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Event Shapes from JADE Data and Studies of Power Corrections

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Event Shapes from JADE Data and Studies of Power Corrections

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Studies of event shape observables at PETRA and LEP energies are presented. Previously published determinations of the strong coupling constant α_s at $\sqrt{s} = 35$ and 44 GeV are complemented using new resummed QCD calculations for the C parameter and improved calculations for the jet broadening variables B_T and B_W which recently became available. Furthermore, recently predicted power corrections to the differential distributions of these observables are investigated. In this study, e^+e^- data between $\sqrt{s} = 35$ and 183 GeV are considered.

1. INTRODUCTION

Data from the intermediate energy region of e^+e^- annihilation, as provided by the JADE experiment at PETRA, allow significant tests of perturbative and non-perturbative aspects of Quantum Chromodynamics (QCD). This was stressed in a recently published analysis of JADE data [1] where determinations of the strong coupling constant α_s at $\sqrt{s} = 22$ to 44 GeV were presented, which are the most precise ones at PETRA energies. Since the analysis is based on event shape observables for which resummed QCD predictions [2] (NLLA) were developed long after the PETRA shutdown, the theoretical uncertainties of previous measurements [3] could be reduced significantly. By applying LEP-established techniques of estimating experimental and theoretical systematics, the running of α_s was tested *consistently* within a large range of energy scales [1].

A reliable estimation of the higher order uncertainties of the predictions, individually for each observable, is supported by considering as many observables as possible. Hence, an update of determinations of α_s at PETRA energies [4] is performed, now additionally considering new calculations for the C parameter [5]. Furthermore, improved calculations for the jet broadening variables B_T and B_W [6] are applied.

JADE data also provide clearer evidence for non-perturbative effects [1,7], which typically contribute with reciprocal powers of $\sqrt{s}$. They are accounted for by so-called *power corrections* which, on general grounds, are found from several theoretical approaches such as renormalons [8] or the dispersive approach [9]. In the following, new predictions for power corrections to the differential distributions are tested using JADE data and also LEP data up to $\sqrt{s} = 183$ GeV.

2. EVENT SHAPES AND α_s

The JADE detector, one of the experiments at the PETRA e^+e^- collider, was designed as a hybrid 4π-detector to measure charged and neutral particles. It was operated from 1979 until 1986 at centre-of-mass energies of $\sqrt{s} = 12.0$ to 46.7 GeV. This analysis focuses on 20926 events at 35 GeV and 6158 events at 44 GeV passing the standard JADE multihadron selection [1].

2.1. Event Shapes

The α_s analysis is based on the event shape distributions of the thrust T, heavy jet mass M_H, the differential 2-jet rate using the Durham jet finder, D_2, the total and wide jet broadening B_T and B_W and the C parameter (cf. [1,4]). For the latter, no experimental results have previously been presented at PETRA energies.

The data are corrected for detector effects and initial state photon radiation using a parton shower plus string fragmention model (JETSET, cf. [1]) and a full detector simulation. As pointed out in [1,4], there is good agreement of the Monte Carlo model with the data, despite the larger hadronization effects at lower energies.

2.2. Update of α_s

The strong coupling constant α_s is determined by χ^2 fits of combined NLLA [2,5,6] and $\mathcal{O}(\alpha_s^2)$ [10] calculations to the event shape distributions after unfolding for hadronization [4]. The previously published measurements of α_s at 35 and 44 GeV [1] are complemented by using new resummed calculations for the C parameter [5] and by applying improved resummed calculations for B_T and B_W [6]. In the latter case, all single logarithmic terms of the prediction are now handled more accurately by a proper treatment of the quark recoil against multi-gluon emission.

In the case of the C parameter, the combined resummed plus fixed order theory gives an excellent description of the data over the entire range of the distribution, even at the low PETRA energies [4]. The recoil-corrected calculations on the jet broadenings do not yield a significant improvement of the previous fits [1,4]. The excess of the theoretical curve over the data in the 3-jet region is still present, but the α_s results are now shifted by about 3% to higher values.

The values of α_s and the errors obtained at $\sqrt{s} = 35$ GeV are shown in Fig. 1, indicating that the results are consistent with each other. The combination of the individual results of the six observables using the weighted average method [4] yields as final results

$$\alpha_s(35\mathrm{GeV}) = 0.1448 \pm 0.0010(\mathrm{stat.})^{+0.0117}_{-0.0070}(\mathrm{syst.})$$

$$\alpha_s(44\mathrm{GeV}) = 0.1392 \pm 0.0017(\mathrm{stat.})^{+0.0106}_{-0.0073}(\mathrm{syst.})$$

Various uncertainties emerging from experimental measurement, event selection, hadronization corrections and the choice of the QCD-renormalization scale were regarded as systematic errors of the fits [4].

3. POWER CORRECTIONS

3.1. Parametrization

A technique for studying power suppressed contributions to event shapes is the dispersive approach [9,11]. A recent publication [11] points out that the effect of power corrections on the event shapes mentioned above is simply a *shift* δV of the perturbative spectrum by an amount proportional to $1/Q$ and $\ln Q/Q$, where $Q = \sqrt{s}$.

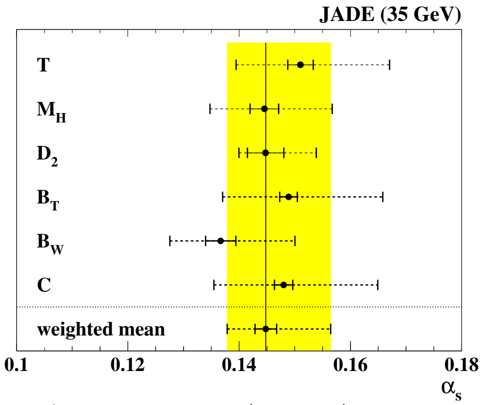

Figure 1. Values of α_s(35 GeV) obtained from $\mathcal{O}(\alpha_s^2)$+NLLA fits to the event shapes. The experimental and statistical uncertainties are represented by the solid, the total error by the dashed error bars.

The shift depends on two parameters $\mathcal{P}$ and $\mathcal{P}'$ and an observable-dependent coefficient c_V:

$$\delta V = c_V \cdot \begin{cases} \mathcal{P} & ; V = T,\, C \\ \left(\mathcal{P} \ln \frac{Q}{\mu_I} - (\xi\mathcal{P} + \mathcal{P}')\right) & ; V = B_T,\, B_W . \end{cases}$$

$\mathcal{P}$ and $\mathcal{P}'$ can be expressed in terms of effective coupling moments α_0 and α_0' [11],

$$\mathcal{P} = a \frac{\mu_I}{Q}\left[\alpha_0(\mu_I) - \alpha_s(Q) - \beta_0 \frac{\alpha_s^2}{2\pi}\left(\ln\frac{Q}{\mu_I} + \frac{K}{\beta_0} + 1\right)\right]$$

$$\mathcal{P}' = a \frac{\mu_I}{Q}\left[\alpha_0'(\mu_I) + \alpha_s(Q) + \beta_0 \frac{\alpha_s^2}{2\pi}\left(\ln\frac{Q}{\mu_I} + \frac{K}{\beta_0} + 2\right)\right]$$

where $a = \frac{4C_F}{\pi^2}\mathcal{M}$ contains the so-called Milan factor $\mathcal{M}$ arising from a two-loop calculation of the observable-dependent factor. The Milan factor is expected to be universal [12]. μ_I is an infrared matching scale [9], usually set to 2 GeV. An important feature of the dispersive approach is that the only free parameters α_0 and α_0' are expected to be approximately *universal* [9,11].

3.2. Global Fits to PETRA and LEP data

The universality of the power corrections is tested using differential data distributions at hadron level measured with JADE at $\sqrt{s} = 35$ and 44 GeV [1,4], and also using data from various LEP experiments up to $\sqrt{s} = 183$ GeV [13]. Both perturbative QCD ($\mathcal{O}(\alpha_s^2)$+NLLA) and power corrections are compared by a global simultaneous fit of α_s, α_0 and, in the case of the jet broadenings, additionally α_0' to the data.

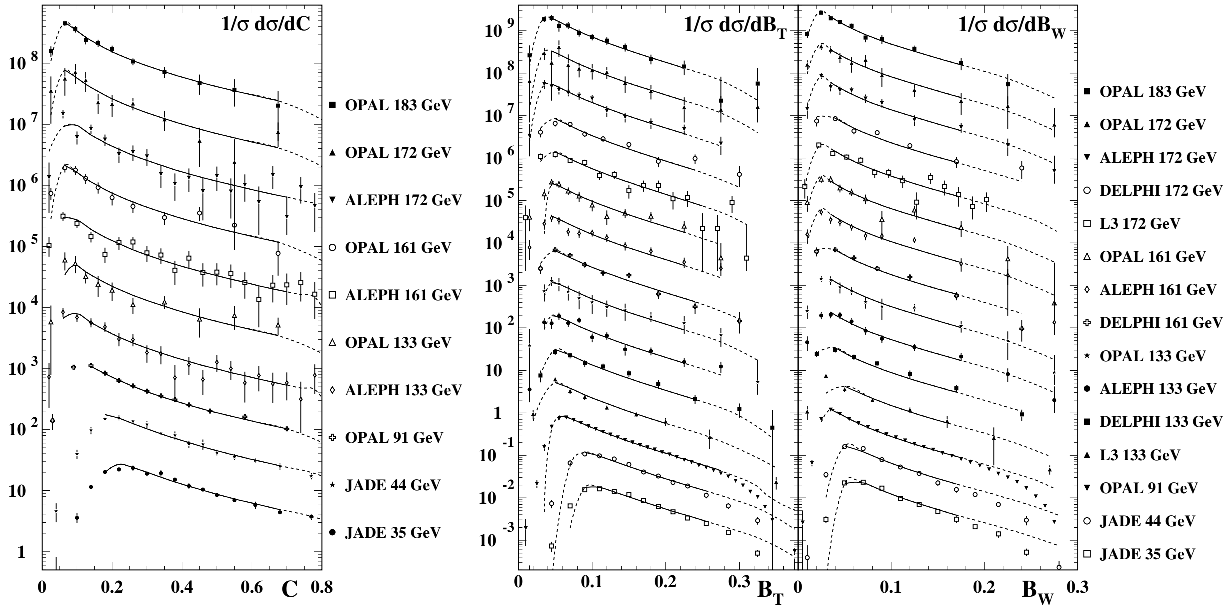

Figure 2. Simultaneous global fits of $\mathcal{O}(\alpha_s^2)$+NLLA theory + power corrections (lines) to the hadron level distributions of C parameter (left), total and wide jet broadening, B_T and B_W (right), measured at $\sqrt{s}$ = 35 to 183 GeV (points). The fit ranges are indicated by the solid lines. The distributions shown are scaled.

Fig. 2 shows the results of the fits (solid lines) to the data (points). Unlike in a similar analysis in [14], each energy has its individual fit range including the maximum peaks in the 2-jet region. The fitted distributions are in good agreement with the data within the fit ranges.

In the case of the jet broadenings, a strong correlation between α_0 and α_0' is observed, presumably because the pure $1/Q$ term $\xi\mathcal{P}+\mathcal{P}'$ containing α_0' was found to be small and fairly energy independent above $\sqrt{s}$ = 35 GeV. A reanalysis of more data at lower energies is needed to resolve both α_0 and α_0'. For now, this contribution and, hence, the dependence on α_0' was neglected.

The corresponding fit results for $\alpha_s(M_{Z^0})$ and α_0(2 GeV) are presented in table 1, and in Fig. 3 with 95% confidence level contours. In the case of C parameter and — for comparison — thrust T, the results for α_s are compatible with the world average value of 0.118 [3]. Furthermore, there is a fair agreement of the corresponding α_0 values. However, α_s from the fits to the jet broadenings * is far off the world average. Here, the universality of the effective coupling moment is not observed.

The presence of possible $1/Q^2$ contributions can be tested by considering LEP data and JADE data separately in the analysis. Fig. 4 demonstrates that, in the case of the C parameter, the JADE data reduce significantly the statistical uncertainties of the fit. In the case of B_T, a minor indication for $1/Q^2$ terms emerges.

A comparison of the fits based on distributions corrected for hadronization as described in section 2 and the hadron level fits using the power correction ansatz points out that the transformation from the perturbative to the non-perturbative level is not sufficiently described by a simple shift. Clearly, an additional *squeeze* of the distributions is needed, i.e. power corrections additionally depending on the value of the observ-

Table 1
Preliminary results for α_s and α_0. The errors stated are the statistical errors of the fit.

Obs.	$\alpha_s(M_{Z^0})$	α_0(2 GeV)	χ^2/dof
T	0.1136±0.0015	0.501±0.009	248/226
C	0.1128±0.0022	0.482±0.008	107/124
B_T	0.0953±0.0015	0.621±0.008	159/141
B_W	0.0854±0.0017	0.671±0.011	112/108

*The 3-parameter fit of the full prediction for B_T yields α_s = 0.0954 ± 0.0017, α_0 = 0.710 ± 0.081, α_0' = -0.707 ± 0.166 and a correlation between α_0 and α_0' of +98 %.

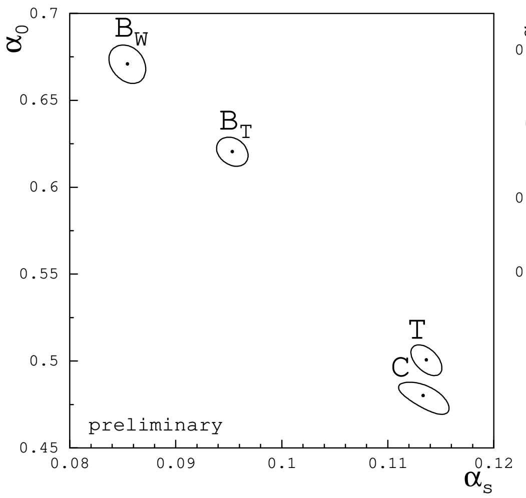

Figure 3. Results for α_s and α_0 from fits to event shape distributions, shown as 95 % CL contours.

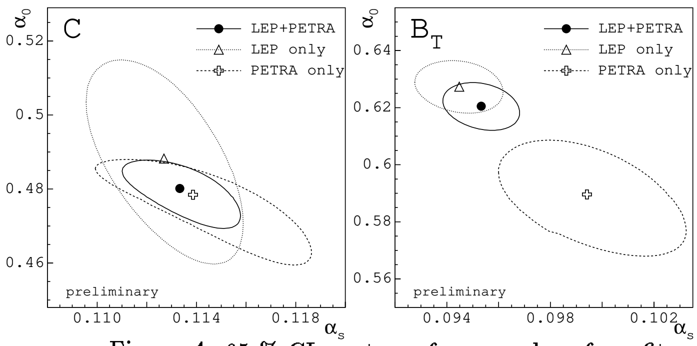

Figure 4. 95 % CL contours for α_s and α_0 from fits to C and B_T using PETRA only (dashed line), LEP only (dotted line) and combined (solid line) data.

able. In the present fits, α_s appears as the only parameter inducing a squeeze. Thus, a combination of rather large values for α_0 and extremely small values for α_s is needed to fit the hadron level distributions. This mechanism explains the observed anticorrelation between α_s and α_0 as seen in Fig.3. However, a shift is sufficient to describe the impact of hadronization on the *means* of the event shape distributions [4,7].

4. SUMMARY

Combined resummed and fixed order QCD provides consistent determinations of α_s at PETRA energies. Recently presented calculations for the C parameter, B_T and B_W fit previously published data at $\sqrt{s} = 35$ and 44 GeV, yielding $\alpha_s(M_{Z^0}) = 0.123\ ^{+0.008}_{-0.005}$ and $0.123\ ^{+0.008}_{-0.006}$, respectively, in good agreement with the world average value [3].

Power corrections to differential event shape distributions are tested using hadron level data between $\sqrt{s} = 35$ and 183 GeV. Reliable fits are obtained in the case of the C parameter and the thrust, where non-perturbative effects are approximately described by the predicted shift of the perturbative spectra. This does not apply to the case of B_T and B_W, yielding α_s results incompatible with other measurements at the Z^0 pole. For the present calculations, the universality of the effective coupling moment α_0 at the level of 20% is only verified for C parameter and thrust.

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