New physics at LEP2 [1]

Ramon Miquel [2]

Dept. ECM and IFAE
Univ. de Barcelona, Facultat de Física
Diagonal 647, E-08028 Barcelona (Spain)

Abstract. Searches for new physics in the first year of running of LEP2, at energies of 161 and 172 GeV, are summarized. After a short review of WW results and their implications on new physics, searches for the Higgs boson and SUSY particles, analyses of four-jet final states and constraints on possible explanations for the HERA high Q^2 anomaly are discussed in turn.

1. Introduction

The second phase of LEP, LEP2, designed to run at energies above the W-pair production threshold started operation in 1996, with two short runs, one at a center-of-mass energy of 161 GeV and another at about 172 GeV. The four LEP experiments, ALEPH, DELPHI, L3 and OPAL, collected about 10 pb^{-1} of luminosity each in each of the two runs.

The main purpose of the 161 GeV run was to measure the W-pair production cross section very close to threshold. This cross section is very sensitive to the value of the W mass and it provides a measurement with good precision. Searches for new particles were also performed at this energy, but they have already been superseded by the searches done at 172 GeV soon after.

In the 172 GeV run, the mass of the W gauge boson was determined directly, through the measurement of the invariant mass of its decay products. Also a first look at the structure of the trilinear gauge-boson vertices

---

[1] To appear in the proceedings of "Beyond the Desert", Castle Ringberg, Tegernsee, Germany, 8-14 June 1997.

[2] E-mail address: miquel@ecm.ub.es

was attempted. A short summary of W physics in the first year of LEP2 and its implications on limits for new physics can be found in section 2.

Results from the searches in the 172 GeV run for Higgs bosons (both from the Standard Model and from Supersymmetry models) and for supersymmetric particles are summarized in sections 3 and 4, respectively.

In the 1995 LEP run at a center-of-mass energy about 130 GeV, the ALEPH collaboration reported an excess of four-jet events with sum of jet-pair invariant masses close to 105 GeV [1]. The analyses of ALEPH and the other LEP collaborations on this topic both in the 161 GeV run and in the 172 GeV run are discussed in section 5.

The reports of the H1 and ZEUS collaborations at HERA hinting at possible new physics in electron-quark interactions [2] has prompted several analyses of electron-positron anihilation into quarks that are sensitive to some types of new physics that could explain the HERA events. Section 6 summarizes the status after analysing the 1996 data.

Finally, section 7 contains a summary of the talk. It should be noted that, unless specified otherwise, all results are to be understood as still preliminary.

2. W physics

The precise determination of the W mass serves as a stringent test of the Standard Model, since it can be predicted from the known values of the other parameters of the Standard Model. The only large uncertainty comes from the lack of knowledge of the Higgs boson mass, and therefore, measuring M_W precisely enough, one can get information on the value of M_H.

The measurement of the W cross section close to the W-pair production threshold provides a clean and precise way to determine the W mass, since the phase-space factors appearing in the cross section expression depend strongly on the W mass.

All four LEP experiments have already published their final results on the WW cross section production at 161 GeV [3]. The combined value for the WW cross section is [4]

$$\sigma_{WW}(161.3\,\mathrm{GeV}) = (3.69 \pm 0.45)\,\mathrm{pb}\,.$$

The error is dominated by statistics. From the total WW cross section at threshold, the W mass is obtained by using a Standard Model calculation that relates the WW cross section near threshold to its mass. The resulting W mass is:

$$M_W(161\ \mathrm{run}) = \left(80.40^{+0.22}_{-0.21} \pm 0.03\right)\mathrm{GeV}\,,$$

where the last error reflects the current uncertainty on the LEP beam energy.

Above the WW threshold, the most efficient way of determining the W mass is by measuring the invariant mass distribution of its decay products, either a charged lepton and a neutrino or a pair of jets. The detector resolution being far too poor to obtain a reasonably narrow invariant mass distribution, energy and momentum conservation have to be imposed in all channels to improve the resolution.

The preliminary determinations of the four experiments agree very well with each other and the combined value reads [4]

$$M_W(172\ \mathrm{run}) = (80.37 \pm 0.18_{exp} \pm 0.05_{theo} \pm 0.03_{beam})\,\mathrm{GeV}\,.$$

The dominant error includes statistical and purely experimental errors, the second one is the estimate of the uncertainty due to soft QCD effects and the third comes from the beam energy uncertainty.

The two numbers can be combined [4] to give the preliminary W mass result from the first year of running of LEP2:

$$M_W = (80.38 \pm 0.14)\,\mathrm{GeV}\,.$$

This value is compared in fig. 1 with the other measurements of M_W, both direct at the Tevatron and indirect at LEP1 and SLD.

The agreement of all measurements is perfect. The current LEP2 error is already quite good but still much larger than the 40 MeV uncertainty in the indirect measurement. To get a direct determination of M_W with this sort of accuracy and to compare it against the indirect measurement, which assumes the Minimal Standard Model, is the next challenge for both LEP2 and the Tevatron.

The other important topic of WW physics at LEP2 is the search for possible anomalous couplings between a pair of Ws and a Z or a photon. However, these studies require the highest possible energy as well as substantial amount of integrated luminosity. The results available so far, which include only the semileptonic WW decays after the 172 GeV run, only improve marginally on the limits obtained previously at the Tevatron.

3. Higgs search

The main production process for the Standard Model Higgs at LEP2 is its production associated with an on-shell Z. The cross section goes down to a fraction of a picobarn once the Higgs mass reaches about $\sqrt{s} - 100$ GeV. This is, more or less, the discovery limit for a fixed center-of-mass energy. Since the LEP1 limit stands at about 65 GeV, it is clear that the 161 GeV

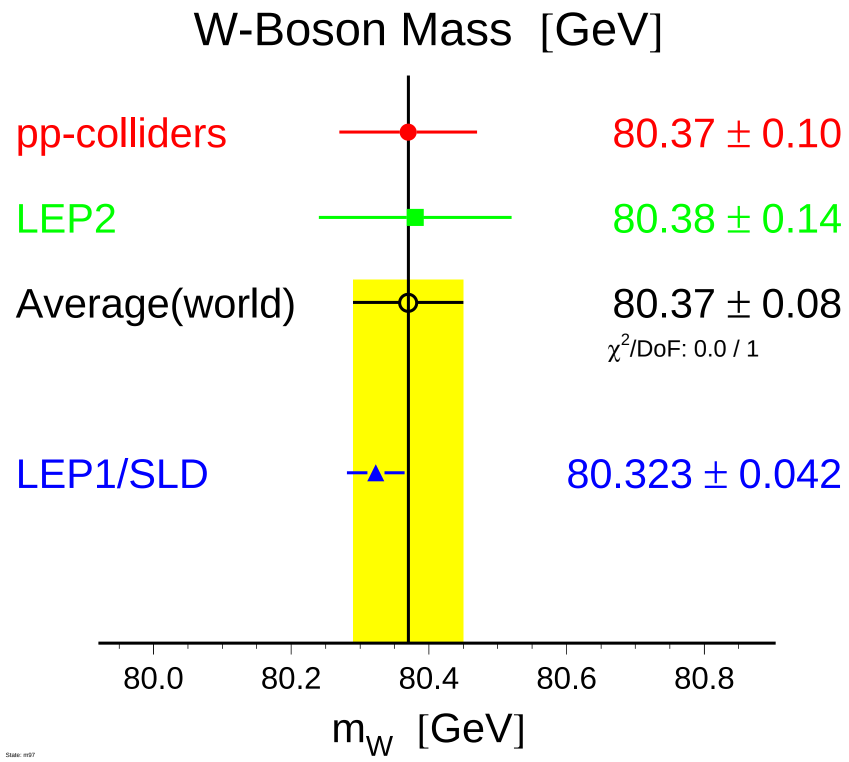


Figure 1. Comparison of the direct W mass measurements at the Tevatron and LEP2 and the indirect determination using LEP1 and SLD data.

run was not useful for Standard Model Higgs search, while the 172 GeV run started to extend the search region.

The main decay channel for a Higgs boson with mass around 70 GeV is to a pair of b quarks. Therefore, according to the Z branching ratios, the final state ZH will consist 70% of the times of four jets, two of them bs; 20% of the times of two b jets and missing energy; and 10% of the times of two b jets and two charged leptons. The four-jet channel is both the most aboundant and the most difficult to separate from the background. Good b-tagging capabilities are mandatory and all the LEP experiments have invested recently in new and more powerful silicon vertex detectors. Typical efficiencies in the four-jet channel are around 30% with very low background contamination. No experiment has found any evidence for an excess in any of the channels that have been searched. Typical 95%

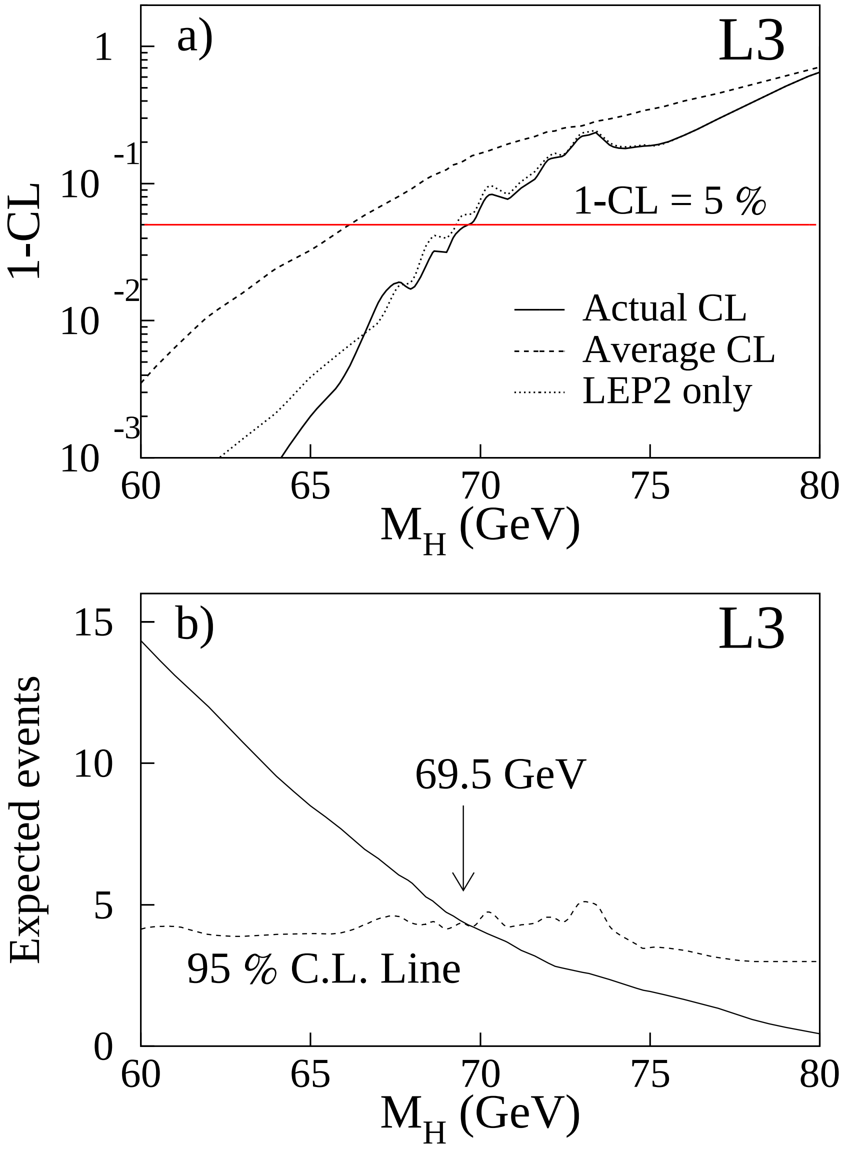


Figure 2. a) Exclusion confidence level as a function of the Higgs mass for L3. b) Expected number of Standard Model Higgs events in L3 as a function of the Higgs mass. The arrow points at the mass excluded at the 95% confidence limit.

confidence level limits on the mass of the Standard Model Higgs boson stand at around 70–71 GeV [5]. Figure 2 shows the number of Higgs bosons expected by L3 as a function of M_H, and the limit taking into account the observed candidates (compatible with background expectations).

In all Supersymmetry models at least two Higgs doublets appear, giving rise to five physical states: two charged Higgses, two neutral CP-even Higges (h, H) and a neutral CP-odd Higgs (A). In most SUSY theories there is an upper limit to the mass of the lightest CP-even neutral Higgs, h, which is around 150 GeV [6]. Furthermore, in many models, its mass is below 100 GeV, suitable for its search at LEP2.

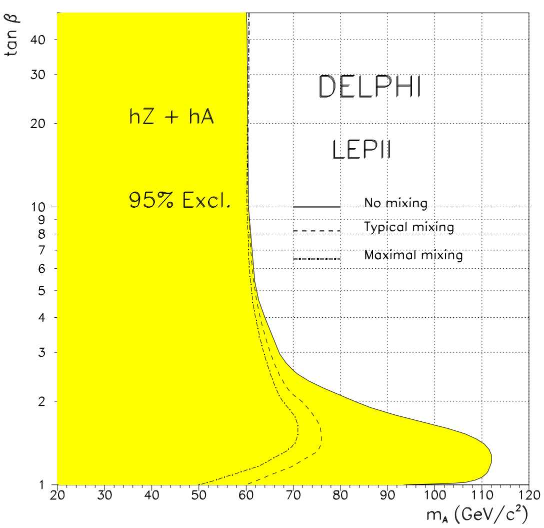
The lightest CP-even Higgs can be produced in association with a Z, in a process very similar to its Standard Model counterpart, or in association with the CP-odd state, A. Both processes are complementary, in the sense that in the regions of the SUSY parameter space in which one cross section is small the other is large and viceversa, so that the overall rate of h production remains sizable in all regions with $M_h, M_A < 60 - 65$ GeV.

Since all neutral Higgses decay predominantly to b jets, the channel hA involves identifying a four-jet event with four bs in the final state. As in the case of the Standard Model Higgs, no excess has been found [5] in any channel. Absolute 95% confidence level mass limits on both h and A have been set at about 62.5 GeV for all values of $\tan\beta \leq 1$, where $\tan\beta$ is the ratio of the vacuum expectation value of the Higgs doublet that gives mass to up-type particles to that of the doublet that gives mass to down-type particles. Figure 3 shows the region in the plane $M_A - \tan\beta$ excluded by the DELPHI collaboration.

4. Supersymmetry searches

Supersymmetry models not only predict more fundamental scalars. They predict for every particle in the Standard Model another particle with spin differing by ±1/2, the supersymmetric partner. The partners of the charged Higgses and Ws are generally called charginos, while the partners of the neutral Higgses and neutral electroweak vector bosons are known as neutralinos. Charginos and neutralinos are expected to be the lightest SUSY particles. In particular, the lightest neutralino, χ, is supposed to be the lightest supersymmetric particle (LSP) in most models with gravity-mediated SUSY breaking.

Searches have been performed for chargino pairs $(\chi^+\chi^-)$, neutralino pairs $(\chi\chi')$, where χ' is the second lightest neutralino, scalar-lepton pairs $(\tilde{l}^+\tilde{l}^-)$, scalar-top pairs $(\tilde{t}_1\bar{\tilde{t}}_1)$, etc. If R-parity is conserved, then the LSP, assumed to be χ, is stable and does not interact in the detector, so that



1

Figure 3. Regions of the M_A–$\tan\beta$ region excluded by the DELPHI collaboration under several assumptions.

the main experimental signature for the production of SUSY particles is the presence of large missing energy in the event.

Several topologies involving jets and/or leptons and missing energy have been searched for by the four collaborations with negative results. Therefore, limits on the masses of the SUSY particles have been put. The cross sections used to derive the limits on the masses and the masses themselves depend on many of the parameteres of the SUSY models, making difficult the task of giving absolute limits.

In most models, one can set a limit on the mass of the lightest chargino close to the kinematical limit, about 85 GeV. If, however, the scalar neutrino mass is light (below 100 GeV), the limit degrades because the cross section for chargino production decreases, due to the diagram with a t-channel scalar neutrino exchange. The mass limit for the lightest neutralino is only about 24 GeV, assuming heavy scalar leptons. The result of the combined searches for charginos and neutralinos is customarily displayed as excluded areas in the $M_2 - \mu$ plot, where M_2 and μ are gauge- and Higgs-mass parameters appearing in the SUSY lagrangian. One such plot, showing the regions excluded by ALEPH, can be seen in fig. 4.

Limits for scalar partners of leptons from 53 GeV (for $\tilde{\tau}$) to 75 GeV (for $\tilde{e}$) have been put. Assuming that the lightest scalar top decays 100% of the times to $c\chi$, the limit on its mass is about 65 GeV for the value of the stop mixing angle which results in the smallest cross section. For some other values, the limit goes up to 73 GeV, as can be seen in fig. 5 from OPAL [7]. More details on all these limits can be found, for instance, in ref. [9].

In models in which supersymmetry is broken via gauge interactions, the gravitino (SUSY partner of the graviton) is the LSP. Then, if χ is the next-to-lightest SUSY particle, the production of a pair $\chi\chi$ can result in a final state $\gamma\gamma\tilde{G}\tilde{G}$, that is, two acoplanar photons plus missing energy, since the gravitinos stay undetected. Searches for these kind of events have been unsuccesful and limits on m_χ around 72 GeV have been set within some particular models [10].

5. Four-jet anomaly

In the autumn 1995 run at energies close to 130 GeV, the ALEPH collaboration reported an excess of four-jet events in which the sum of the two jet-pair invariant masses that differed the least was peaked at about 105 GeV, as shown in fig. 6 from ref. [1]. The excess was not confirmed by the other three LEP collaborations. Four-jet events have been studied by all LEP collaborations at both runs at 161 GeV and 172 GeV. While

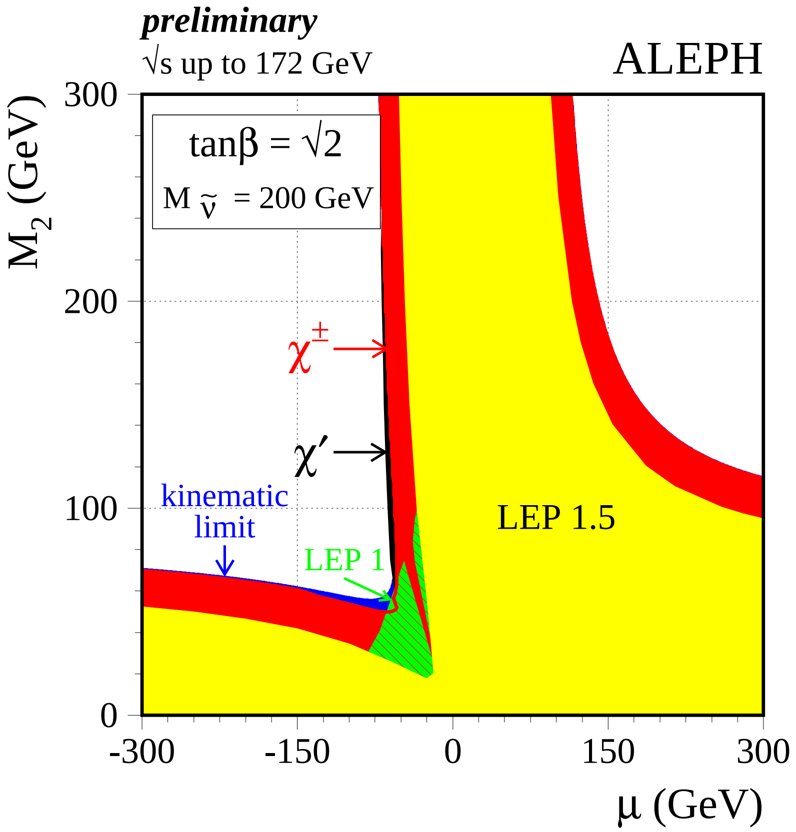


Figure 4. Regions of the M_2–μ region excluded by the ALEPH collaboration for $\tan\beta = \sqrt{2}$ and scalar neutrino mass of 200 GeV.

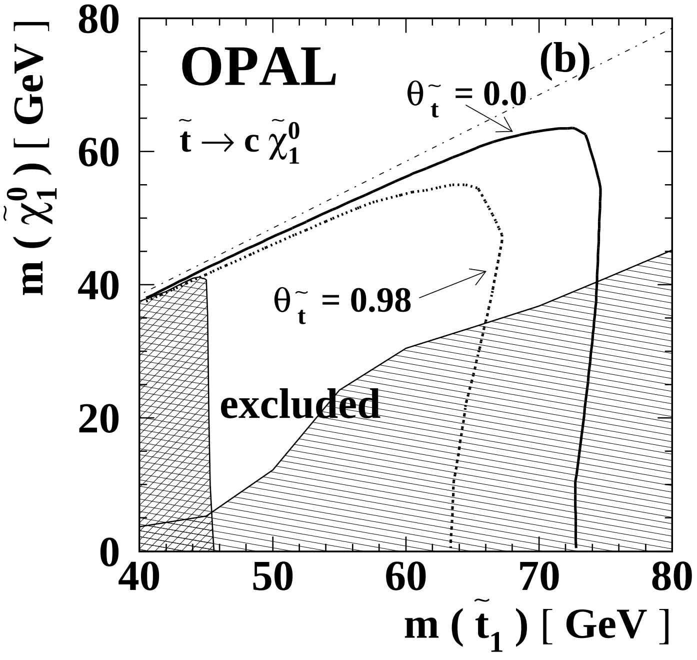


Figure 5. Regions in the $m_{\tilde{t}_1} - m_\chi$ plane excluded by OPAL [7] for several values of the stop mixing angle, assuming the decay goes as $\tilde{t}_1 \rightarrow c\chi$ 100% of the times. The cross-hatched area had already been excluded at LEP1, while the single-hatched area has been excluded by D0 [8].

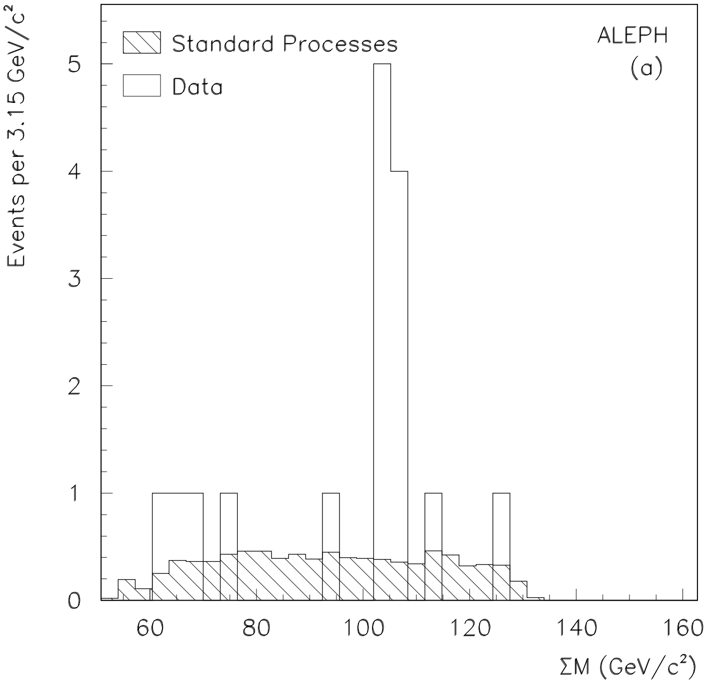


Figure 6. Distribution of the sum of the invariant masses of the two jet pairs with smallest invariant mass difference in four-jet events, from ALEPH at 130 GeV [1].

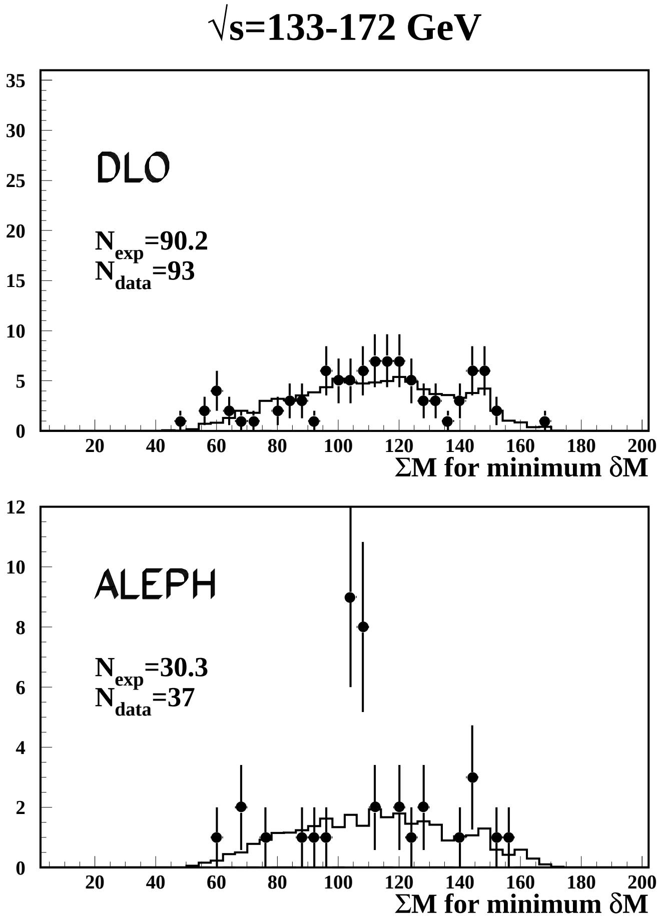


Figure 7. Distribution of the sum of the invariant masses of the two jet pairs with smallest invariant mass difference in four-jet events at 130, 161 and 172 GeV put together, from DELPHI, L3 and OPAL (top plot) and from ALEPH (bottom plot).

ALEPH seems to confirm their initial finding, although with lower significance, DELPHI, L3 and OPAL continue to see no deviation from the Standard Model expectations. A LEP-wide working group on the subject has concluded [11] that the four experiments are able to select and reconstruct four-jet events with similar efficiencies and mass resolutions. Figure 7 shows the combined results at all energies from 130 to 172 GeV for DLO (that is, DELPHI, L3 and OPAL combined) and for ALEPH. The discrepancy is clear.

The study concludes that the probability for the ALEPH observation to be due to a statistical fluctuation is about 7×10^{-4}, while the probability for both the ALEPH and the DLO observations to be compatible with a signal at 105 GeV is also about 7×10^{-4}! It is clear that, so far, the origin of the effect is not understood.

6. Constraints on possible explanations of HERA events

If the excess of high Q^2 events seen in H1 and ZEUS at HERA [2] is due to new physics affecting the coupling between quarks and electrons, there could be also effects in the process $e^+e^- \to q\bar{q}$, very well studied at LEP. The OPAL collaboration has investigated two scenarios [12], either with the presence of four-fermion contact iteractions between $e - e - q - q$, or with the exchange of a scalar particle in the t-channel of the reaction $e^+e^- \to q\bar{q}$.

By measuring the cross section for hadron production and, separately, the ratio of $b\bar{b}$ final states to all hadronic final states, both at 161 and at 172 GeV, OPAL has put limits on the mass scale appearing in the contact-term lagrangian between 1.0 and 2.5 TeV, depending on the type of interaction and on whether the interaction affects one up-type quark or one down-type quark. It should be noted that, in spite of the huge statistics accumulated at LEP1, this kind of search is more sensitive at LEP2 because at the Z peak the interference between the new amplitude (purely real) and the dominant Z amplitude (almost purely imaginary) almost vanishes and one is left with the purely new effect squared.

If a t-channel exchange of a scalar leptoquark or a scalar quark violating R-parity is assumed, some constraints on possible models explaining the HERA excess events can be obtained. The constraints will become truly severe once the 1997 data is analysed.

7. Summary

After analysing the data from the first year of LEP2, no deviation from the Standard Model predictions has been found:

- The direct measurement of the W mass agrees with the previous indirect determinations using LEP1/SLD data and assuming the Standard Model.
- Limits on Higgs and Supersymmetry particles have been greatly extended. For example, the Standard Model Higgs has to be heavier than 71 GeV, the SUSY Higgses h and A heavier than 62.5 GeV, and the lightest chargino heavier than 85 GeV in most of the SUSY parameter space.
- The four jet anomaly reported by ALEPH in 1995 remains a mistery, having been confirmed by ALEPH in 1996 but not seen by any of the other LEP experiments.
- Analysing the reaction $e^+e^- \to q\bar{q}$ the LEP experiments can start to get interesting constraints on models trying to explain the high Q^2 HERA events

Acknowledgments

It has been a great pleasure to attend this conference in such a nice setting and with such an attendance. I am most thankful to Prof. Klapdor-Kleingrothaus for his invitation to give this talk and to him and all his team for making the whole week so enjoyable. I would also like to thank Dr. Michael Schmitt for his help in the preparation of this talk.

References

[1] Buskulic D *et al* (ALEPH Collaboration) 1996 *Z. Phys.* **C71** 179

[2] Adloff C *et al* (H1 Collaboration) 1997 *Z. Phys.* **C74** 191
Breitweg J *et al* (ZEUS Collaboration) 1997 *Z. Phys.* **C74** 207

[3] Barate R *et al* (ALEPH Collaboration) 1997 *Phys. Lett.* **B401** 347
Abreu P *et al* (DELPHI Collaboration) 1997 *Phys. Lett.* **B397** 158
Acciarri M *et al* (L3 Collaboration) 1997 *Phys. Lett.* **B398** 223
Ackerstaff K *et al* (OPAL Collaboration) 1996 *Phys. Lett.* **B389** 416

[4] Abbaneo D *et al* (LEP Electroweak Working Group) *A Combination of Preliminary Electroweak Measurements and Constraints on the Standard Model*, LEPEWWG/97-01

[5] Barate R *et al* (ALEPH Collaboration) 1997 CERN-PPE/97-070
Acciarri M *et al* (L3 Collaboration) 1997 CERN-PPE/97-081

[6] Kane G L, Kolda C and Wells J D 1993 *Phys. Rev. Lett.* **70** 2686
Espinosa J R and Quiros M 1993 *Phys. Lett.* **B302** 51

[7] Ackerstaff K *et al* (OPAL Collaboration) 1997 CERN-PPE/97-046

[8] Abachi F *et al* (D0 Collaboration) 1996 *Phys. Rev. Lett.* **76** 2222

[9] Cerutti F (1997) to appear in *Proceedings of the SUSY 97 conference, Philadelphia*

[10] Lopez J and Nanopoulos D (1997) *Phys. Rev.* **D55** 4450

[11] Bizouard M A *et al* (LEP Working Group on Four Jets) *Report of the LEP Working Group on four-jet production in* e^+e^- *collisions at centre-of-mass energies of 130–172 GeV*, ALEPH 97-056 PHYSIC 97-050, DELPHI 97-57 PHYS 707, L3 note 2090, OPAL Technical Note TN 486

[12] Komamiya S LEPC presentation, CERN, February 25th 1997.