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Measurement of α_S with JADE using Moments of event shape Observables and the Four-Jet Rate

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Data from e^+e^- annihilation into hadrons collected by the JADE experiment at centre-of-mass energies between 14 GeV and 44 GeV were used to study moments of event shape distributions and the four-jet rate as a function of the Durham algorithm's resolution parameter y_{cut}. The data were compared to a QCD NLO order calculations and including NLLA resummation in the case of the four-jet rate. The strong coupling measured from the moments was

$$\alpha_S(M_{Z^0}) = 0.1286 \pm 0.0007(\text{stat.}) \pm 0.0011(\text{exp.}) \pm 0.0022(\text{had.}) \pm 0.0068(\text{theo.}),$$

and from the four-jet rate was

$$\alpha_S(M_{Z^0}) = 0.1169 \pm 0.0004(\text{stat.}) \pm 0.0012(\text{exp.}) \pm 0.0021(\text{had.}) \pm 0.0007(\text{theo.}),$$

both in agreement with the world average.

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1. Introduction

The annihilation of an electron and a positron into hadrons allows precise tests of Quantum Chromodynamics (QCD). We measured the first five moments of event shape observables and the four-jet rate in e^+e^- annihilation and compared the data to predictions by Monte Carlo Models and by perturbative QCD. From the comparison of the data with the theory we extracted the strong coupling α_S. A more detailed description of this analysis can be found in [1]. We used data collected by the JADE experiment [2] in the years 1979 to 1986 at the PETRA e^+e^- collider at DESY at six center-of-mass energies of $\sqrt{s} = 14.0, 22.0, 34.6, 35.0, 38.3$ and 43.8 GeV. The total integrated luminosity was 195 pb^{-1} corresponding to about 40000 events. Large samples of Monte Carlo simulated events were used to correct the data for experimental acceptance, resolution, backgrounds and fragmentation effects. The process $e^+e^- \to$ hadrons was simulated using PYTHIA and corresponding samples using HERWIG and ARIADNE were used for systematic checks. The event selection for this analysis aimed to identify hadronic event candidates and rejected events with a large amount of energy emitted by initial state radiation (ISR), leptonic final states and two photon events. Events from the process $e^+e^- \to b\bar{b}$ were considered as background, since especially at low center-of-mass energy the large mass of the b quarks and of the subsequently produced B hadrons will influence the measurement. Therefore the contribution from expected $b\bar{b}$ events was subtracted [3]. The effects of detector acceptance and resolution and of residual ISR were accounted for by a multiplicative correction procedure. In order to confront the theoretical prediction valid for partons with the data the theoretical prediction was corrected for hadronization with PYTHIA. Several sources of possible systematic uncertainties were studied. The experimental uncertainties evaluate deficiencies in the reconstruction of the data and the modelling of the detector. The uncertainties associated with the correction for hadronization effects were assessed by using alternative models (HERWIG and ARIADNE instead of the default PYTHIA). The theoretical uncertainty associated with missing higher order terms in the theoretical prediction, was assessed by setting the renormalization scale x_μ to 0.5 and 2 instead of the default value one. The results from the fits at the various center-of-mass energies were combined in order to determine a single value of $\alpha_S(M_{Z^0})$.

2. Event Shape moments

The properties of hadronic events may be characterized by event shape observables. The following event shapes were considered in this analysis: Thrust, C-Parameter, Heavy Jet Mass, Jet Broadening Observables B_T and B_W and the transition value between 2 and 3 jets y_{23} using the Durham scheme. The nth, $n = 1, 2, \ldots, 5$ moment of the distribution of an event shape observable y was defined by $\langle y^n \rangle = \int_0^{y_{max}} y^n \frac{1}{\sigma}\frac{d\sigma}{dy} dy$, where y_{max} was the kinematically allowed upper limit of the observable. The measurement involved a full integration over the available phase space. Comparisons of QCD predictions were thus complementary to tests of the theory using the differential distributions. In the case of the moments of event shape observables the QCD predictions were obtained by numerical integration of the QCD matrix elements using the program EVENT2 [4]. A χ^2 value was minimized with respect to $\alpha_S(M_{Z^0})$ for each moment $\langle y^n \rangle$ separately. The fit results are shown in figure 1. The fit $\langle M_H \rangle$ did not converge and therefore no result is shown. We observed values of $\chi^2/\text{d.o.f.}$ of $\mathcal{O}(1)$; the fitted QCD predictions including the running of α_S were

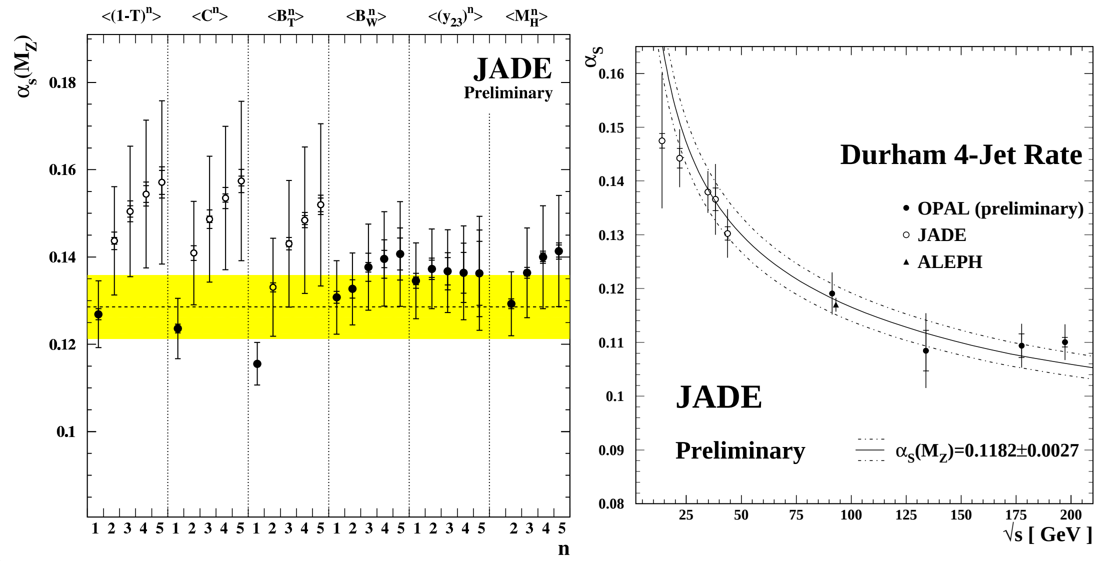

Figure 1: The figure on the left shows the measurements of $\alpha_S(M_{Z^0})$ using fits to moments of six event shape observables. The inner error bars represent statistical errors, the middle error bars include experimental errors and the outer error bars show the total errors. The dotted line indicates the weighted average described in the text; only the measurements indicated by solid symbols were used for this purpose. The figure on the right shows the values for α_S using the four-jet rate at the various energy points. The errors show the statistical (inner part) and the total error. The full and dash-dotted lines indicate the current world average value of $\alpha_S(M_{Z^0})$ [6]. The results at $\sqrt{s} = 34.6$ and 35 GeV have been combined for clarity. The results from ALEPH [8] and OPAL [7] (preliminary) are shown as well.

thus consistent with our data. However, we fond that for $\langle(1-T)^n\rangle$, $\langle C^n\rangle$ and $\langle B_T^n\rangle$ the fitted values of $\alpha_S(M_{Z^0})$ increased steeply with the order n of the moment used. This effect was in clear correlation with increasing ratio of the NLO and LO coefficient with moment n for $\langle(1-T)^n\rangle$, $\langle C^n\rangle$ and $\langle B_T^n\rangle$. We considered only those results for which the NLO term was less than half the LO term, namely $\langle 1-T\rangle$, $\langle C\rangle$, $\langle B_T\rangle$, $\langle B_W^n\rangle$ and $\langle(y_{23})^n\rangle$, $n = 1,\ldots,5$ and $\langle M_H^n\rangle$, $n = 2,\ldots,5$; i.e. results from 17 observables in total. The purpose of this requirement was to select observables with an apparently converging perturbative prediction. The statistical correlations between the 17 results were determined using Monte Carlo simulation at the hadron level. The result of the combination was

$$\alpha_S(M_{Z^0}) = 0.1286 \pm 0.0007(\text{stat.}) \pm 0.0011(\text{exp.}) \pm 0.0022(\text{had.}) \pm 0.0068(\text{theo.})\ ,$$

above but still consistent with the world average value of $\alpha_S(M_{Z^0}) = 0.1182 \pm 0.0027$ [6]. Combining only the fit results from $\langle 1-T\rangle$, $\langle C\rangle$, $\langle B_T\rangle$, $\langle B_W\rangle$, $\langle y_{23}\rangle$ and $\langle M_H^2\rangle$ yields a value of

$$\alpha_S(M_{Z^0}) = 0.1239 \pm 0.0001(\text{stat.}) \pm 0.0008(\text{exp.}) \pm 0.0009(\text{had.}) \pm 0.0059(\text{theo.})\ .$$

The slightly smaller error of α_S reflects the fact that the lower order moments were less sensitive to the multi-jet region of the event shape distributions. This leads to a smaller systematic uncertainty.

2.1 Four-Jet Rate

Besides event shape observables jet rates reflect the parton structure of the event. The four-jet rate $R_4(y_{\text{cut}})$ is the fraction of four-jet events as a function of y_{cut}, the jet-resolution parameter determined in the Durham scheme. In QCD the fraction of four-jet events R_4 is predicted in NLO as a function of the strong coupling α_S. The prediction was calculated by the program DEBRECEN 2.0 [5] combined with an all order resummation using the "modified R-matching" scheme. In the case of jet rates a single event usually contributed to several y_{cut} points in the four-jet rate distribution and for this reason the data points were correlated. The complete covariance matrix was determined and used in the χ^2 fit for the extraction of α_S. The χ^2 value was minimized with respect to α_S for each center-of-mass energy separately. The fit ranges covered the decreasing parts of the distributions at large y_{cut}, where the perturbative QCD predictions were able to adequately describe the data corrected for hadronization. We found that the fit result from the 14 GeV data had large hadronization and experimental uncertainties because the corresponding corrections were large and not well known at this energy. We therefore chose not include this result in the combination. The result of the combination using all results with $\sqrt{s} \geq 22$ GeV was

$$\alpha_S(M_{Z^0}) = 0.1169 \pm 0.0004(\text{stat.}) \pm 0.0012(\text{exp.}) \pm 0.0021(\text{had.}) \pm 0.0007(\text{theo.})\ ,$$

consistent with the world average value of $\alpha_S(M_{Z^0}) = 0.1182 \pm 0.0027$ [6]. The results at each energy point are shown in figure 1 and compared with the predicted running of α_S based on the world average value.

3. Summary

In this note we present preliminary measurements of the four-jet rate and the first five moments of event shape observables at center-of-mass energies between 14 and 44 GeV using data of the JADE experiment. The value of the strong coupling is determined to be $\alpha_S(M_{Z^0}) = 0.1169 \pm 0.0026(\text{tot.})$ using the four-jet rate and $\alpha_S(M_{Z^0}) = 0.1286 \pm 0.0072(\text{tot.})$ using moments of event shape observables.

References

[1] C. Pahl *et al.* JADE note 146, hep-ex/0408122,unpublished;
J. Schieck *et al.* JADE note 147, hep-ex/0408123, unpublished.

[2] B. Naroska, *Phys. Rept.* **148** (1987) 67.

[3] P.A. Movilla Fernández *et al.*, *Eur. Phys. J.* C **1** (1998) 461.

[4] S. Catani, M.H. Seymour *Phys. Lett.* B **378** (1996) 287.

[5] Z. Nagy and Z. Trócsányi, *Phys. Rev.* D **59** (1999) 14020;
Erratum, ibid. **62** (2000) 099902.

[6] S. Bethke, *Nucl. Phys. Proc. Suppl.* **135** (2004) 345.

[7] OPAL Coll., G. Abbiendi *et al.*, OPAL physics note PN527 (2004), unpublished

[8] ALEPH Coll., A. Heister *et al.*, EPJC **27** (2003) 1.

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