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MEASUREMENTS OF SPIN-SENSITIVE QUANTITIES IN HADRONIC DECAYS OF Z^0 BOSONS PRODUCED IN e^+e^- ANNIHILATIONS⋆

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Represented by

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1. INTRODUCTION

Properties of hadronic decays of Z^0 bosons produced in e^+e^- annihilation events can be described by QCD calculations. Such calculations have been performed for many final-state observables up to $O(\alpha_s^2)$ in perturbation theory [1], and have been compared extensively with data in the c.m. energy range 14 - 91 GeV [2,3]. A most important test of QCD has been study of the value of the gluon spin. In QCD the gluon is postulated to be a vector (spin 1) boson, which results in restricted

⋆ Work supported by Department of Energy contracts DE–AC03–76SF00515 (SLAC) and DE–AC02–76ER03069 (MIT).

MEASUREMENTS OF SPIN-SENSITIVE QUANTITIES IN HADRONIC DECAYS OF Z^0 BOSONS PRODUCED IN e^+e^- ANNIHILATIONS*

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1. INTRODUCTION

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possibilities for the topology of the hadronic final states. One can consider an alternative model in which the gluon is a scalar (spin 0) boson, and this gives rise to different topologies.

In terms of the QCD perturbation series for $e^+e^- \to$ hadrons, the most substantial gluon contribution is at leading order via the tree-level Feynman diagrams shown in Fig. 1, which, for a sufficiently hard gluon, give rise to planar events with a characteristic three-jet topology.

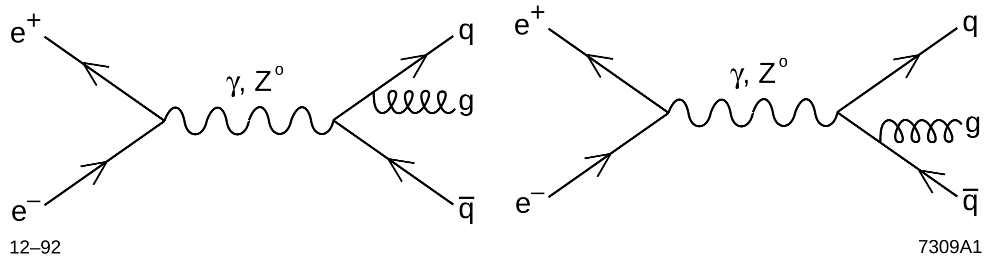

Figure 1. Tree-level Feynman diagrams for three jet production in e^+e^- annihilation.

The differential cross-section for three-jet production on the Z^0 resonance has been calculated to $O(\alpha_s)$ [4,5] assuming massless partons. In the general case [5], the cross-section is five-fold differential in terms of (a) any two of the three parton momenta, and (b) three angles which define the orientation of the event plane. It may be written as a sum of terms each comprising two factors, one a function of (a), the other of (b), the latter dependent upon the polarisations of the incoming beams. The dynamics of the strong interaction are contained in the factors (a) and electroweak production effects in the factors (b). Integrating over (b) one finds, for example [6], for vector gluons (V):

$$\frac{d^2\sigma^V(x_1,x_2)}{dx_1dx_2} \quad \sim \quad \frac{x_1^3+x_2^3+(2-x_1-x_2)^3}{(1-x_1)(1-x_2)(x_1+x_2-1)} \tag{1}$$

whilst for scalar gluons (S):

$$\frac{d^2\sigma^S(x_1,x_2)}{dx_1dx_2} \sim \frac{x_1^2(1-x_1)+x_2^2(1-x_2)+(2-x_1-x_2)^2(x_1+x_2-1)}{(1-x_1)(1-x_2)(x_1+x_2-1)} - 10\frac{a_f^2}{v_f^2+a_f^2} \tag{2}$$

where $x_i \equiv 2\,E_i/\sqrt{s}$ ($i = 1,2,3$ and $E_1 > E_2 > E_3$) are the energy-ordered scaled parton energies and v_f (a_f) is the vector (axial vector) coupling of the Z^0 to quarks of flavour f. For $x_1, x_2 \to 1$ the formulae for the vector case diverge, whilst those for the scalar case remain finite. It is this feature which gives rise to the difference in shape of the x_i distributions between the vector and scalar cases, and provides the basis for the test of the value of the gluon spin.

Another useful quantity is the Ellis-Karliner angle θ_{EK} [7], defined to be the angle between the direction of jet 2 with respect to the direction of jet

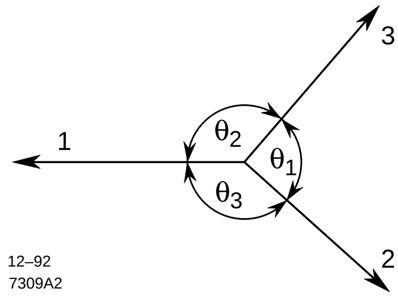

Figure 2: Definition of the angles θ_1, θ_2, θ_3.

1, in the rest frame of jets 2 and 3. For massless partons these variables may be written (Fig. 2):

$$x_i \quad = \quad \frac{\sin\theta_i}{\sum_{i=1}^{3} \sin\theta_i} \qquad \text{and} \qquad \cos\theta_{EK} \quad = \quad \frac{x_2 - x_3}{x_1} \tag{3}$$

2. THE SLD AND EVENT SELECTION

The SLAC Linear Collider (SLC) produces Z^0 bosons from collisions of polarised electrons with unpolarised positrons; the decays of the Z^0s are recorded by the SLC Large Detector (SLD) [8]. During the first physics run, March - September 1992, over 11,000 such hadronic events were recorded, approximately 9,000 of which were used in the analysis presented here. Details of the polarisation program and a first measurement of the left-right cross-section asymmetry were contributed separately to this conference [9].

The detector is described in detail elsewhere [8]. Briefly, 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 acceptance. Tracks were required to approach the nominal interaction point to within 25 cm, to have a polar angle, θ_{tr}, with respect to the beam axis within $|\cos\theta_{tr}| < 0.8$, and a minimum momentum transverse to this axis of $p_T > 150$ MeV/c. Events were required to have a minimum of five such tracks, 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, $E_{vis} > 20$ GeV, where all tracks were assigned the charged pion mass.

3. RESULTS ON TESTS OF THE GLUON SPIN

In order to compare experimental measurements with theoretical calculations one needs to define three-jet events in a consistent way for both. This is most conveniently done using a jet-finding algorithm which results in infra-red safe theoretical predictions. Such an algorithm is the so-called 'JADE algorithm' [10], which has been used extensively in multijet studies of hadronic final states at PETRA/PEP [11] and SLC/LEP [3,12]. In this scheme pairs of particles are clustered together in an iterative procedure based on their invariant masses, until all cluster-pairs have masses which exceed some cutoff value, parametrised as $\sqrt{y_c\, s}$. The fraction, R_n, of the total cross-section classified as being n-jet final states thereby depends on y_c, which is usually treated as an arbitrary parameter.

The JADE jet-finding algorithm was applied to the SLD data and a sample of three-jet events was selected using $y_c = 0.02$. In order to ensure that the event plane was well contained within the detector acceptance the angle between the normal to the event plane and the beam direction, θ_N, was required to satisfy $|\cos\theta_N| > 0.70$. A total of 1123 events remained.

Using the definitions (3), distributions of x_i and $\cos\theta_{EK}$ were generated from the SLD data and compared with the predictions of two perturbative QCD plus fragmentation Monte Carlo programs, JETSET 6.3 [13] and HERWIG 5.3 [14]. For JETSET we used a parameter set tuned at 35 GeV [15]. For HERWIG we used the default parameters. In each case, 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. Both models give a good description of the data. Therefore, the JETSET program was used to correct [15] the data for the effects of initial state radiation, unmeasured neutral particles, acceptance, resolution and other detector effects, and bias from the analysis cuts applied. A further correction was applied for the effects of hadronisation, again using JETSET. Detailed studies of systematic uncertainties associated with these procedures are in progress.

Preliminary results are presented in Fig. 3, where the parton-level corrected data are compared with vector and scalar gluon calculations. For convenience we have used the O(α_s) calculations implemented in JETSET 7.3 [16].* It can be seen that the data are well described by QCD, whereas the scalar gluon model is clearly inconsistent with the data. Similar results were found at LEP [6,17] and at lower energies [18].

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* An O(α_s^2) calculation is available only for the vector case and gives small corrections to the leading order result for the distributions considered here (see *e.g.* [6]).

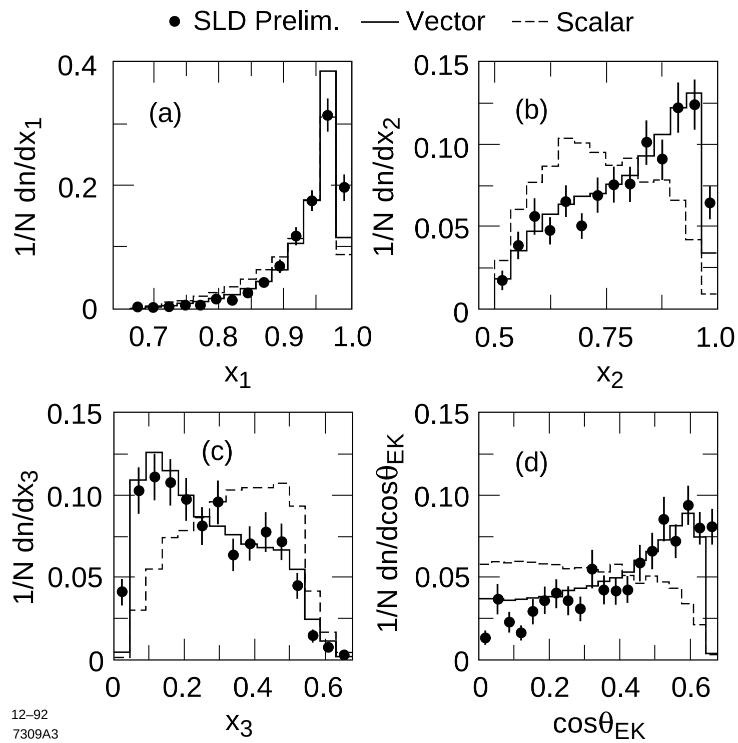

Figure 3: Distributions of x_1 (a), x_2 (b), x_3 (c) and $\cos\theta_{EK}$ (d). Preliminary SLD data are compared with vector (QCD) and scalar gluon calculations.

4. ORIENTATION OF THE EVENT PLANE

In the analysis presented in Section 3 no attempt was made to make an association between each hadronic jet and its underlying parton parent, *i.e.* to identify explicitly in each event which jet originates from the quark, which from the antiquark and which from the gluon. If such identification could be made, it would be possible to measure distributions of the orientation of the event plane whose shapes depend on the degree of longitudinal polarisation (p) of the electron beam [19].

Consider the angles θ and χ (Fig. 4) in a $Z^0 \rightarrow q\overline{q}g$ event: θ is the polar angle of the quark direction with respect to the electron beam, and χ is the angle between the quark-electron plane and the event plane (x, z), defined such that the gluon has a positive x-component of momentum. Using the leading order calculation [5], where all possible lepton beam polarisation states are considered, one finds [19] for the case of collisions of longitudinally polarised electrons with unpolarised positrons that the θ (χ) distributions depend dramatically on p, as illustrated in Fig. 5a (5b) for down-type quarks. The first case gives rise to the well-known 'forward-backward asymmetry' for quark production at the Z^0, which can be measured also in $e^+e^- \rightarrow q\overline{q}$ events. The second case represents an electroweak production effect observable in $q\overline{q}g$ events.

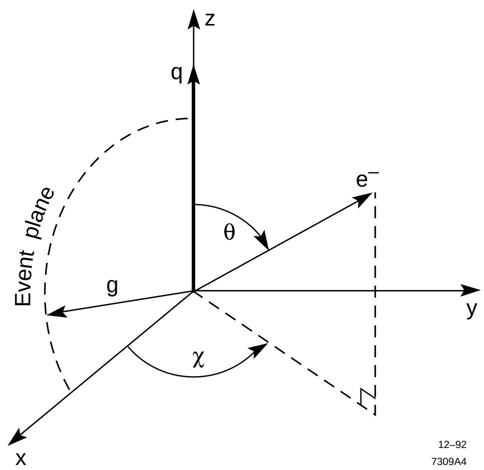

Figure 4: Definition of the angles θ and χ.

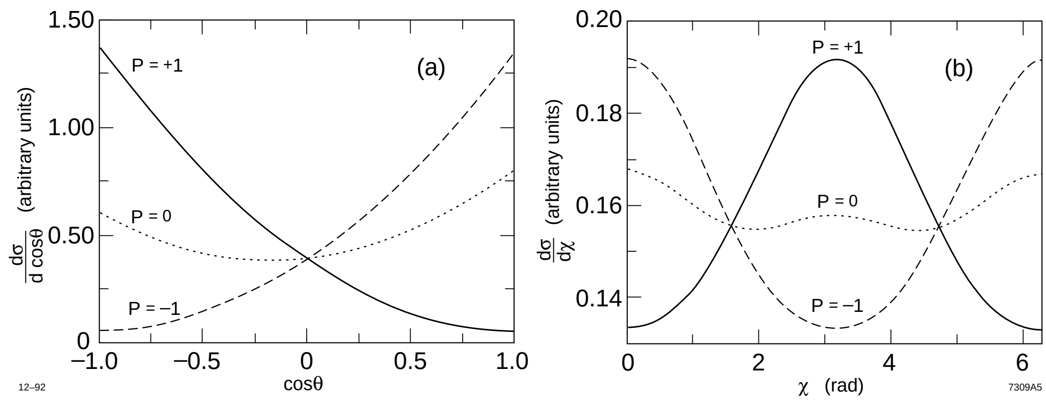

Figure 5: Distributions of cosθ (a) and χ (b) for different longitudinal polarisations of the electron beam.

5. SUMMARY AND CONCLUSIONS

Distributions of three-jet events have been measured by the SLD experiment at SLAC. A QCD calculation involving vector gluons is in good agreement with the data, whereas an analogous calculation for scalar gluons can be excluded. If explicit association of the hadronic jets with their quark, antiquark or gluon parents can be made, event plane orientation angles can be defined whose distributions are predicted to depend on the degree of longitudinal polarisation of the electron beam.

The goal for the 1993 SLD/SLC run is to record at least 50,000 hadronic Z^0 decays produced with a 40% polarised electron beam [9]. In addition, heavy quark tagging studies using the SLD vertex detector [20] are in progress, and provide the possibility to separate quark/antiquark from gluon jets in three-jet events. Quark and antiquark jets could then be distinguished on the basis of the sign of the lepton emitted in their semi-leptonic decays, or by established jet charge techniques, allowing a first measurement of the polarised orientation angles.

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