Measurement of α_S in Radiative Hadronic Events at OPAL

Jochen Schieck [a]

[a]Max-Planck-Institut für Physik
Föhringer Ring 6, 80805 München, Germany

Hadronic final states with a hard isolated photon are studied using data taken at centre-of-mass energies around M_Z with the OPAL detector at LEP. The strong coupling α_S is extracted by fitting event shape variables for the reduced centre-of-mass energies ranging from 20 GeV to 80 GeV, and the energy dependence of α_S is studied. Combining all the values using different event shape variables and energies gives:

$\alpha_s(M_Z) = 0.1176 \pm 0.0012(\text{stat.})^{+0.0093}_{-0.0085}(\text{syst.})$.

1. Introduction

The structure of QCD predicts a decrease of the strong coupling constant α_S for high energy or equivalently for short distance reactions. At e^+e^- collider experiments the energy scale is provided by the center-of-mass energy $\sqrt{s}$. The LEP collider covers energy ranges from 91 to 210 GeV [1–3]. The change of α_S at these energy ranges is relatively small compared to lower center-of-mass energies and therefore it is desirable to access α_S at a lower $\sqrt{s}$.
The radiation of high energy photons either through initial state radiation (ISR) or through quark bremsstrahlung (FSR) allows to access lower center-of-mass energies. To make sure that the photon does not interfere with QCD processes the time scale of the photon radiation has to be smaller than the time scale of the parton shower. With radiative multi-hadronic events (i.e. $e^+e^- \rightarrow q\overline{q}\gamma$ a measurement of α_S is possible at a reduced centre-of-mass energy, $\sqrt{s'}$. At LEP1, isolated high energy photons observed in the detector are mainly photons originating from FSR. Here we report on a measurement of α_S from event shape variables of the hadronic system in events with observed photons in the OPAL experiment [4]. The OPAL detector operated at the LEP e^+e^- collider at CERN. A more detailed description of the analysis can be found in [5].

2. Event Selection

2.1. Hadronic Event Selection

This study is based on a sample of 3 million hadronic Z^0 decays selected as described in [6] from the data accumulated between 1992 and 1995 at centre-of-mass energy of 91.2 GeV. We required that the central detector and the electromagnetic calorimeter were fully operational.

2.2. Isolated Photon Selection

Isolation Cuts

A signal event is defined as an $e^+e^- \rightarrow q\overline{q}$ event with an initial or final state photon with energy greater than 10 GeV. The selected photon candidate is required to be well contained within the detector. In addition the candidate cluster is required to be well isolated from other clusters and tracks. The angle of the candidate cluster with respect to the axis of any jet, $\alpha^{\text{iso}}_{\text{jet}}$, has to to be larger than 25°.

Likelihood Photon Selection

Isolated photon candidates are selected by using a likelihood ratio method with four input variables. The first two variables are the same as described above, two more variables are defined to reduce the background from clusters arising from the decay of neutral hadrons. The cluster shape fit variable C determines the difference between the measured energy deposit in a electromagnetic calorimeter and the expected energy deposit from a simulated single photon. The second new variable is a measure of the distance between the electromagnetic calorimeter cluster and the associated presampler cluster. A disagreement between data and Monte Carlo is seen for C and $\alpha_{\rm jet}^{\rm iso}$. It is related to the difficulty in predicting the rate of isolated neutral hadrons in the Monte Carlo generators, as explained in Section 2.3. In this analysis, the rate of isolated neutral hadrons used in the background subtraction is estimated from data.

Hadronic events with hard isolated photon candidates are divided into seven subsamples according to the photon energy for further analysis. Table 1 shows the mean values of $\sqrt{s'}(= 2E_{\rm beam}\sqrt{1-E_\gamma/E_{\rm beam}})$, and the number of data events.

Table 1
The selected number of events and the mean value of $\sqrt{s\prime}$ for each $\sqrt{s\prime}$ subsample.

E_γ[GeV]	Events	$\sqrt{s\prime}_{Mean}$[GeV]
10-15	1200	78.0 ± 1.7
15-20	764	71.7 ± 1.8
20-25	511	65.0 ± 2.1
25-30	418	57.6 ± 6.7
30-35	383	48.9 ± 2.6
10-15	303	38.5 ± 3.4
10-15	248	24.3 ± 5.3

2.3. Background Estimation

As mentioned in [7], the JETSET Monte Carlo fails to reproduce the observed rate of isolated electromagnetic clusters, both from isolated photons and from isolated π^0's. Isolated neutral hadrons are the dominant source of background for this analysis, and their rate has been estimated directly from data using the following two methods.

The observed likelihood distributions in the data in bins of photon energy were fitted with a linear combination of the Monte Carlo distributions for signal and background events which pass the isolation cuts and likelihood preselection requirements. The overall normalization of the Monte Carlo distribution is fixed to the number of data events. The fit is a binned maximum likelihood with the fraction of background events as a free parameter.

Alternatively the fraction of background from isolated neutral hadrons was estimated from the rates of isolated charged hadrons. When isospin symmetry is assumed, the rates of neutral pions, neutral kaons and neutrons can be estimated from the rates of charged pions, charged kaons and protons, respectively. According to JETSET tuned with OPAL data, the deviation due to isospin violating decay is predicted to be 10% for pions and 5% for kaons and protons. This is assigned as a systematic uncertainty for the isolated tracks method and combined with the statistical uncertainty. Consistent results are obtained from the two methods within the errors.

The non-radiative multihadron background varies between $15.7 \pm 3.5\%$ and $4.4 \pm 0.8\%$. The contamination from $\tau\tau$ background is about 1%. The contribution of two photon processes is less than 0.01% in all subsamples.

3. Global Event Shape Variables

The determination of $\alpha_{\rm S}$ is based on measurements of event shape variables, which are calculated from particles with momenta p_i in an event. In this analysis the following event shape variables are used: Thrust $\boldsymbol{T}$ [8], Heavy Jet Mass $\boldsymbol{M_H}$ [9] and the Jet Broadening variables $\boldsymbol{B_T}$ and $\boldsymbol{B_W}$ [10].

The event shape variables are calculated from tracks and electromagnetic clusters excluding the isolated photon candidate. Contribution of electromagnetic clusters originating from charged particles are removed by the method described in [11].

Since these variables are defined in the centre-of-mass frame of the colliding beams, the hadronic system is boosted back into the centre-of-mass frame of the hadrons. The Lorentz boost is determined from the energy and angle of the photon candidate. The contribution from non-radiative hadronic events is removed statistically by subtracting the Monte Carlo distribution scaled by the fraction of non-radiative hadronic events and τ pair events listed in Table 1. The effects of the experimental resolution and acceptance are unfolded using Monte Carlo samples with full detector simulation (detector correction). We refer to the distributions after applying these corrections as data corrected to the hadron level.

4. Measurement of α_S from Event Shape Distribution

The measurement of α_S is performed by fitting perturbative QCD predictions to the event shape distributions corrected to the hadron level for $(1-T)$, M_H [12], B_T and B_W [13]. The $O(\alpha_S^2)$ and NLLA calculations are combined with the $\ln(R)$ matching scheme. The hadronization correction is applied to the cumulative theoretical calculation to conserve normalization as in our previous analysis at centre-of-mass energies of 130 GeV and 136 GeV and above [2,3]. `JETSET`, `HERWIG` and `ARIADNE` are used for this hadronization correction and `JETSET` is chosen for the central results.

The fit to the event shape variables uses a least χ^2 method with $\alpha_S(Q)$ treated as a free parameter. When the total number of events is small, the differences in statistical error between bins with a larger or smaller number of events than the theoretical prediction is not negligible. To deal with fluctuations of the error, the value of the fitted theoretical distribution is used instead of the number of events in each bin of the data distribution. The statistical uncertainty is estimated from fit results derived from 100 Monte Carlo subsamples with same number of events as selected data events. The background subtraction, detector and hadronization corrections are required to be small and uniform in the region used for the fit.

4.1. Systematic Uncertainties

The total systematic uncertainties where estimated by adding experimental, hadronization and theoretical uncertainties in quadrature. The largest contributions originate from the choice of the hadronization model and the variation of the renormalization scale.

4.2. Combination of α_S Results

The values of α_S obtained by fits to event shape variables at each energy are used to study the energy dependence of α_S, and to obtain an overall combined result for $\alpha_s(M_Z)$.

Values of α_S for each event shape variable and for all event shape variables combined are fitted to the solution of the renormalization group equation at NNLO described in [14]. $\Lambda^{(5)}_{\overline{MS}}$ is treated as a free parameter in the fit. When combining all event shape variables, the statistical correlations between results from different variables are taken into account. The systematic uncertainties for $\Lambda^{(5)}_{\overline{MS}}$ from each variable are obtained by the procedure described in Section 4.1. The value of $\Lambda^{(5)}_{\overline{MS}}$ derived from the values of α_S combining the event shape variables is

$$\Lambda^{(5)}_{\overline{MS}} = 0.2027 \pm 0.0141(\text{stat.})^{+0.1130}_{-0.0939}(\text{syst.})\ \text{GeV} \quad (1)$$

with χ^2/d.o.f $=$ 33.1/6. The systematic uncertainty has contributions from experimental effects (± 0.0417), hadronization effects (± 0.0668) and variations of renormalization scale ($+0.0810, -0.0512$). This value and its total errors correspond to $\alpha_s(M_Z) = 0.1175^{+0.0085}_{-0.0102}$ in NNLO. QCD prediction of α_S with $\Lambda^{(5)}_{\overline{MS}}$ obtained by the fitting is shown in Figure 1. The χ^2 value is dominated by the subsample with $\sqrt{s'}$ of 38.5GeV, the othe subsamples agree well with the prediction.

All values of α_S are propagated to the energy scale of M_Z using the equation for the evolution of α_S quoted in [14]. The combined values and values for individual event shape variables for all $\sqrt{s'}$ subsamples are combined into one value for all systematic variations. Since there is no statistical correlation between values for different $\sqrt{s'}$ subsamples, a weighted mean is calculated using statistical uncertainties only. The systematic uncertainties on the combined values are obtained by the procedure described in Section 4.1. These other values are consistent with each other and in good agreement with the present result. As

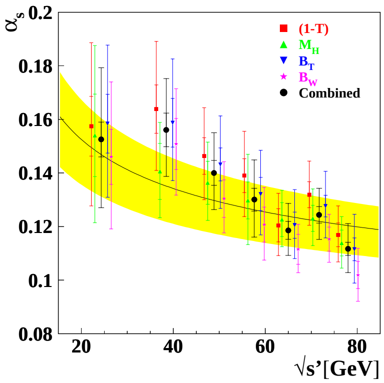

Figure 1. Energy dependence of α_S for all subsamples.

pointed out in the analysis with non-radiative events at LEP1 [1] and LEP2 [3], the α_S value obtained by fitting B_W is lower than for the other three variables The combined value of $\alpha_s(M_Z)$ for all $\sqrt{s'}$ subsamples and all event shape variables is

$$\alpha_s(M_Z) = 0.1176 \pm 0.0012(\text{stat.})^{+0.0093}_{-0.0085}(\text{syst.}).(2)$$

The systematic uncertainty has contributions from experimental effects (± 0.0034), hadronization effects (± 0.0061) and variations of renormalization scale ($+0.0062, -0.0049$). This value is consistent with the result from the analysis using non-radiative events in LEP1 data, $\alpha_s(M_Z) = 0.120 \pm 0.006$. More event shape variables are fitted for the non-radiative events. If the variables are restricted to the set used in the present analysis, the combined value from the non-radiative events is $\alpha_s(M_Z) = 0.1155^{+0.0071}_{-0.0060}$.

5. Summary

The strong coupling α_S has been measured at reduced centre-of-mass energies, $\sqrt{s'}$, ranging from 20 GeV to 80 GeV using the event shape of the hadronic system in radiative hadronic events. Four event shape variables, $1-T$, M_H, B_T and B_W of the hadronic system boosted into the centre-of-mass frame are fitted with $O(\alpha_S^2)$ and NLLA QCD predictions and values of α_S are obtained for several values of $\sqrt{s'}$. We obtained the fundamental constant of QCD, $\Lambda^{(5)}_{\overline{MS}}$, from the energy dependence of these values of α_S. Values at each $\sqrt{s'}$ are evolved to $\mu = M_Z$ and combined for each event shape variable. The combined value from all event shape variables and $\sqrt{s'}$ values is $\alpha_s(M_Z) = 0.1176 \pm 0.0012(\text{stat.})^{+0.0093}_{-0.0085}(\text{syst.})$.

This agrees with the previous OPAL analysis with non-radiative LEP1 data and the world average PDG value. Within errors, QCD is consistent with our data sample of events with isolated FSR.

REFERENCES

1. P. D. Acton *et al.* Z. Phys. C **59** (1993) 1.
2. G. Alexander *et al.* Z. Phys. C **72** (1996) 191.
3. K. Ackerstaff *et al.*Z. Phys. C **75** (1997) 193; G. Abbiendi *et al.* Eur. Phys. J. C **16** (2000) 185.
4. K. Ahmet *et al.*Nucl. Instrum. Meth. A **305** (1991) 275.
5. K. Ahmet *et al.* OPAL Physics Note PN519 (unpublished)
6. G. Alexander *et al.* [OPAL Collaboration], Z. Phys. C **52** (1991) 175.
7. K. Ackerstaff *et al.*Eur. Phys. J. C **5** (1998) 411.
   O. Adriani *et al.*Phys. Lett. B **292** (1992) 472.
8. S. Brandt *et al.*, Phys. Lett. **12**(1964) 57;
   E. Farhi, Phys. Rev. Lett. **39**(1977) 1587.
9. T. Chandramohan and L.Clavelli, Nucl. Phys. **B184** (1981) 365;
   A. Peterson *et al.*, Phys. Rev. **D37** (1988)1;
   W. Braunschweig *et al.*, Z. Phys. **C45** (1989) 11.
10. S. Catani *et al.*, Phys. Lett. **B295** (1992) 269.
11. K. Ackerstaff *et al.* [OPAL Collaboration], Eur. Phys. J. C **2** (1998) 213.
12. S. Catani, L. Trentadue, G. Turnock and B. R. Webber, Nucl. Phys. B **407** (1993) 3.
13. Y. L. Dokshitzer, A. Lucenti, G. Marchesini and G. P. Salam, JHEP **9801** (1998) 011.
14. K. Hagiwara *et al.*Phys. Rev. D **66** (2002) 010001.