 0.4 \times 10^{-3}$. All errors are statistical only. These $\Lambda_{\overline{MS}}$ values can be translated into $\alpha_s(M_Z)$ measurements via the solution[16] of the renormalisation group equation, giving $\alpha_s(M_Z) = 0.121 \pm 0.010$ and 0.109 ± 0.007 respectively. These results are in agreement with previous measurement from SLC and LEP.[17]

Extensive studies were performed of systematic effects arising from detector effects and cuts, the data correction procedure, hadronisation effects and varying the renormalisation scale between 0.001 and 1.0. Our preliminary result is thus:

$$\alpha_s(m_Z) \quad = \quad 0.117 \pm 0.009\,(\text{stat.}) \pm 0.006\,(\text{exp.syst.}) \pm 0.003\,(\text{had.})\,^{+0.006}_{-0.009}\,(\text{scale})$$

Even with the modest data sample available to this analysis we are very sensitive to the details of the theoretical calculations; therefore the precision of the measurement is already limited by the uncertainty in choosing the scale μ^2.

4. α_s FROM ENERGY-ENERGY CORRELATIONS

$O(\alpha_s^2)$ perturbative QCD calculations have also been performed for the energy-energy correlations (EEC) distribution.[18] This is shown in Fig. 4(a) for the SLD data corrected as described above; the data are in excellent agreement with similar measurements by OPAL.[19] The $\Lambda_{\overline{MS}}$ values resulting from fits to the calculations by Kunszt and Nason (KN),[10] Ali and Barreiro (AB)[20] and Richards *et al.* (RSE) [21] are summarised in Table 1. The systematic error contributions are as described for jet rates, with the addition of a theoretical error [10,20,21] arising from the numerical precision of the calculation of the perturbative expansion coefficients. The statistical errors on the data were calculated from an ensemble of Monte Carlo datasets containing the

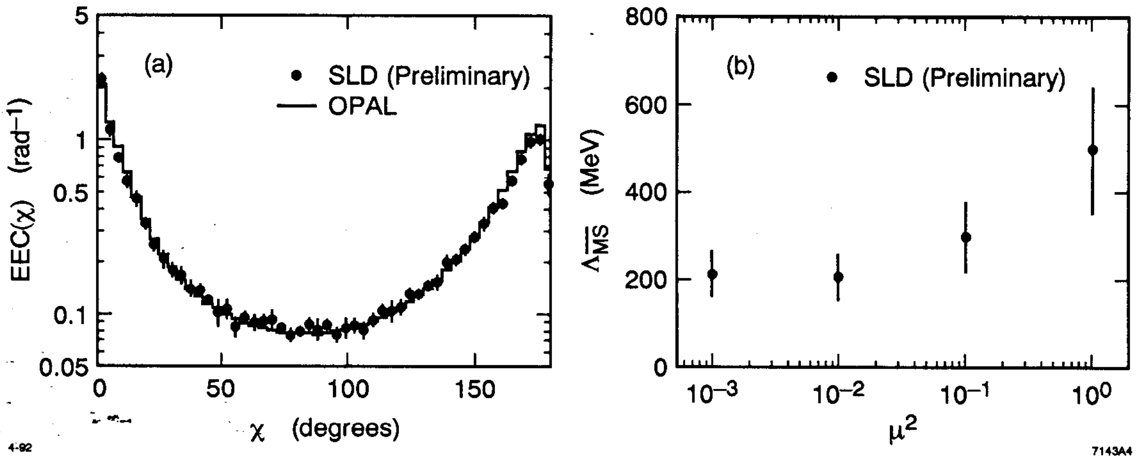

Figure 4. (a) The EEC distribution comparing corrected SLD and OPAL data. (b) The dependence of the fitted value of $\Lambda_{\overline{MS}}$ on μ^2 (see text).

same number of events as the data.

Table 1: Values of $\Lambda_{\overline{MS}}$ and its errors from QCD fits to EEC

	μ^2	$\Lambda_{\overline{MS}}$	stat.	det.	had.	fit region	coefficient
KN	0.001	214	±41	$^{+18}_{-10}$	$^{+23}_{-22}$	$^{+14}_{-10}$	$^{+53}_{-38}$
	0.01	206	±41	$^{+19}_{-2}$	±21	$^{+19}_{-11}$	$^{+25}_{-20}$
	0.1	298	±63	$^{+30}_{-1}$	$^{+33}_{-34}$	$^{+27}_{-17}$	$^{+27}_{-25}$
	1.0	500	±111	$^{+56}_{-0}$	$^{+59}_{-55}$	$^{+48}_{-28}$	$^{+40}_{-36}$
AB	1.0	572	±126	$^{+64}_{-0}$	$^{+67}_{-63}$	$^{+57}_{-36}$	$^{+48}_{-45}$
RSE	1.0	711	±157	$^{+49}_{-8}$	$^{+84}_{-78}$	$^{+29}_{-60}$	$^{+6}_{-7}$

Also shown in Table 1 and Fig. 4(b) for the KN calculations is the dependence upon the renormalisation scale μ^2. The central value of $\Lambda_{\overline{MS}}$ more than doubles when μ^2 is varied in the range 0.001 to 1.0. A systematic tendency is also apparent in the fits to the different theoretical calculations, with higher central $\Lambda_{\overline{MS}}$ values from AB and RSE than KN. All of these findings are in agreement with previous results.[19,22] Taking the fitted value of $\Lambda_{\overline{MS}}$ for the KN calculation at $\mu^2 = 0.1$, we find:

$$\alpha_s(M_Z) = 0.123 \pm 0.004(\text{stat.})^{+0.003}_{-0.002}(\text{exp. syst.}) \pm 0.003(\text{had.}) \pm 0.002(\text{coefft.})^{+0.011}_{-0.007}(\text{scale})$$

As for the jet rates analysis, the precision of the measurement is limited by the scale uncertainty.

5. FUTURE QCD MEASUREMENTS BY SLD

The first physics run of the SLD detector is in progress. With the exception of the endcap CRID's, all components are fully installed and instrumented. At the time of writing the SLC has effectively doubled its luminosity performance compared with 1991, mainly as a result of having increased the repetition rate from 60 to 120 Hz. A peak Z^0 production rate of 16/hour was reached, with 10/hour being achieved routinely. During the last three weeks of March SLD logged just over 1000 hadronic Z^0 events. The goals for this run are for SLD to log 10 000 Z^0 events and for SLC to reach a peak instantaneous luminosity of 50 Z^0/hour.

Future QCD analyses will utilise those features of SLC/SLD which enable unique and/or very precise measurements to be made. If polarised Z^0's are produced 23) * by SLC, the orientation of the event plane, inter-jet angles and jet correlations will be studied in hadronic events to search for any deviations from QCD. The small SLC beampipe, micron-sized beam spot and precise vertex detector will allow heavy quark tagging with high efficiency and purity,1) and also light quark identification from an anti-tag requirement. The flavour independence of the strong coupling can thus be tested24) by measuring α_s in bottom, charm and light quark events separately. Efficient tagging of quark jets in multijet events will also permit tests24) of the different colour charges of quarks and gluons in terms of jet widths25) and particle multiplicities.26)

The particle identification capabilities of the CRID will allow inclusive measurements of hadron species production up to very high particle momenta.3) These spectra will be used to test perturbative QCD calculations27) incorporating modified leading logarithm approximation calculations and the ansatz of local parton-hadron duality.

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* During May 1992 more than 1000 hadronic Z^0's, with an average polarisation ~ 20%, were logged by SLD.

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