TESTS OF QCD AT CLEO II

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ABSTRACT

We report on tests of QCD performed at CLEO II. Jet production rate distributions from the continuum below the $\Upsilon(4S)$ are compared with $\mathcal{O}(\alpha_s^2)$ QCD calculations in this four flavor regime. Values of α_s are extracted from fits of the predicted differential two jet rate which yields a final value of $\alpha_s(10.53) = 0.164 \pm 0.004 \pm 0.014$. Comparison of this result with LEP's $\alpha_s(M_Z)$ measurements also constitutes a test of the renormalization group equation. In a separate study, a contrast is made between the measured and QCD predicted two-photon production of KK and $\pi\pi$ using $1.2 fb^{-1}$ of e^+e^- data. The measurement is compared to a leading order QCD calculation. Evidence for the transition to the perturbative QCD regime is displayed.

1. Jet Production Rates

The measurements of relative production rates of multi-jet events in the e^+e^- continuum and around the Z^o peak have been found in good agreement with the theoretical predictions.[2] However, in the four flavor regime, the QCD predictions of next to leading order coefficients are substantially different due to the different contributions from vacuum polarization diagrams. Thus, the study of jet rates in four flavor continuum provides a validity check on QCD.

In order to bridge the QCD theoretical calculations with measurements, a resiliant definition of a jet is required. This definition must be applicable and yield finite cross sections to any order of perturbation theory. We have studied the JADE-algorithm in the E_0 and P scheme (referred to as JJ and JP, respectively) and the Durham algorithm[12] in the P scheme (DP). In all cases, the degree for which jets are resolved is characterized by the jet resolution parameter y_{cut}.

The 3 and 4 jet rates R_3 and R_4 are calculated in $\mathcal{O}(\alpha_s^2)$ QCD[11] perturbative calculation. Coefficients for the R_n expressions are determined for the four flavor regime using the procedure of P. Nason.[9] The shape of the two-jet rate distribution is fitted to an $\mathcal{O}(\alpha_s^2)$ calculation and shown in figure 1.

The value of α_s is determined by a fit to a differential two jet distribution[7] using the DP jet merging algorithm over a select region of y_{cut}. This region between $0.04 < y_{cut} < 0.20$ was chosen because of minimal 4 and 5-jet contributions.

The final result, $\alpha_s(10.53) = 0.164 \pm 0.004 \pm 0.014$, is compared to values measured at LEP by using the renormalization group equation to transform $\alpha_s(10.53)$ to $\alpha_s(M_Z)$. This yields $\alpha_s(M_Z) = 0.113 \pm 0.002 \pm 0.006$. The substantial decrease of the fractional error in α_s from extrapolating up to M_Z is a result of the logrithmic energy dependency of $\alpha_s(\mu)$.[8] This illustrates an advantage of determining α_s from low energy processes.

The data were corrected for hadronization before comparing to QCD calculations, which were performed at the parton level. As in the LEP analyses, we used the string hadronization scheme model of the JETSET Monte Carlo.[6] A systematic error was contrived by repeating the analysis using a suitably tuned HERWIG Monte Carlo.[10] Within the QCD shower models, the parton virtuality Q_0, which defines the parton shower cutoff energy, is varied about its central value $Q_0 = 1$ to provide a component to the theoretical error estimate.

Since μ is unspecified in the QCD calculations, there remains an ambiguity as to which renormalization scale $\alpha_s(\mu)$ is to be used in the evaluation. This component of the theoretical uncertainty is estimated by performing fits for fixed values of μ and also allowing μ as an additional free fit parameter.

The uncertainty due to the y_{cut} fit range in addition to the errors mentioned above are added in quadrature to form the quoted theoretical error estimate. The quoted experimental error is determined from detector acceptance.

Algorithm	α_s	Δ_{exp}	Δ_{had}	Δ_{Q_0}	Δ_μ	Δ_y
JJ	0.156	± 0.004	$^{+0.014}_{-0.000}$	± 0.004	± 0.023	± 0.002
JP	0.165	± 0.004	± 0.005	± 0.007	± 0.015	± 0.002
DP	0.164	± 0.004	± 0.003	± 0.007	± 0.012	± 0.002

The extrapolated value of $\alpha_s(M_Z)$ is consistent with the value extrapolated from LEP jet data[2] $\alpha_s(M_Z) = 0.120 \pm 0.006$.

2. Pion and Kaon Pair Production in Two Photon Collisions

The two photon process $e^+e^- \to e^+e^-X$ provides an excellent laboratory for the study of the photon parton interaction and production of C-even final states. Hard scattering at the two photon - parton vertex is treated in perturbative QCD. However, the formation of colorless hadrons from parton pairs is a nonperturbative effect at small momentum transfers because of unmanagable "higher twist" effects.

With the applicability of perturbative QCD limited to high momentum transfers, one can calculate a qualified cross section for $\gamma\gamma \to M^+M^-$ where M represents the pseudoscalar mesons π and K. The calculations utilize the factorability of the scattering amplitude into a hard scattering piece T_H describing the interaction of the photons with partons, and a soft piece ϕ_M describing the distribution of the partons within the observable mesons. The lowest order pseudoscalar result is expressed in terms of the cross section for the two photon production of muon pairs is given by

$$\frac{d\sigma}{d\cos\theta^*}(\gamma\gamma \to M^+M^-) = \frac{4|F_M(W^2;\alpha_s,f_M)|^2}{1-\cos^4\theta^*}\frac{d\sigma}{d\cos\theta^*}(\gamma\gamma \to \mu^+\mu-).$$

Fig 1 *(LEFT)* The measured R_2 in DP-algorithm compared to $\mathcal{O}(\alpha_s^2)$ QCD predictions. *(RIGHT)* Measured distribution D_2 in the DP algorithm. The value of $\alpha_s(10.53)$ was determined from a fit to this distribution.

The overall angular dependence is $\sin^{-4}\theta^*$ when one folds in the muon pair cross section. The form factor $F_M(W^2)$ depends on α_s, the $\gamma\gamma$ invariant mass W, and the pseudoscalar decay constant f_M.

Because of the limited region in momentum to get reasonable π/K separation from the CLEO II detector, we forfeit our ability to extract individual meson cross sections.

The cross section is measured at invariant masses of the two-photon system between 1.5 and 5.0 GeV/c^2 and at scattering angles of greater than 53^o from the $\gamma\gamma$ collision axis in the $\gamma\gamma$ center-of-mass. The leptonic background process $\gamma\gamma \rightarrow \mu\mu$ is up to three orders of magnitude larger than the M^+M^- cross section within our accessible energy range. This background is reduced by using shower shape requirements within the CsI crystal calorimeter as well as loose hit requirements of the muon detector. Trigger efficiencies are measured by using higher multiplicity $\tau\tau$ processes.

The measured cross section (figure 2) is seen to agree well in shape with the QCD models over the entire range in $W_{\pi\pi}$ although the models are approximately 40% below the data. There is no compelling reason to expect that the cross section should exhibit good agreement at low $W_{\pi\pi}$ since perturbation theory is less valid there and resonance formation contributions become important.

The evolution of the $\cos\theta^*$ distribution as a function of $W_{\pi\pi}$ constitutes a test of the $\sin^{-4}\theta^*$ dependence of the QCD prediction. This is illustrated in figure 3. where the $\cos\theta^*$ distribution is plotted for two bins in $W_{\pi\pi}$. The measured cross section exhibits a rise at small scattering angles at large $W_{\pi\pi}$ consistent with the QCD calculation. The behavior in the lower $W_{\pi\pi}$ range is contrary to the QCD prediction. The disparity of the measured low $W_{\pi\pi}$ angular distribution with leading order QCD may be related to the non-perturbative nature of the cross section near the resonance region, and in particular, to the interference of the f_2 resonance with the continuum.

References

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Fig 2 The measured cross section for the two-photon production of charged pion and kaon pairs as a function of the $\pi\pi$ invariant mass $W_{\pi\pi}$. Only statistical errors are shown. The leading order QCD predictions by Brodsky and Lepage,[3] and Benayoun and Chernyak[4] are also shown.

Fig 3 The $\cos\theta^*$ dependency of the charged pion and kaon pair cross section for two bins in $W_{\pi\pi}$ compared with predictions of Brodsky and Lepage.

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