α_S EVOLUTION FROM 35 GEV TO 202 GEV AND FLAVOUR INDEPENDENCE

O. BIEBEL

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

Determinations of the strong coupling constant α_S at centre-of-mass energies of 192 through 202 GeV at LEP are presented. The energy evolution of α_S is in agreement with the prediction of QCD. The combined investigation of OPAL and JADE data in the energy range of 35 through 189 GeV yields $\alpha_S(m_Z) = 0.1187^{+0.0034}_{-0.0019}$. The strenght of the strong coupling is flavour independent if quark mass effects are taken into account.

1 Motivation

Three fundamental properties follow from QCD: (i) the scale dependence of the renormalised coupling strength, (ii) the flavour independence of the coupling apart from effects due to finite quark masses, and (iii) the scale dependence of the renormalised quark masses. It constitutes a significant experimental test of QCD if the strong interaction obeys these properties.

The large range of energy covered by e^+e^- colliders makes an investigation of the energy evolution of α_S possible. Although the expected running of the coupling is more pronounced towards lower centre-of-mass energies, the uniform analyses at LEP provide significant QCD tests up to the highest energies accessible.

2 α_S(200 GeV)

The excellent performance of the LEP collider in 1999 provided data at $\sqrt{s} = 192$, 196, 200, and 202 GeV comprising together about 220 pb^{-1} per experiment. The results at each of the four $\sqrt{s}$ will be combined to derive the coupling strength at $\sqrt{s} = 198$ GeV which is the luminosity weighted average energy.

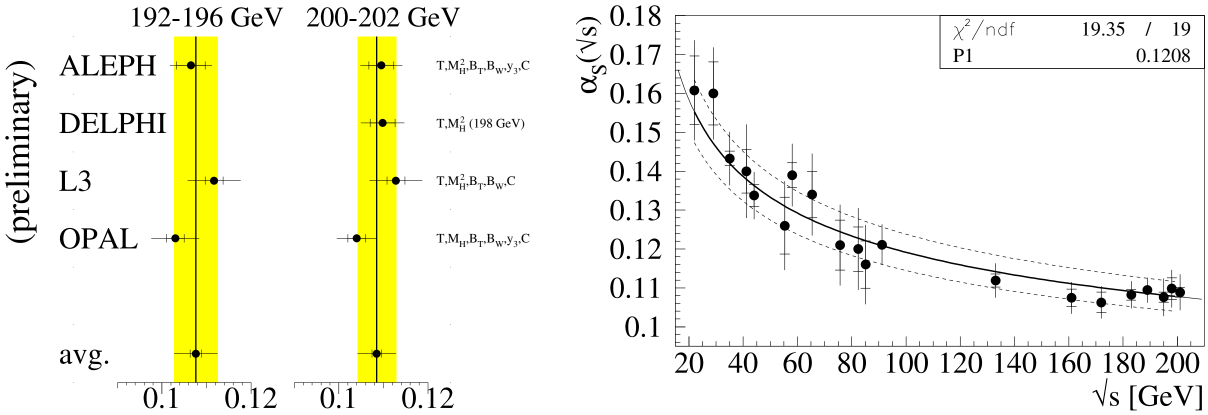

Figure 1: Left: α_S results at the highest LEP energies. The experimental contribution to the total errors is indicated. Right: α_S between $\sqrt{s} = 22$ and 202 GeV, fitted with the 4-loop prediction of the scale dependence.

Even though the selection of hadronic final states is trivial, background contributions from essentially W pair production and large initial state radiation have to be rejected. W pair events are excluded using the wide separation of the four jets and requiring di-jet masses different from the W mass. The demand that the effective centre-of-mass energy of the hadronic final state is within 10-20% of the nominal value is applied against initial state radiation events. These criteria select more than 75% of the real hadronic final states and reduce the contribution from other processes to less than 20%.

From the selected events the observables thrust (T), heavy jet mass (M_H), total and wide jet broadening (B_T, B_W), C parameter (C), and the value of the jet resolution parameter at the transition from 3 to 2 jets using the Durham jet algorithm (y_3) are measured. The strong coupling constant is found from fitting the QCD prediction, convolved with the hadronisation correction, to the distribution of an observable. The QCD prediction is the matched resummed next-to-leading logarithmic approximation (NLLA) with the full second order matrix element ($\mathcal{O}(\alpha_S^2)$). The hadronisation correction is taken from various Monte Carlo event generators which although they were tuned to describe the data measured at 91 GeV yield a good representation of the data at energies of around 200 GeV.

The left part of Fig. 1 shows the fit results of the LEP experiments [1] for α_S at $\sqrt{s} = 192$-196 and 200-202 GeV. Combining the values yields $\alpha_S(198\text{ GeV}) = 0.109 \pm 0.001_{(\text{expt})} \pm 0.005_{(\text{theo})}$.

3 Energy evolution

The LEP experiments contributed a large number of α_S determinations for $\sqrt{s} \geq m_Z$ (see [1] and references therein). Exploiting initial and hard final state photon radiation, $\sqrt{s}$ as low as 30 GeV are accessible and have been investigated by L3 and DELPHI [2]. These determinations of α_S below the Z mass are complemented by results of experiments at lower centre-of-mass energies [3,4] which, even though already completed since long, re-analysed their data to employ the matched resummed NLLA and $\mathcal{O}(\alpha_S^2)$ predictions for an α_S determination.

The right part of Fig. 1 shows the α_S values versus the centre-of-mass energy. The values with their experimental errors are fitted with the 4-loop formula for the scale dependence [5] of α_S. To estimate the theory uncertainty the scale uncertainties of the single measurements are considered to be fully correlated. The fit yields $\alpha_S(m_Z) = 0.1208 \pm 0.0006_{(\text{expt})} \pm 0.0048_{(\text{theo})}$ which is not dominated by the single measurement at 91.2 GeV and which agrees with the world average of 0.1184 ± 0.0031 [6].

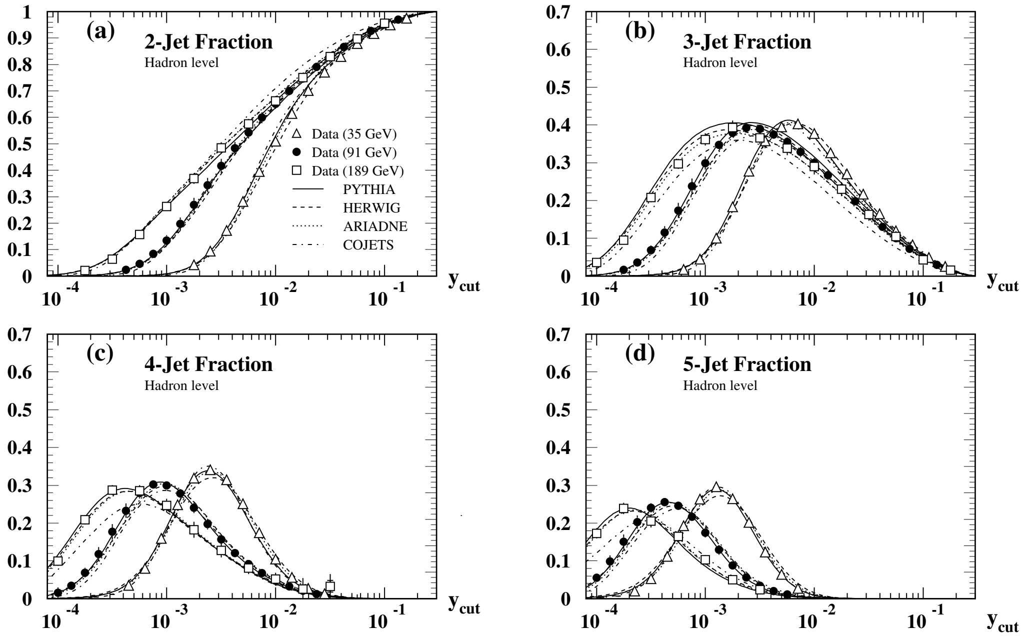

Figure 2: 2-, 3-, 4-, and 5-jet fractions for the Durham jet algorithm at $\sqrt{s} = 35$, 91, and 189 GeV.

Recently jet observables for the Durham and Cambridge jet algorithms have been investigated using data of the OPAL and the JADE experiments [7]. The analysis treated the data of both experiments and estimated the errors of α_S in a similar way. Fig. 2 shows the 2-, 3-, 4-, and 5-jet fractions for the Durham jet algorithm at three different $\sqrt{s}$. Predictions of several models are overlaid. The coupling strength has been obtained from fits of the matched resummed NLLA plus second order matrix element to the differential 2-jet rate (D_2) and the jet multiplicity (N) of both jet finders. Fig. 3 shows the results with the world average overlaid. Combining all eight determinations and taking correlations into account yields $\alpha_S(m_Z) = 0.1187 \pm 0.0010_{(\mathrm{expt})}\,{}^{+0.0032}_{-0.0016}\,{}_{(\mathrm{theo})}$ which is in excellent agreement with the world average [6] and has a very small total error.

4 Flavour independence

Finite quark masses affect the result of α_S determinations. In particular bottom quark events at the Z mass yield a 7% lower value of α_S if the quark mass effect is neglected [8]. To account for the mass effect for an inclusive determination which neglected this effect, the value of α_S has to be increased by about 1%, which is covered by the typical total error.

Being precisely confirmed for the heavy charm and bottom quarks, the flavour independence has been scarcely tested for the light quarks at high energies. At $\sqrt{s} \approx 0$ evidence for the flavour independence comes from e.g. isospin invariance and approximate $SU(3)_{\mathrm{flav}}$ symmetry. The challenge for an investigation of the flavour independence at $\sqrt{s} = m_Z$ is to separate u, d, and s quark events. Using the leading particle effect [9] for $K^{\pm}$, K^0_S, and all kinds of charged particles OPAL [10] selected events which are enriched differently in u, d, and s quarks and thus allows for a statistical decomposition of the contribution of each of the three light quark flavours. α_S is determined from the charged multiplicities, $\langle N \rangle$, obtained for each quark flavour from the decomposition, using $\langle N \rangle \sim \alpha_S^B \cdot \exp(C/\sqrt{\alpha_S})$ where B and C are known from QCD calculations [11]. This yielded the preliminary ratios: $\alpha_S^{\mathrm{u}}/\alpha_S^{\mathrm{d}} = 0.88 \pm 0.08$, $\alpha_S^{\mathrm{s}}/\alpha_S^{\mathrm{d}} = 0.96 \pm 0.06$, and $\alpha_S^{\mathrm{s}}/\alpha_S^{\mathrm{u}} = 1.09 \pm 0.06$ which are consistent with flavour independence at a level of better than 10% and constitute an improvement over the previous OPAL result [12].

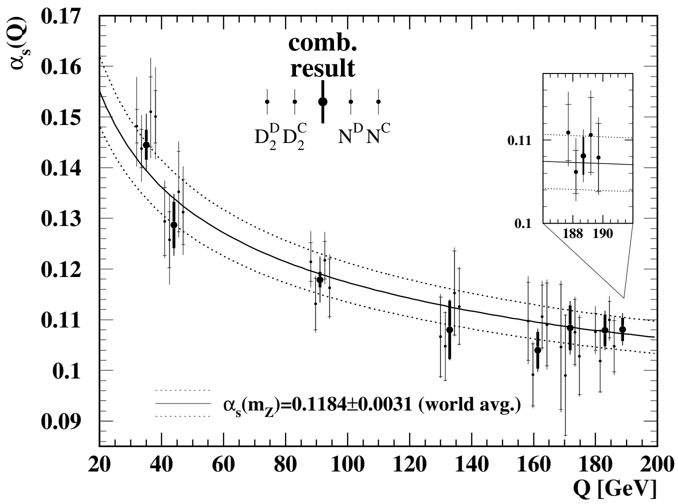

Figure 3: α_S obtained from the differential 2-jet rate (D_2) and the jet multiplicities (N) for the Durham (^{D}) and Cambridge (^{C}) jet algorithms.

5 Summary

QCD is in a very good shape! The fundamental properties of the theory, i.e. the running of α_S, its flavour independence and also the running of the renormalised quark masses are observed and confirmed in experimental investigations. At the highest energies of LEP the value of the coupling is determined to be $\alpha_S(198\text{ GeV}) = 0.109 \pm 0.005$ (prelim.) which agrees with the expected running. The value of the strong coupling constant is now very precisely determined from a combined analysis of OPAL and JADE data covering centre-of-mass energies from $\sqrt{s} = 22$ through 189 GeV to be $\alpha_S(m_Z) = 0.1187^{+0.0034}_{-0.0019}$. The flavour independence of the coupling at high energies is now confirmed for the light quarks at the level of better than 10%.

References

1. ALEPH Coll.: ALEPH 2000-017, CONF 2000-014, March 10, 2000;
   DELPHI Coll.: DELPHI 2000-022 CONF 343, March 1, 2000;
   L3 Coll.: L3 Note 2505, March 1, 2000;
   OPAL Coll.: OPAL Physics Note PN420, December 3, 1999.
2. DELPHI Coll.: DELPHI 99-114 CONF 301, June 15, 1999;
   L3 Coll.: L3 Note 2504, March 1, 2000.
3. TPC Coll., D.A. Bauer *et al.*, SLAC-PUB-6518;
   TOPAZ Coll., Y. Ohnishi *et al.*, *Phys. Lett.* B **313**, 475 (1993);
   TOPAZ Coll., M. Aoki *et al.*, GLS0944, contributed paper to ICHEP 1994.
4. P.A. Movilla Fernández *et al.* and JADE Coll., *Eur. Phys. J.* C **1**, 461 (1998);
   O. Biebel *et al.* and JADE Coll., *Phys. Lett.* B **459**, 326 (1999).
5. T. van Ritbergen *et al.*, *Phys. Lett.* B **400**, 379 (1997).
6. S. Bethke, MPI-PhE/2000-07, `hep-ex/0004021`.
7. JADE Coll. and OPAL Coll., P. Pfeifenschneider *et al.*, CERN-EP/99-175.
8. OPAL Coll., G. Abbiendi *et al.*, *Eur. Phys. J.* C **11**, 643 (1999).
9. OPAL Coll., G. Abbiendi *et al.*, CERN-EP/99-164.
10. OPAL Coll.: OPAL Physics Note PN396, July 7, 1999.
11. see e.g.: B.R. Webber, *Phys. Lett.* B **143**, 501 (1984).
12. OPAL Coll., R. Akers *et al.*, *Z. Phys.* C **60**, 397 (1993).