EVENT SHAPE STUDIES, $\alpha_s$ AND ITS RUNNING FROM LEP

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Data from electron positron annihilations at different center of mass energies are collected by the four LEP experiments. Direct tests of hard QCD are performed by measuring and analysing event shape observables.

1 Introduction

From LEP1 data millions of hadronic events at and around $M_Z$ are collected and analysed by the four LEP experiments. By selecting events with prompt and hard photon radiation the energy range below $M_Z$ is accessible. At LEP2 energies the statistics is about three orders of magnitudes smaller compared to LEP1, but still sufficient for measurements of event shape observables. The background conditions at LEP2 are much more various and complicated compared to LEP1. Events with initial state photon radiation and (semi-)hadronically decaying W- and Z-pairs have to be discarded.

From hadronic events infrared and collinear safe event shape observables and their mean values are deduced. All measurements are in good agreement with Monte Carlo simulations, none of the LEP collaborations reports about a significant excess of multi jet events at neither energy. By comparing the measurements with theoretical predictions from perturbative QCD the strong coupling $\alpha_s$ and its running as well as the QCD structure constants $C_A$ and $C_F$ are accessible. The theoretical prediction has to be corrected for hadronisation effects. Two different approaches are followed by the LEP collaborations. Either the transition from colour charged partons into colourless hadrons is simulated by Monte Carlo generators or power corrections are applied. Different generators based on string and cluster fragmentation, all tuned to LEP1 data have been used. Within power corrections a universal parameter $\alpha_0(\mu_I)$ is introduced, accounting for non perturbative contributions below an infrared matching scale $\mu_I$. Power corrections can be applied to most of the event shape observables, to their shapes as well as to their mean values.

By comparing results at different center of mass energies the energy dependence of event shape observables and of $\alpha_s$ is accessible.
2 Results

2.1 Measurements of $\alpha_s$

Measurements of $\alpha_s$ are performed by fitting QCD predictions to event shape observables. Predictions in fixed order ($O(\alpha_s^2)$ for 3-jet final states and $O(\alpha_s^3)$ for 4-jet final states) and in NLLA are used as well as resummed predictions (R, lnR matching). The predictions are folded either by a hadronisation correction with Monte Carlo Models (Pythia, Ariadne, Herwig, Apacic++) or by power corrections. The DELPHI collaboration is performing fits with optimised renormalisation scales, leading to much more consistent results.

Using power corrections fits to event shape means leads to significantly larger results in $\alpha_s$ compared to fit results to event shape distributions. The expected universality of the parameter $\alpha_0$ is marginally fulfilled.

The LEP QCD working group is working on unifying the analyses to merge the results. Inputs from the experiments with separated statistical, experimental, systematic, hadronisation and scale uncertainties allow to combine the single results by taking correlations into account. From highest energetic LEP data of the year 2000 an average value of $\alpha_s(206\text{GeV}) = 0.1080 \pm 0.0014 \pm 0.0043$, corresponding to $\alpha_s(M_Z) = 0.1210 \pm 0.0018 \pm 0.0054$ is derived. By comparing $\alpha_s$ measurements at different energies the running of $\alpha_s$ is accessible, being in good agreement with the QCD expectation (Fig.1).

An overall $\alpha_s$ fit to LEP data yields: $\alpha_s(M_Z) = 0.1195 \pm 0.0007 \pm 0.0048$ with a reasonable $\chi^2/\text{ndf} = 31.3/36$. The measurement uncertainties are dominated by systematics.

2.2 Measurements of $C_A$ and $C_F$

By performing QCD fits with $C_A$ and $C_F(n_f)$ as free parameters, the structure constants of the QCD are accessible. Measurements are performed either to mainly 4-jet observables from LEP1 data or to the energy dependence of the mean values of event shape observables. In the latter case also data from lower energetic $e^+e^-$ experiments are included. All measurements confirm the SU(3) being the gauge symmetry of QCD. The measurement uncertainties are dominated by systematics.

2.3 Renormalisation Group Invariant measurements

The DELPHI collaboration presents an analysis with a renormalisation group invariant approach, where scale and scheme dependencies cancel out.
Figure 1. The running of the strong coupling $\alpha_s$.

completely. A very surprising result is that rgi fits are able to describe the energy evolution of event shape means without any need of hadronisation corrections, implying that power corrections to event shape means mainly parametrise terms which can in principle be calculated perturbatively. This approach gives the most precise measure of the $\beta$-function of QCD. By including data from lower energetic $e^+e^-$ experiments the first coefficient can be determined to be $\beta_0 = 7.9 \pm 0.3$, corresponding to $n_f = 4.8 \pm 0.4$.  

\[ \alpha_s(E_{cm}) \begin{align*} &\text{LEP/Jade} \quad 35\ldots207\text{GeV} \\ &\text{NLLA+O}(\alpha_s^2) \log(R) \end{align*} \]
3 Summary

Event shape distributions at centre of mass energies from 41GeV to 206GeV are measured from LEP data and are used for direct tests of hard QCD. The strong coupling is derived from the data and measured to be $\alpha_s(M_Z) = 0.1195 \pm 0.0007 \pm 0.0048$. The running of $\alpha_s$ is in good agreement with the QCD expectation. The measurement of the structure constants $C_A$ and $C_F$ underline the SU(3) being the gauge symmetry of QCD.

Within the analyses of the four LEP collaborations there are still many options: Theoretical predictions are used in fixed order and in NLLA, different matching schemes are applied. Hadronisation corrections are applied by power corrections or by Monte Carlo generators with different tunings. Scale optimisation, giving a more consistent measure of $\alpha_s$, are only slowly accepted by all experiments. There is still work to be done to unify the analyses to merge their results.

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