Hadron production at 130 GeV $\leq \sqrt{s} \leq$ 140 Gev at LEP

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Abstract

In November 1995 data were taken at LEP at energies well above the Z resonance. The cross sections and the hadronic event shape were analysed by the four LEP experiments. A good agreement with the standard model is obtained . The strong coupling constant at $\sqrt{s}$= 133 GeV has also been measured.

1 Introduction

In November 1995 LEP was operated for the first time at energies well above the Z resonance ($\sqrt{s}$= 130.3,136.3,140.GeV). An integrated luminosity of 6.3 pb^{-1} was delivered to each of the four LEP experiments in very clean background conditions. All experiments have analysed their data, measuring the cross sections $e^+e^- \rightarrow hadrons(\gamma)$ [1]- [4]. The event shape variables were also studied [5]- [8]. In the framework of QCD, an high energy measurement of α_s has been obtained.

2 Cross sections

In previous years, when LEP was operated at energies of $88 \leq \sqrt{s} \leq 93$ GeV , around the Z resonance, the total measured energy was, for the large majority of the the events, the same as the total center of mass energy $\sqrt{s}$. By increasing the collider energy a big fraction of the events are due to the initial state radiation (ISR) which favours the return to the Z pole : $e^+e^- \rightarrow Z\,\gamma$ (table 1). The center of mass energy squared of the hadronic system is in this case reduced to

$$s' = s - 2E_\gamma \sqrt{s} \tag{1}$$

Moreover, at high energies, the two photon interactions $e^+e^- \rightarrow e^+e^-\gamma^*\gamma^* \rightarrow e^+e^-$hadrons, become dominant, however these events are characterised by a very low $\sqrt{s'}$ value and easily excluded from the analysis with a cut on the visible energy : $E_{vis}/\sqrt{s} > 0.5$.

Reaction	Events
$e^+e^- \rightarrow$ hadrons	400
$e^+e^- \rightarrow Z\,\gamma \rightarrow$ hadrons γ	1100
$e^+e^- \rightarrow e^+e^-\gamma^*\gamma^* \rightarrow e^+e^-$hadrons	7000

Table 1: Classification of hadronic events observed by a typical LEP detector for an integrated luminosity $\mathcal{L}$ = 5 pb^{-1}. The two photon events are given for a visible mass greater than 5 GeV.

The hadronic events are selected with little or no modification to the cuts already applied at $\sqrt{s}$= 91 GeV [9]- [12]. These cuts require an high multiplicity, a large visible energy and small energy inbalance; they have a good efficiency (>90%) and a low background contamination. The events found by each experiment and the cross sections are given in table 2. The measurements are dominated by the statistical error, the systematic error is $\sim$ 1-2%. The combined statistics of the four LEP experiments agree well with the Standard Model predictions (table 3).

The analysis has than to separate the genuine high energy events from ISR.The radiative photon is detected only in about 15 % of the events, most of the time it escapes in the beam pipe. In this case the hadrons are clustered in two jets and a kinematical fit $e^+e^- \rightarrow j_1 j_2 \gamma$ is performed, fixing the γ direction along the beam. The center of mass energy $\sqrt{s'}$ is than calculated from eq. (1) or from the polar angles of the two jets. The variable $\sqrt{s'}$ is used to separate the events $e^+e^- \rightarrow Z\ \gamma$ from the events $e^+e^- \rightarrow$hadrons (fig 1a). The cross section of the two processes has been calculated and compared with the Standard Model predictions (fig 1b).

	Aleph	Delphi	L3	Opal
$\sqrt{s}$=130 GeV				
Events	889	908	921	819
$\mathcal{L}$ (pb^{-1})	2.88	2.85	2.74	2.7
σ (pb)	328 $\pm$ 11 $\pm$ 3	329 $\pm$ 12 $\pm$ 5	343 $\pm$ 11 $\pm$ 4	315 $\pm$ 11 $\pm$ 5
$\sqrt{s}$=136 GeV				
Events	755	755	645	658
$\mathcal{L}$ (pb^{-1})	2.86	2.98	2.25	2.6
σ(pb)	273 $\pm$ 10 $\pm$ 3	261 $\pm$ 11 $\pm$ 4	293 $\pm$ 12 $\pm$ 3	261 $\pm$ 11 $\pm$ 4
$\sqrt{s}$=140 GeV				
Events		13	11	11
$\mathcal{L}$ (pb^{-1})		0.04	0.05	0.04
σ(pb)		358 $\pm$ 101 $\pm$ 5	235 $\pm$ 71 $\pm$ 3	281 $\pm$ 91 $\pm$ 4

Table 2: Total number of hadronic events and total cross sections with statistical and systematic errors as measured by the four LEP experiments.

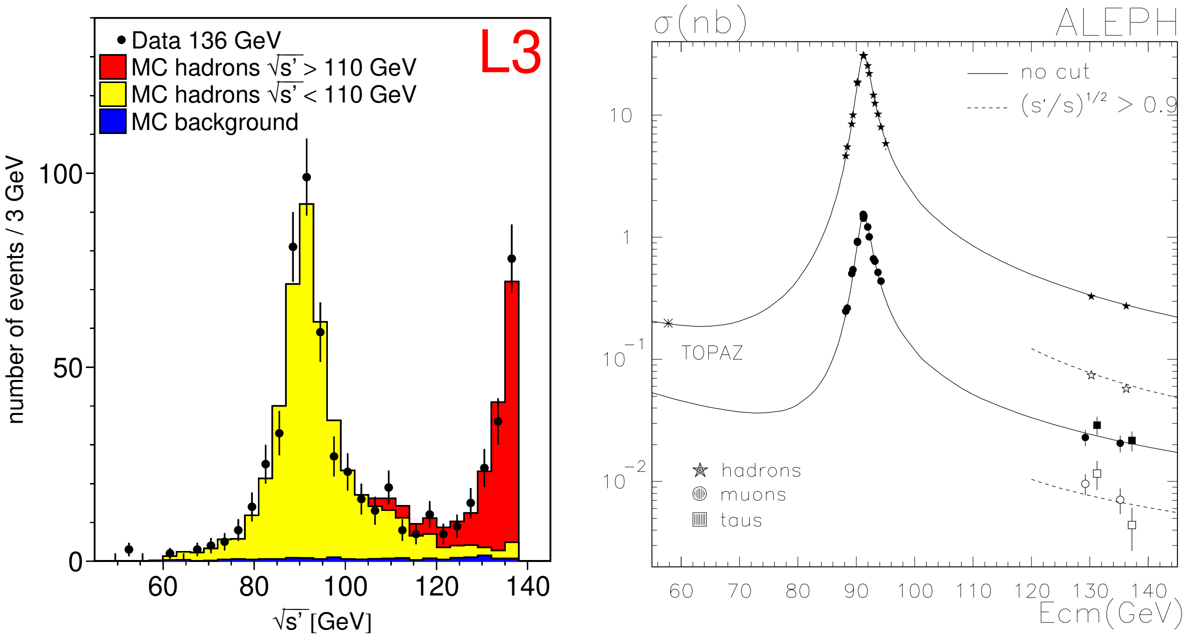

Figure 1: a) The reconstructed $\sqrt{s'}$ distribution compared to the result of a fit determining the cross section below and above $\sqrt{s'}$= 110 GeV. The Monte Carlo events generated below and above the cut are also indicated. b) Measured hadronic and leptonic cross sections, compared to the SM predictions (continous line). The open symbols and the dashed lines correspond to the measurements with $\sqrt{s'/s} \geq 0.9$.

$\sqrt{s}$	Events	σ (pb) experiment	σ (pb) Standard Model
130	3537	330 $\pm$ 6	336
136	2813	269 $\pm$ 5	280
140	35	278 $\pm$ 47	251

Table 3: Combined LEP statistics of hadronic events and comparison of the cross sections with the SM predictions, only statistical errors are quoted, the systematics is $\simeq$1-2 %.

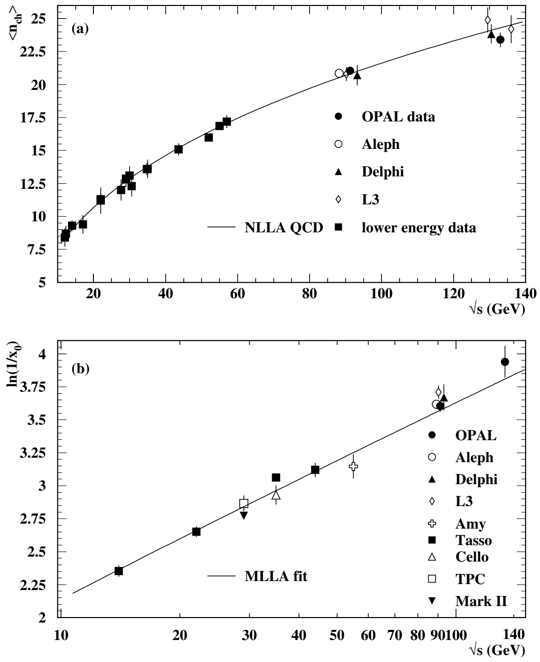

Figure 2: a) Average number of charged particles. The increase of the particles multiplicity with energy is well represented by a fit of NLLA QCD. b) Value of the peak position $\xi_0 = \ln(1/x_0)$ as function of $\sqrt{s}$ [8].

3 Event shape and measurement of α_s

Although the number of genuine hadronic events is small, the experiments were able to measure the event shape characteristics [5]- [8] and to observe their evolution as the center of mass energy increases. Two main effects are expected to influence QCD observables : the running of the strong coupling α_s and the change of the quark flavour composition: the fraction of u-type quarks should change from 34% at the Z peak to 45% at 133 GeV in events without ISR.

The observed evolution of the event shape, including data from 14 to 133 GeV, agree rather well with the predictions of parton shower Monte Carlos (PYTHIA,ARIADNE, HERWIG) tuned at Z energies. A matrix element calculation to $O(\alpha_s^2)$ is not sufficient to reproduce the observed $\sqrt{s}$ variation, it is necessary to model also the soft gluon emission (NLLA) (fig. 2a) [13].

The charged particle multiplicity and the momentum spectrum of soft particles are described by analytical calculations. The distribution of $\xi = -\ln x_p$ ($x_p = p/p_{beam}$)

has been measured [5], [8], the peak position ξ_0 follows the evolution predicted by the Modified Leading Log Approximation (MLLA) [14]

$$\xi_0 = \tau(1/2 + \sqrt{C/\tau} - C/\tau) \qquad \tau = \ln(\sqrt{s}/2\Lambda)$$

where the parameter C is fixed by the theory and the parameter Λ is an effective QCD scale, obtained from a fit to the data [8].

From the analysis of infrared finite quantities such as the jet rates, thrust, heavy jet mass and jet broadening the value of α_s has been measured (table 4) by using $O(\alpha_s^2)$+NLLA QCD calculations with the renormalization scale parameter fixed to $\sqrt{s}$. The average value of the four measurements gives $\alpha_s(133\ \text{GeV}) = 0.110 \pm 0.003 \pm 0.006$. By extrapolating this value to the Z mass, assuming the energy dependence as predicted by QCD with five quark flavours, we obtain $\alpha_s(M_Z) = 0.116 \pm 0.003 \pm 0.006$ consistent with analogous measurement at LEP I : $\alpha_s(M_Z) = 0.121 \pm 0.005$ [15].

Variable	Aleph	Delphi	L3	Opal
$<n_{ch}>$	$24.1 \pm 0.3 \pm 0.3$	$23.8 \pm 0.5 \pm 0.5$	$24.5 \pm 0.4 \pm 0.8$	$23.4 \pm 0.4 \pm 0.5$
ξ_0	$3.83 \pm 0.04 \pm 0.04$			$3.94 \pm 0.05 \pm 0.11$
$<1\text{-}T>$	$.067 \pm .006 \pm .003$		$.055 \pm .003 \pm .007$	$.065 \pm .004 \pm .002$
$\alpha_s(133\ \text{GeV})$	$.119 \pm .005 \pm .007$	$.105 \pm .003 \pm .008$	$.107 \pm .005 \pm .006$	$.110 \pm .005 \pm .009$

Table 4: Average value of some event shape variables and $\alpha_s$measurement at 133 GeV. For $\alpha_s$the first error includes statistics, systematics and hadronization uncertainties, the second error is the theoretical uncertainty.

4 Conclusions

The November 1995 LEP run was very successful in opening up the era of high energies at LEP. We acknowledge the excellent performance of the machine. The measurements of the four experiments confirm the Standard Model and QCD predictions. We are confident that the higher energies and the high luminosity planned for the next years will bring us a wealth of interesting data.

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