Results on QCD from the CLEO-II Experiment

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We discuss new results in QCD from the CLEO-II experiment.

1 Determination of the strong coupling constant α_s from $\Upsilon(1S)$ radiative decay

The primary decay modes of the $\Upsilon(1S)$ resonance are the OZI-suppressed three gluon decay, and the decay to two gluons and a photon. It is also possible for the $\Upsilon(1S)$ to couple directly to a virtual photon and then decay to $q\bar{q}$. The ratio of the number of radiative $\Upsilon(1S) \to \gamma gg$ events to the number of $\Upsilon(1S) \to ggg$ events is proportional to the ratio of the electromagnetic and strong coupling constants, α_{EM}/α_S, and provides a means of determining the strong coupling constant at low energy. This measurement of α_S has good statistical precision and can be compared to the values determined at the Z pole in order to test theoretical speculations about new physics or anomalous energy dependence of fundamental coupling constants.[1]

A data sample with an integrated luminosity of 62.5 pb^{-1} was recorded on the $\Upsilon(1S)$ resonance using the CLEO-II detector. To subtract the non-resonant $e^+e^- \to q\bar{q}$ background (which is henceforth referred to as continuum), a sample recorded at 10.52 GeV, just below the $\Upsilon(4S)$ resonance is used. The continuum sample is caled to correct for the energy dependence of the $e^+e^- \to q\bar{q}$ cross section and the difference in luminosity. The primary experimental difficulty is extracting the number of radiative $\Upsilon(1S)$ decays in the sample. These events must be distinguished from the large backgrounds from asymmetric π^0 decay, as well as from smaller backgrounds due to hadronic showers, QED events, η, $\eta^{'}$, ω decays as well as initial state radiation in the non-resonant background ($e^+e^- \to q\bar{q}\gamma$).

1.1 Background subtractions

We can divide the backgrounds into roughly two general categories: misreconstructed single photons and real single photons from other physics processes[2,3].

The sources of misreconstructed single photons are the following:

- Merged π^0s: Cuts on the second moment of the shower ("shower mass") are used to suppress this background. The fine segmentation of the CsI(Tl) crystal calorimeter is quite powerful. For example, only 50% of π^0s at 5 GeV merge.

- Asymmetric π^0 decays: A π^0 veto is employed. Estimating the residual background using reconstructed π^0s is statistics limited and does not take into account all correlations. Instead we use isospin invariance, the π^+ spectrum, a parameteric Monte Carlo tuned to agree with data, and the normalization of π^0/π^+ observed in data, to extract the background as a function of scaled photon energy. To verify this procedure, we check the calculated backgrounds against continuum data and find good agreement.

- Photons from $\eta \to \gamma\gamma$, $\eta^{'} \to \gamma\rho, \gamma\omega, \gamma\gamma$, and $\omega \to \gamma\pi^0$ decays: A data driven procedure similiar to that used for π^0 decays is employed for this subtraction.

- Unmatched charged hadrons: We cut on the distance between the extrapolated charged track and the shower centroid as well as on the second moment of the shower shape. For neutral hadrons such as K_L, neutrons and other hadronic debris, the residual background is estimated using a GEANT Monte Carlo simulation.

The sources of real single photons from other physics processes are the following:

- Photons from initial state radiation ($q\bar{q}\gamma$) and $e^+e^- \rightarrow \tau^+\tau^-$ backgrounds are removed by subtracting the continuum (off-resonance) photon spectrum.

- The size of the direct $\Upsilon(1S) \rightarrow q\bar{q}$ background can be calculated from the leptonic width of the $\Upsilon(1S)$.

- Radiative Bhabbas (i.e. $e^+e^- \rightarrow e^+e^-\gamma$) and QED events. There is a lepton veto and a cut on the maximum scaled photon energy. The residual background is removed by the continuum subtraction.

- Two photon processes ($e^+e^- \rightarrow \gamma\gamma$) and beam gas are suppressed by the use of the minimum energy fraction cut and cuts on the position of the event vertex. The remaining background is also removed by the subtraction of the continuum.

The analysis is performed in terms of the scaled photon energy $X_\gamma = E_\gamma/E_{beam}$. This allows the continuum spectrum to be subtracted correctly. We restrict the analysis to the scaled energy range $0.30 < X_\gamma < 0.98$. The upper cutoff removes contamination from QED backgrounds, while the lower cutoff restricts the analysis to the photon energy range in which the systematics of the background subtractions are manageable. To extrapolate to the full photon energy range, we fit the scaled energy distribution to the model of Field or to the model of Catani and Hautmann (which includes final state radiation from the fragmentation quarks). We find that the X_γ requirement has an efficiency of approximately 85%. A comparison of the difference between the two models gives a measure of the model dependence. To eliminate QED backgrounds and to reduce systematics in detector modeling, we require $|\cos\theta_\gamma| < 0.7$ where θ_γ is the angle of photon in the laboratory. To correct for the effect of the $|\cos\theta_\gamma|$ cut, we use the prescription of Koller and Walsh.[6]

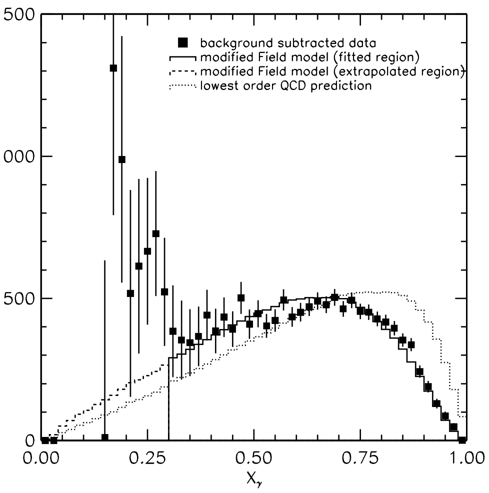

Figure 1: Spectrum of observed scaled photon energy compared to the model of Field.

After subtracting backgrounds and correcting for detection efficiency, there are $(2.652 \pm 0.038) \times 10^4$ $\Upsilon(1S) \rightarrow \gamma gg$ events. After removing the contribution of $\Upsilon(1S) \rightarrow q\bar{q}$ decays and subtracting the non-resonant background, there are $(9.657 \pm 0.010) \times 10^5$ $\Upsilon(1S) \rightarrow ggg$ events. The ratio of these yields is denoted $R_\gamma = N_{\gamma g\bar{g}}/N_{ggg}$ and are given for two models,

$$R_\gamma = 2.75 \pm 0.04\%$$

using the modified model of Field[4] and

$$R_\gamma = 2.72 \pm 0.04\%$$

using the model of Catani and Hautmann.[5] There is insufficient sensitivity at low x_γ to verify the Catani-Hautmann model in detail.

Uncertainty Source	$\delta R_\gamma(\%)$
Tracking efficiency, multiplicity modeling	0.12
π^0 veto	0.07
continuum subtraction	0.04
ϵ_{ggg}	0.03
π^0 spectrum	0.03
Luminosity, E_{cm} scaling	0.02
Υ(1S) data samples	0.02
$\delta R_{\Upsilon(1S)}$	0.01

Table 1: Contributions to the Systematic Error

The Monte Carlo model of hadronization (LUND/JETSET) does not agree well with the observed multiplicity distribution in data. We have taken this disagreement into account and estimate a 0.12% systematic error. Another systematic effect is due to the subtraction of the background from asymmetric $\pi^0 \to \gamma\gamma$ decays, and contributes 0.07% to the uncertainty in R_γ. Other effects include the detection efficiency for $\Upsilon(1S) \to ggg$ events, the energy and luminosity scaling required for the continuum subtraction and are listed in Table 1.1.

Using the procedures described by Bardeen et al[7] and Mackenzie and LePage[8,9], one obtains

$$\alpha_S(M_{\Upsilon(1S)}) = 0.163 \pm 0.002 \pm 0.009 \pm 0.010$$

where the first systematic error is from experiment (see Table 1.1) and the second systematic error is from the uncertainty in the renormalization scale in the $\overline{MS}$ scheme. This can be extrapolated to the Z mass and gives:

$$\alpha_S(M_Z) = 0.110 \pm 0.001 \pm 0.004 \pm 0.005$$

which is smaller than the LEP world average of $0.123 \pm 0.004 \pm 0.002$, computed by the Particle Data Group. Due to the size of the systematic error, it is not possible to conclude that there is a significant discrepancy.

2 Comparison of the multiplicity of quark and gluon jets

At a center of mass energy near 10 GeV, we can also isolate clean samples of quark and gluon jets using the $\Upsilon(1S)$ data sample. The idea is to use

$$\Upsilon(1S) \to \gamma gg$$

events to isolate a sample of *two-gluon jet* events and to use

$$e^+e^- \to \gamma q\bar{q}$$

events (i.e. initial state radiation in the continuum) to isolate a sample of *two-quark jet* events with similiar kinematics (we use a sample of 198.3 pb^{-1} recorded at 10.52 GeV)[10].

Having isolated these two samples, we subtract the backgrounds discussed in the section on the α_s determination, and correct for systematic differences in detection efficiency. One can then compare the inclusive multiplicity distributions of these two samples.

This approach to comparing quark and gluon jets has the advantage that the result will not be dependent on the jet algorithm used. This is in contrast to the results from the LEP experiments. However, the disadvantage is the low energy characteristic of these jets and the possibility of non-perturbative effects.

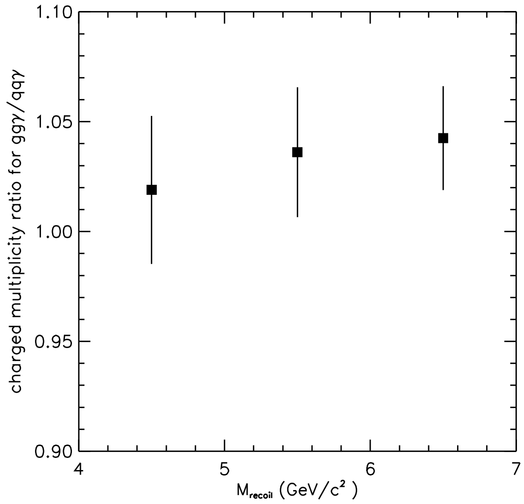

Figure 2: Ratio of charged multiplicity for gluon jets to quark jets as a function of recoil mass.

We define

$$R_{chrg} = < n^{\pm}_{gluon} > / < n^{\pm}_{quark} >$$

which is the ratio of charge multiplicities in quark and gluon jets. The quantity R_{chrg} is measured in bins of recoil mass.

Source of Systematic Error	Value
π^0 background	0.003
$\cos(\theta)$ cut dependence	0.02
truncated mean $4<Nchrg<11.5$	0.02
Variation between data sets	0.03
Recoil effects	0.006
Total	0.04

We have investigated whether differences in production mechanisms and event shape can bias the multiplicity migration matrix and the effect of the difference in center of mass energy between the two jet samples (0.006 systematic error). Initial cuts reduce the contamination from final state radiation events to a negligible level in this sample. The other contributions to the systematic error are listed in Table 2.

The presence of flavor thresholds can also complicate the interpretation of the results. The

CLEO analysis imposes the cut $M_{recoil} > 4.0$ GeV so that the sample contains a uniform admixture of u, d, s, c quark jets. CLEO finds

$$R_{chrg} = 1.03 \pm 0.02(stat) \pm 0.04(sys)$$

2.1 Comparisons to other Multiplicity Measurements

It is important to remember that the average jet energies are quite different between CLEO and LEP and *the difference between quark and gluon jet multiplicity is expected to be energy dependent* [11,12,13]. A comparison of the CLEO result to measurements at higher energies is given in Table 2.1. The CLEO result is consistent with the expected energy dependence.

Experiment	$< N >_g / < N >_q$	E_{jet} (GeV)
CLEO 96	1.03 ± 0.04	$2 - 7$
DELPHI	1.24 ± 0.015	$10 - 40$
SLD	1.36 ± 0.24	24
OPAL 93	1.27 ± 0.04	24
ALEPH	1.19 ± 0.04	24
OPAL 96 $*$	1.58 ± 0.03	39

$*$ The second OPAL result is for $< N >_g -1 / < N >_q -1$, and applies to u,d,s quark jets only.

3 Future work on QCD at CLEO

The program of studying QCD at CLEO is continuing. Results in the near future are expected in the following areas:

- The anomalously large cross-section for high-P_T ψ and ψ' production at the Tevatron has been attributed to a new QCD production mechanism referred to as color-octet (as opposed to the color singlet mechanism). This mechanism has observable signatures in the angular distributions of continuum ψ production in e^+e^- collisions at CLEO.[14] These are currently being investigated.

- We will also report a precise measurement of R, the hadronic cross section at 10.5 GeV. The expected statistical error is $\mathcal{O}(1.4\%)$ and systematic error is $\mathcal{O}(2.7\%)$. The measurement avoids some of the systematic problems of other techniques; there is no dependence on jet algorithms or cone cuts. Theoretically, the higher order corrections to R have been calculated and are under control[15]. Thus, the R measurment will provide an important low energy determination of α_s.

3.1 Acknowledgments

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