Review of α_s measurements at LEP 2

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Abstract. Since 1995, LEP has steadily increased the center of mass energy of the colliding beams, from the M_Z resonance to 133, 161 and 172 GeV. New measurements of the strong coupling constant, α_s, at these energies have been performed by the LEP experiments, L3, ALEPH, OPAL and DELPHI. In this article, the new results are summarized, and combined with the previous LEP measurement of $\alpha_s(M_Z)$ in order to obtain an updated LEP average of $\alpha_s(M_Z) = 0.120 \pm 0.005$.

INTRODUCTION

Over the past two years (1995 and 1996), the RF system of LEP has been upgraded with the inclusion of new superconducting RF cavities. Thus the energy of the LEP electron and positron beam has grown giving data with center of mass energy of 133[1], 161 and 172 GeV. The analysis of the hadronic system produced in the $e^+e^- \to Z/\gamma^* \to q\bar{q}$ process allows the measurement of the running of the strong coupling constant, α_s, testing the QCD prediction. Any deviation can be interpreted as a sign of new physics (e.g. production of light gluinos) appearing at the new energy accessible at LEP 2.

Theoretical predictions

It is well known that α_s is not a fixed but a running quantity. Its value depends on the physical energy scale (μ) of the process. The beta function describes the renormalization scale dependence of the strong coupling constant:

$$\mu \frac{d\alpha_s(\mu)}{d\mu} = -\frac{\beta_0}{2\pi}\alpha_s^2(\mu) - \frac{\beta_1}{4\pi^2}\alpha_s^3(\mu) + \mathcal{O}(\alpha_s^4) \quad (1)$$

[1] The true energies were 130 and 136 GeV. However, as the integrated luminosity at this two energy points was the same, the data are usually merged together by the experiments, and presented uniquely as the data collected at the mean energy of 133 GeV.

For SU(3) colour gauge symmetry: $\beta_0 = 11 - 2n_f/3$ and $\beta_1 = 51 - 19n_f/3$ are obtained, n_f being the number of active quark flavours. Solving equation 1, the α_s dependence in the scale goes as: $\ln(\mu^2/\Lambda^2)$, Λ being the fundamental QCD scale.

Combination of individual results

It is a matter of discussion how the different measurements of α_s are combined, given that most of the theoretical uncertainties are correlated [1]. As for a set of measurements, $x_i \pm \sigma_i$, a robust determination of the mean is given by $\langle x \rangle = \Sigma x_i w_i$ (with weights inversely proportional to squares of the error), in this article, the average is calculated following this prescription. The experimental error is obtained in a similar way, while the theoretical uncertainties are taken in average. The total error corresponds with the quadratic sum of the experimental and theoretical uncertainties.

MEASUREMENTS OF α_S AT LEP 1

The high statistics collected at the Z peak by the four LEP experiments (over 15 million of hadronic Z decays) has allowed $\alpha_s(M_Z)$ to be measured with high accuracy[2]. All four LEP experiments have published α_s measurements with a wide range of methods. These can be summarized by: inclusive quantities as R_h and R_τ (the total hadronic decays of the Z and the τ), analysis of the global event shapes (thrust, broadness, etc), scaling violations [2,3], three-jet rate, etc. Another set of important measurements have been the test of the α_s universality for all the quark flavours [4,6]. Also important are the measurements with $q\bar{q}\gamma$ events, where the boost to the center of mass of the hadronic system allows the running of α_s to be tested [5,7,8].

The global average of all LEP I measurements is: $\alpha_s(M_z) = 0.121 \pm 0.005$, where the main source of the error is the theoretical uncertainty.

MEASUREMENTS OF α_S AT LEP 2

The α_s measurements at LEP 2 have new problems with respect the measurements in LEP 1. The first is the limited statistics. So far, the integrated luminosity of the four experiments in LEP 2 is ≈ 100 pb^{-1} (representing about 10,000 hadronic events). The second problem is the background, mainly from events with radiative return to the Z, and from $\gamma\gamma$ collisions. Another type of background comes from the W^+W^- pairs decaying into $q\bar{q}q\bar{q}$ and $q\bar{q}l\nu$, but

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2) Most of the published results of α_s from other experiments at different energy scales are extrapolated to a common reference, usually taken as M_Z.

this background is only present with LEP operating over the W^+W^- production threshold. Due to these problems, the total sample available for each individual experiment and energy point is about 400∼1000 events.

Global event shapes

All the LEP experiments obtain the new values of $\alpha_s(\sqrt{s})$ by comparing the global event shape variables with the exact $\mathcal{O}(\alpha_s^2)$ QCD calculations plus either NLLA or resumed series. The new LEP 2 results for α_s are summarized in figure 1.

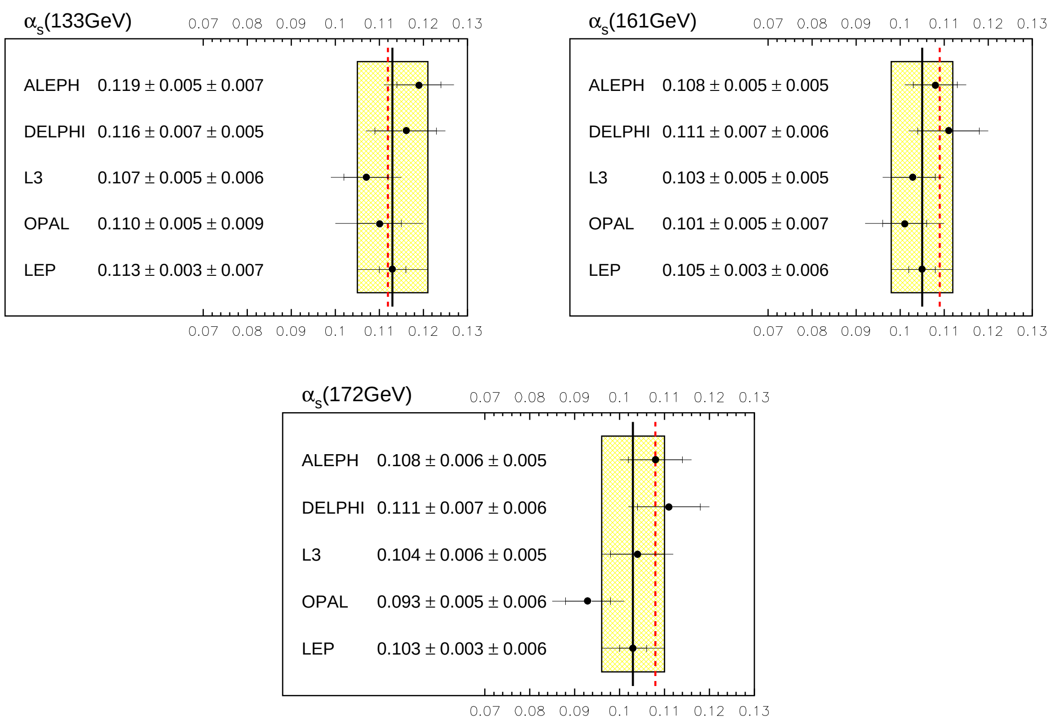

FIGURE 1. Measurements of α_s in LEP 2 at 133, 161 and 172 GeV. For each measurement, the errors quoted are the experimental and theoretical respectively. Dashed lines correspond with the QCD prediction assuming $\alpha_s(M_Z) = 0.118$.

The first result of $\alpha_s(133\text{GeV})$ was published by L3 [9]. In that analysis the distributions of thrust, scaled heavy jet mass and jet broadening variables are compared with resumed $\mathcal{O}(\alpha_s^2)$ QCD calculations. ALEPH [10] used the differential two jet rate with the Durham jet algorithm. In the DELPHI analysis [11] a similar set of event shape variables was used, plus the three jet rate with Durham amb JADE algorithms. In the OPAL analysis [12] the distributions of $1 - T$, scaled heavy jet mass, jet broadening variables and the Durham differential two jet rate were fitted to the $\mathcal{O}(\alpha_s^2)$+NLLA QCD predictions. The same event variables were used in the analysis of the 161 GeV data, providing the first α_s(161 GeV) LEP measurement [13].

The results at 172 GeV shown in figure 1 were provided by the QCD representatives of each experiment and are still preliminary.

The size of the nonperturbative effects in the event shape variables decreases with the energy, as shown in a DELPHI study [11,14]. This is due to the convergence of the $\mathcal{O}(\alpha_s^2)$ perturbative calculations with the nonperturbative contribution estimated with a power series of α_s.

LEP average

In figure 2, the global LEP values for α_s are presented for each energy available at LEP. The lines corresponds with the running of α_s as obtained assuming $\alpha_s(M_Z) = 0.118 \pm 0.003$ and using the renormalization group equation. The new measurements are compatible with the expected values of α_s. Combining all values of $\alpha_s(M_Z)$ measured so far at LEP 1 and LEP 2, the new LEP average is:

$$\alpha_s(M_Z) = 0.120 \pm 0.005$$

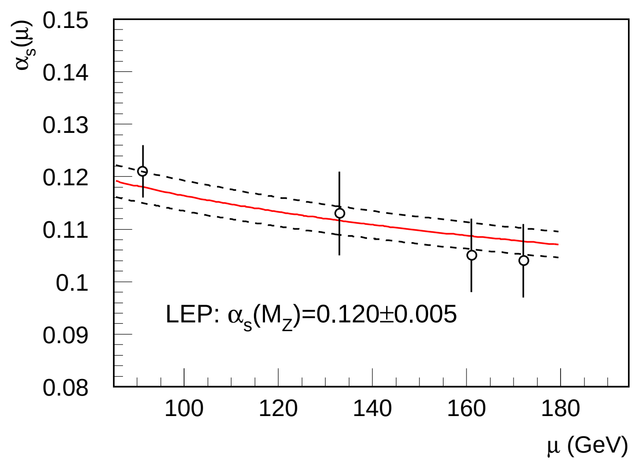

FIGURE 2. Running of the strong coupling constant: measurements at different scales in LEP (M_Z, 133, 161 and 172 GeV by order). Only total errors are displayed.

COMPARISON WITH OTHER EXPERIMENTS

The LEP averages for α_s at 133, 161 and 172 GeV can be added to the plot showing α_s running (figure 3) from low energies [1]. Adding these points to those in reference [1] does not change substantially the global average which is found to be:

$$\alpha_s(M_Z) = 0.118 \pm 0.003$$

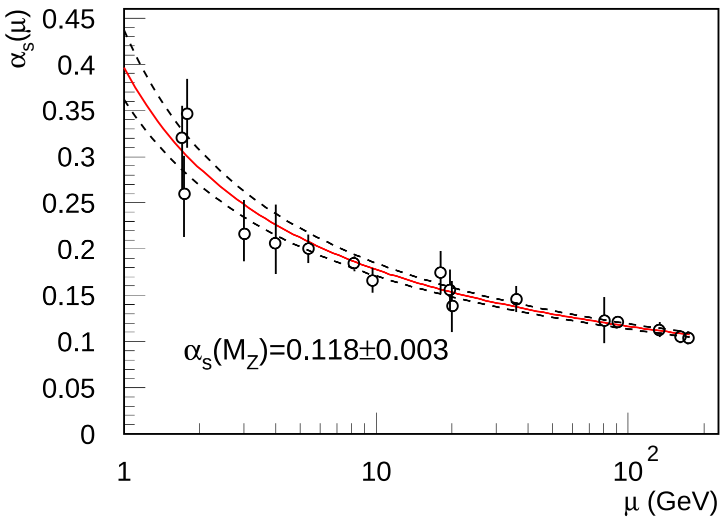

FIGURE 3. Running of the strong coupling constant: measurements at different scales compared to the QCD prediction for $\alpha_s(M_Z) = 0.118 \pm 0.003$. The last three points correspond with the new LEP 2 measurements. Only total errors are displayed.

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