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α_S and Power Corrections from JADE

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Re-analysed JADE data were used to determine α_S at $\sqrt{s} = 14\text{-}44\,\text{GeV}$ on the basis of resummed calculations for event shapes and hadronisation models tuned to LEP data. The combined result is $\alpha_S(M_{Z^0}) = 0.1194^{+0.0082}_{-0.0068}$ which is consistent with the world average. Event shapes have also been used to test power corrections based on an analytical model and to verify the gauge structure of QCD. The only non-perturbative parameter α_0 of the model was measured to $\alpha_0(2\,\text{GeV}) = 0.503\,^{+0.066}_{-0.045}$ and is found to be universal within the total errors.

1. INTRODUCTION

The re-analysis of e^+e^- annihilation data collected with the JADE detector at the PETRA collider (1978-1986) has been shown to be a valuable effort [1–4] since the characteristic energy evolution of Quantum Chromodynamics (QCD) becomes more manifest towards decreasing centre-of-mass energies $\sqrt{s}$. Recently, data at energies down to $\sqrt{s} = 14\,\text{GeV}$ could be employed in state-of-the-art QCD studies due to the successful resurrection of the original JADE software.

Since the PETRA shutdown, significant progress has been made in the theoretical calculations of event shape observables. In the following, we present an α_S analysis at $\sqrt{s} = 14\text{-}44\,\text{GeV}$ based on the most complete perturbative calculations for event shapes [5,6] available so far. We included recently analysed data in the energy region $\sqrt{s} = 14\text{-}22\,\text{GeV}$ for which the calculations are applied for the first time. Furthermore, power corrections based on an analytical model by Dokshitzer, Marchesini, and Webber [7] (DMW) were investigated as a promising approach to describe non-perturbative effects in event shapes. Besides α_S, the model depends only on one additional free parameter. Also the consistency of power corrections with the gauge structure of QCD was tested.

2. EVENT SHAPES

From multihadronic data samples, the distributions of *thrust* $(1-T)$, *heavy jet mass* (M_H), *total* and *wide jet broadening* (B_T and B_W), *C parameter* and the *differential 2-jet rate* y_{23} in the Durham scheme are calculated (cf. [1]). The data are corrected for the limited acceptance and resolution of the detector and for initial state photon radiation. Since electroweak decays of the heavy b-hadrons fake hard gluon radiation particularly at $\sqrt{s} \leq 22\,\text{GeV}$, we take the contribution $e^+e^- \to b\bar{b}$ as an additional background to be subtracted from the distributions.

The data have been used to assess the performance of various QCD event generators tuned to LEP data at $\sqrt{s} = M_{Z^0}$ (cf. [8]). The parton shower and string fragmentation model implemented in PYTHIA/JETSET is found to be well capable of describing event shapes down to 14 GeV. The quality of the models ARIADNE (colour dipole scheme) and HERWIG (cluster fragmentation), however, is more moderate, and COJETS (independent fragmentation) is clearly disfavoured. Obviously, the model parameters of these generators need a re-tune at lower $\sqrt{s}$.

3. DETERMINATION OF α_S

The determination of α_S is based on a combination of an exact QCD matrix element calculation $\mathcal{O}(\alpha_S^2)$ [5] intended to describe the 3-jet region of phase space and a next-to-leading-logarithmic approximation (NLLA) [6] valid in the 2-jet region where multiple radiation of soft and collinear gluons from a system of two hard back-to-back partons dominate. We perform χ^2-fits of the theoretical predictions corrected for

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Table 1
Preliminary α_S results from JADE.

$\sqrt{s}$ [GeV]	$\alpha_S(\sqrt{s})$	fit+exp.	had.	hi. ord.	tot.
14.0	0.1704	± 0.0051	$^{+0.0141}_{-0.0136}$	$^{+0.0143}_{-0.0091}$	$^{+0.0206}_{-0.0171}$
22.0	0.1513	± 0.0043	± 0.0101	$^{+0.0101}_{-0.0065}$	$^{+0.0144}_{-0.0121}$
34.8	0.1431	± 0.0019	± 0.0073	$^{+0.0091}_{-0.0060}$	$^{+0.0118}_{-0.0096}$
38.3	0.1397	± 0.0040	± 0.0054	$^{+0.0084}_{-0.0056}$	$^{+0.0108}_{-0.0087}$
43.8	0.1306	± 0.0037	± 0.0056	$^{+0.0068}_{-0.0044}$	$^{+0.0096}_{-0.0080}$

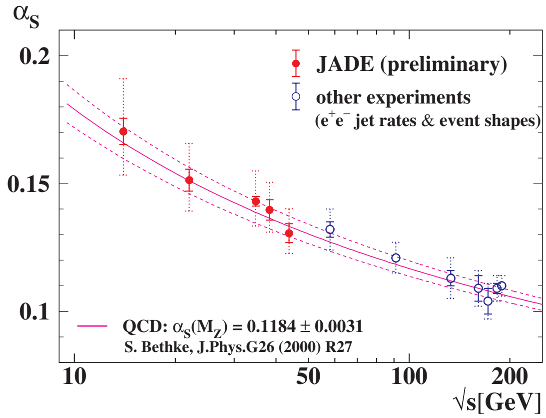

Figure 1. $\alpha_S(\sqrt{s})$ derived using $\mathcal{O}(\alpha_S^2)$+NLLA predictions for event shapes in e^+e^- annihilation.

hadronisation effects. For the main results, we use the $\ln(R)$-scheme [6] for the perturbative prediction with the renormalisation scale factor $x_\mu \equiv \mu/\sqrt{s} = 1$ and PYTHIA for the estimation of non-perturbative contributions. We generally observe stable fits and good agreement with the data at each $\sqrt{s}$ with χ^2/d.o.f. $\simeq$ 0.2-2.0. In case of B_W, a significant excess of the theory over the data in the 3-jet region of the distributions is present.

Experimental errors are under control for all data samples. Expectedly, hadronisation uncertainties increase rapidly towards 14 GeV. The individual results agree with each other within 1-2 standard deviations of the fit and experimental errors. For each $\sqrt{s}$, the α_S values from the six observables are combined using the weighted mean method of Ref.[1] (Tab. 1). The total errors are dominated by higher order uncertainties. At 14 and 22 GeV, hadronisation uncertainties are of the same order as the QCD scale ambiguities.

The α_S results obtained here and in similar analyses at higher energies based on resummed event shapes (Fig. 1) agree well with the QCD expectation for the running coupling [9]. A χ^2-fit taking statistical and experimental errors into account yields $\alpha_S(M_{Z^0}) = 0.1213 \pm 0.0006$ with χ^2/d.o.f. = 8.3/11. Even considering the total errors, the unphysical hypothesis α_S = const. is disfavoured by a fit probability of $\approx 10^{-5}$.

4. TEST OF POWER CORRECTIONS

The DMW model [7] describes non-perturbative effects to event shapes as contributions from gluon radiation at low energy scales, assuming that the physical strong coupling $\alpha_S(\mu)$ remains finite in the energy region around the Landau pole where simple perturbative evolution of α_S breaks down. This leads to the introduction of a parameter $\alpha_0(\mu_I) = 1/\mu_I \int_0^{\mu_I} d\mu\, \alpha_S(\mu)$ that absorbs all non-perturbative details of $\alpha_S(\mu)$ up to an arbitrary infrared matching scale μ_I. The principle structure of power corrections is a shift $\mathcal{P}D_\mathcal{F}$ of the perturbative spectrum away from the 2-jet region, with $\mathcal{P} \propto \alpha_0/\sqrt{s}$ and $D_\mathcal{F}$ depending on $\mathcal{F}$. In case of B_T and B_W, the shift is superimposed by a squeeze $D_\mathcal{F} \propto \ln 1/\mathcal{F}$. For mean values one obtains also an additive correction. The perturbative part is $\mathcal{O}(\alpha_S^2)$+NLLA for the distributions and $\mathcal{O}(\alpha_S^2)$ for the means.

The prediction, in particular the universality of $\alpha_0(\mu_I)$, has been tested by global fits to the hadron level data from this analysis and from other experiments e.g. at LEP/SLC up to $\sqrt{s}$ = 189 GeV (cf. [2]), with $\alpha_S(M_{Z^0})$ and $\alpha_0(2\,\text{GeV})$ as only free parameters. The major features of the distributions are reproduced well, thus supporting the $1/\sqrt{s}$ evolution of power corrections in event shapes. However, we observe discrepancies for the distributions of the less inclusive quantities M_H and B_W in particular at $\sqrt{s} < M_{Z^0}$.

For y_{23} the leading power correction is known to be quadratic in $1/\sqrt{s}$. This expectation has been verified by means of the new JADE distributions at $\sqrt{s}$ = 14 and 22 GeV using a simple additive power correction ansatz.

As shown in Fig. 2, there is a reasonable agreement between the individual results within the

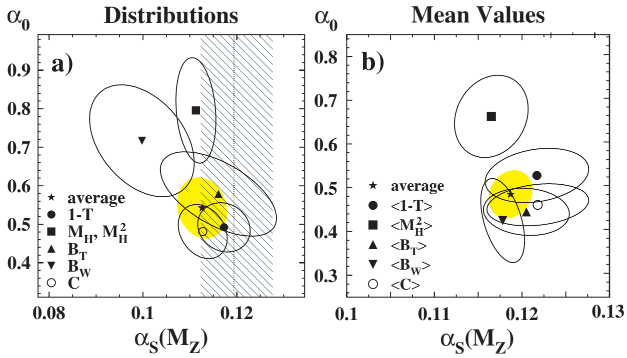

Figure 2. $\alpha_S(M_{Z^0})$ and $\alpha_0(2\,\mathrm{GeV})$ and one standard deviation errors of DMW-fits to distributions a) and means b). The hatched band represents the combined $\alpha_S(M_{Z^0})$ derived from the "conventional" analysis.

total uncertainties. However, the α_0 results from the M_H and B_W distributions are large compared to the results from the other observables. This observation may be related to the non-inclusiveness of these variables. The α_S values from power corrections to the distributions are systematically smaller than the results based on MC corrections. This is due to the different amounts of squeeze of the perturbative spectrum predicted by both types of model, particularly in case of B_W.

Combining the results for the mean values and the distributions taking correlations between the systematic errors into account yields $\alpha_S(M_{Z^0}) = 0.1175^{+0.0031}_{-0.0021}$ and $\alpha_0(2\,\mathrm{GeV}) = 0.503^{+0.066}_{-0.045}$. The scatter of the α_0 values is mostly covered by the theoretical uncertainty of the Milan factor [7].

5. STUDY OF QCD COLOUR FACTORS

The DMW ansatz has been exploited to extract the QCD colour factors C_A, C_F, and n_f [3]. Various global fits to the event shape spectra trying alternative sets of the free model parameters support the $SU(3)$ symmetry group. The most stable and precise measurements are provided by $1-T$ and C. Combining the corresponding results for these variables with $\alpha_0(2\,\mathrm{GeV})$ and n_f fixed, and $\alpha_S(M_{Z^0})$, C_F, and C_A free, one finds $C_F = 1.29 \pm 0.18$ and $C_A = 2.84 \pm 0.24$. This is in good agreement with the QCD expectation while some other gauge symmetry groups are excluded.

6. CONCLUSIONS

Resummed QCD theory combined with LEP tuned hadronisation models fits event shape data well down to $\sqrt{s} = 14\,\mathrm{GeV}$ and allow consistent determinations of α_S. The combined result evolved to the Z^0 mass scale is $\alpha_S(M_{Z^0}) = 0.1194^{+0.0082}_{-0.0068}$ which is substantially more precise than former PETRA measurements and also in good agreement with the world average value [9].

Power corrections $\propto 1/\sqrt{s}$ generally reproduce the overall event shape spectra, except for the distributions of the less inclusive variables (M_H and B_W) at $\sqrt{s} < M_{Z^0}$. The results for α_0 support the DMW prediction of universality within 25%. Using power corrections, the gauge structure of QCD has been verified with uncertainties competitive e.g. with traditional 4-jet angular correlation analyses. Potential biases from hadronisation models are reduced within this approach.

Thus, exploiting JADE data significantly improves the verification of QCD on the basis of e^+e^- annihilation.

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