SEARCHES AT LEP2 WITH THE DELPHI DETECTOR

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Some sample result of the searches for new physics carried on in the DELPHI experiment at LEP is reviewed. The data refer to the high energy runs taken in 1995-96, in which DELPHI collected an integrated luminosity of about 26 pb^{-1} at centre-of-mass energies between 130 and 172 GeV.

1 Introduction

In spite of its great success in explaining the current experimental results, the Standard Model (SM) is not believed to be the ultimate theory of physics. Besides the fact that the Higgs boson, a fundamental brick of the construction, has not been discovered yet, SM features known as hierarchy and naturalness problems [1] prevent it to be extrapolated toward the high energy domain near the Planck scale.

Amongst the theories having the SM as a low energy approximation, there is a widespread interest in supersymmetry (SUSY) [2], in which the supposed symmetry between fermions and bosons requires that new (s)particles must exist mirroring the known particles. The non observation of SUSY particles having the same mass as their ordinary matter superpartners means that supersymmmetry is not an exact symmetry, but must be broken somehow at low energies.

Various SUSY models have been proposed. Here we will deal with searches in the framework of the Minimal Supersymmetric Standard Model (MSSM), with R-parity conservation, where $R = 1$ for ordinary particles and $R = -1$ for all sparticles. The relevant parameters of this model, besides the sfermion masses, are the masses M_1, M_2 and M_3 of the gaugino sector, the mass of the CP-odd Higgs scalar m_A, the Higgs mixing parameter μ, the ratio $\tan\beta$ of the two Higgs vacuum expectation values and the universal Yukawa coupling A.

From the conservation of R it follows that all sparticles must be pair produced and that the lightest supersymmetric particle (LSP) is stable. It is a common assumption that the LSP is neutral and only weakly interacting. Here, either the lightest neutralino or the gravitino will be taken into account as the possible LSP. M_1 and M_2 are usually assumed to satisfy the GUT relation $M_1 = \frac{5}{3}\tan^2\theta_W \cdot M_2 \simeq 1/2 \cdot M_2$, although this constraint is not fundamental and it will be released when needed.

The fit of the electroweak data prefers a mass of the (lightest) higgs not so far from the Z^0 mass [1], and a consistent solution of the naturalness problem suggests that some of the SUSY particles could be even lighter [3]. LEP2, the second phase of operations for the LEP collider in which the e^+e^- center-of-mass energy is pushed well above the Z^0 mass, is therefore an ideal place where to look for supersymmetry. In the following will be presented the searches for pair produced neutral higgses, charginos and neutralinos, among the many other SUSY searches actually going on within the DELPHI experiment.

Also compositeness [4] could be invoked to cure the problems of the SM. Excited leptons are a signal of compositeness and their search in DELPHI is shortly reported as well.

2 The experimental setup

A detailed description of the DELPHI detector and its performances can be found in [5]. A peculiarity of DELPHI with respect to the other LEP experiments is the use of RICH detectors to measure the velocity (and then to tag the mass) of the charged particles. In view of the phase 2 of LEP, some upgrade of the various subdetectors has been undertaken. Particularly interesting for the searches is the extended angular coverage of the vertex detector, which allows efficient reconstruction of secondary vertices down to polar angles of about 26^o. This can be seen in figure 1, which shows the efficiency of the b-tagging algorithm for a fixed purity of 70% in Z^0 decays, as a function of the polar angle, for the 'old' and the 'new' μVTX configuration. A still better coverage is expected with the Very Forward Silicon Tracker, whose upgrade

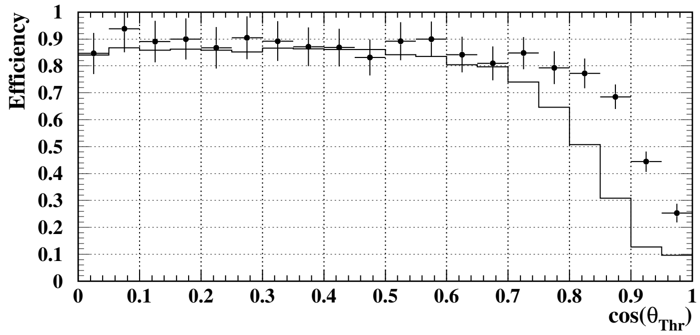

Figure 1: The efficiency versus the polar angle of the thrust axis for $b\bar{b}$ events with the new microvertex detector (points) and the previous shorter one (full line). The purity is fixed at 70% in a sample of Z^0 decays.

was completed in 1997; it consists of ministrip and pixel detectors and reaches polar angles down to 10^o. Also fundamental for the searches are the hermeticity lead-scintillator counters positioned in the calorimetric holes of DELPHI: now the detection efficiency for photons of energy above 5 GeV not emitted in the beam pipe is around 99%.

In 1995 and 1996 DELPHI collected integrated luminosities of about 6, 10 and 10 pb^{-1} at centre-of-mass energies of 130/140, 161 and 172 GeV respectively. Analyses are going on: all the following results, except for the heavy stable charged particle and excited leptons searches, are still preliminary.

3 Searches at LEP2

3.1 Search for neutral Higgses in the channel $e^+e^- \to hA \to 4$ jets

The Standard Model Higgs boson is produced at LEP2 through the Higgs-strahlung process $e^+e^- \to Zh$, with a cross-section which is of the order of a pb, when kinematically admitted. In models with two Higgs doublets, like SUSY, that process and the associated pair production $e^+e^- \to Ah$ are complementary, with an overall cross-section similar to the SM one.

Higgs particles are characterized by their decay, predominantly into a $b\bar{b}$ pair, with a smaller but still sensitive branching into $\tau^+\tau^-$. In the MSSM, for small $\tan\beta$ and $M(\tilde{\chi}^0) < M(h, A)$, the Higgs decays into a pair of neutralinos with probability close to 1. All these production and decay modes are being searched for in DELPHI [6].

Here only the results for the hA production with both Higgses decaying into a $b\bar{b}$ pair will be presented. The hA cross-section is maximal at high $\tan\beta$, where the two Higgses are almost degenerate in mass. Energy flow measurement and b-tagging are essential tools for this analysis [5].

The branching ratio $hA \to 4$ jets is around 85% in MSSM. First hadronic events with no missing energy and at least four jets, according to the JADE algorithm with $y_{cut} = 0.004$, are selected. Configurations with soft and/or collinear jets are rejected by requiring that the product of the dijet energies and their opening angle be above 10 GeV $\times$ rad. After a kinematical fit, aimed to reject $Z\gamma$ and badly reconstructed events, the sum of the masses of the two jets, for the dijet combination with the smallest mass difference, is plotted in figure 2 for the data taken at 161 and 172 GeV: no mass accumulation is visible above the standard background. After a tight b-tag no event at high mass ($m_h + m_A > 80$ GeV/c^2) survives in the data at any of the LEP2 centre-of-mass energies, whilst 0.6 and 1.2 are expected from standard processes at 161 and 172 GeV. The selection efficiencies depend on the Higgs masses and

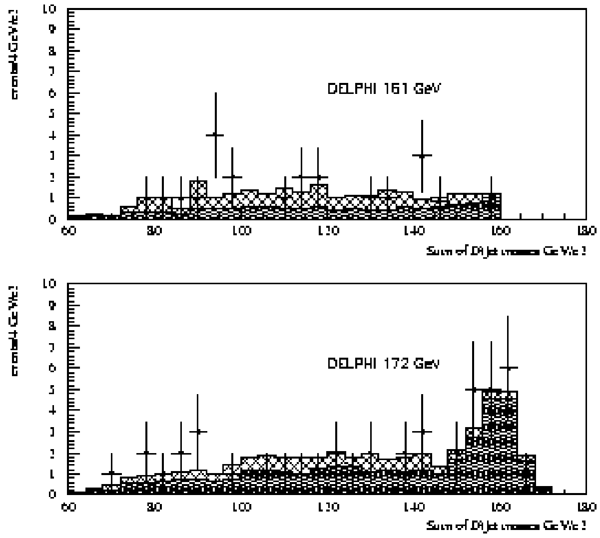

Figure 2: Distribution of the sum of the dijet masses after the four jet selection but before the b-tag; the jets are paired so that the difference between the dijet masses is minimal. Points are data, dark cross-hatched histogram stands for the WW contribution and the light one is the remaining $q\bar{q}\gamma$ background.

stay around 40% at all the centre-of-mass energies.

With these results, the exclusion plot in the plane $\tan\beta$ vs m_A is shown in figure 3, where the improvement obtained by adding the data at 172 GeV is pointed out. The region at low $\tan\beta$ will be covered by the search in the hZ channel.

3.2 Search for charginos

The production of the lightest chargino at LEP proceeds through $e^+e^- \to \tilde{\chi}_1^+\tilde{\chi}_1^-$. The physical chargino is the result of the superposition of the two interaction eigenstates, the wino and the charged higgsino. The cross-section for the wino depends on the mass $m_{\tilde{\nu}}$ of the sneutrino, which is exchanged in the t-channel and has a destructive interference with the s-channel production. $\tilde{\chi}_1^+$ decays into $l^+\nu_l\tilde{\chi}_1^0$ or into $q\bar{q}'\tilde{\chi}_1^0$. The experimental signatures are acollinear leptons and/or jets together with missing energy and momentum [7,8]. In the models where the gravitino is the LSP, the lightest neutralino further decays as $\tilde{\chi}_1^0 \to \tilde{G}\gamma$ and the experimental signatures described above are accompanied

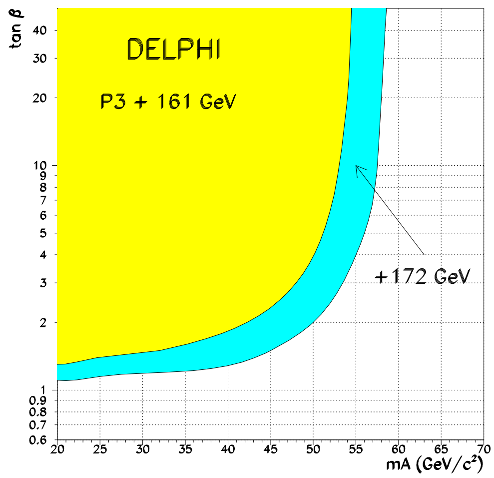

Figure 3: Regions in the (m_A , $\tan\beta$) plane excluded at 95% CL by the $hA \to b\bar{b}b\bar{b}$ search.

Table 1: Experimental results of the search for charginos when the $\tilde{\chi}^0_1$ is stable.

	$5 < \Delta M < 10$ GeV/c^2		$\Delta M > 10$ GeV/c^2	
$\sqrt{s}$ (GeV)	Data	Tot. bckg	Data	Tot. bckg
130/136	0	$0.35 \pm .04$	1	$1.05 \pm .10$
161	0	$1.51 \pm .13$	2	$2.36 \pm .31$
172	1	$0.87 \pm .08$	1	$2.4 \pm .6$

by one or two hard and isolated photons.

The search strategies and their efficiencies depend on the difference ΔM between the mass of the chargino and that of the neutralino. In DELPHI two different analyses are tailored for $\Delta M > 10$ GeV/c^2 and for $3 < \Delta M < 10$ GeV/c^2 and their combined efficiency is shown in figure 4 as a function of ΔM; they refer to the neutralino as LSP.

The results for the two selections are shown in table 1 for the stable $\tilde{\chi}^0_1$ case. In the case in which the gravitino is the LSP, no candidates remain in all data samples, while 0.7 SM background events are expected overall.

The non evidence of eccesses above the SM expectations leads to lower limits at the 95% CL on the mass of the chargino which runs from 84.5 GeV/c^2 (when $m_{\tilde{\nu}}$ is above 300 GeV/c^2) to 71.3 GeV/c^2 (for any $m_{\tilde{\nu}}$) for large ΔM;

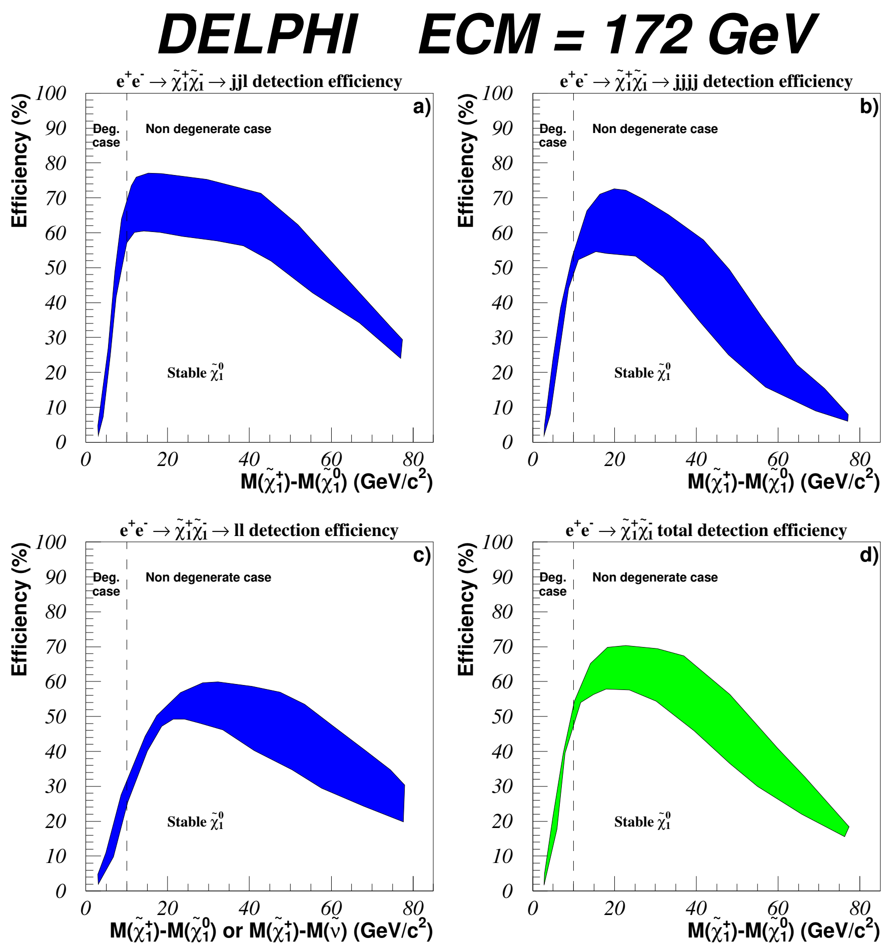

Figure 4: Efficiencies for chargino detection as a function of ΔM. The first three plots show separately the efficiencies for all the possible visible final states; in the fourth the branching ratios of the W are assumed.

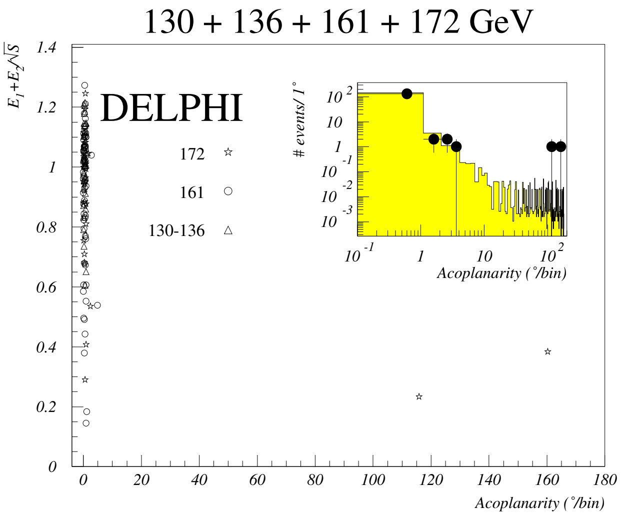

Figure 5: Total energy, normalized to the centre-of-mass energy, versus the acoplanarity in events with two visible photons and nothing else. The window shows the projection of the acoplanarity distribution in the data, compared with the $e^+e^- \to \gamma\gamma(\gamma)$ and $e^+e^- \to \nu\bar{\nu}\gamma\gamma$ backgrounds.

to 80.0 GeV/c^2 (for $\Delta M = 5$ GeV/c^2); to 52.4 GeV/c^2 (for $\Delta M = 3$ GeV/c^2). Higher lower limits are derived when the gravitino is the LSP.

3.3 Search for neutralinos

The most promising neutralino production process at LEP2 is $e^+e^- \to \tilde{\chi}_1^0\tilde{\chi}_2^0$, where the next to lightest neutralino decays into a $\tilde{\chi}_1^0$ plus a particle-antiparticle pair. The signature is similar to the one of the chargino, but not the same, because here the visible objects come from the decay of the same particle. The selection criteria used in the search for charginos have to be slightly modified and optimized for the search for the neutralino [9,8].

If the lightest neutralino is unstable and decays into $\tilde{G}\gamma$, different searching strategies can be applied. The chain $e^+e^- \to \tilde{\chi}_1^0\tilde{\chi}_1^0 \to \tilde{G}\gamma\tilde{G}\gamma$ would appear as an eccess of pairs of photons with missing quantities. Two strategies apply for heavy and light $\tilde{\chi}_1^0$. In the first case the two photons tend to be acollinear and acoplanar. Figure 5 shows the sum of the two energies versus the acoplanarity for all photon pairs detected in DELPHI during all runs at high energy. Two events with large acoplanarity have been selected at 172 GeV, where the $\nu\bar{\nu}\gamma\gamma$ background is expected to contribute for a fraction of an event: off course, the statistical significance of such an eccess is still limited. In case of light neutralino, the two photons tend to be collinear and the excess has been searched for (and not found) in events with two collinear photons and missing energy.

The $\tilde{\chi}_1^0\tilde{G}\gamma$ vertex responsible for the neutralino decay permits also $e^+e^- \to \tilde{G}\tilde{\chi}_1^0 \to \tilde{G}\tilde{G}\gamma$ events. The consistency of the number of single photon events detected in DELPHI with the SM expectations leads to 95% upper limits on the above cross section of the order of 1 pb, once combined all runs at high energy, for $\tilde{\chi}_1^0$ mass below 80 GeV/c^2.

3.4 Search for heavy stable charged particles

Heavy charged particles decaying outside the tracking devices can be recognized in DELPHI by the anomalously high amount of specific ionization released in the TPC and by the absence of the Čerenkov light cone in the gaseous and liquid radiator of the barrel RICH. Events of that kind have been searched for in 130/136, 161 and 172 GeV data [10], without any limitation on the particle multiplicity of the event. No candidates survive the selection, whilst a couple of background events could be expected, mainly due to the coincidence of spurious hits in the two RICH radiators.

Possible interpretations in the MSSM of events with long-lived heavy charged particles are:

- $\tilde{\chi}_1^+$ highly mass-degenerate with the $\tilde{\chi}_1^0$ (LSP). This happens preferably when the GUT relation $M_1 \simeq 1/2M_2$ is released. Chargino masses below 84 (for large $m_{\tilde{\nu}}$) or 80 (for any $m_{\tilde{\nu}}$) GeV/c^2 can be excluded after this search, provided $\Delta M \leq 100$ MeV/c^2.

- If the $\tilde{G}$ is the LSP, scalar leptons can acquire a long enough decay length, depending on the slepton and on the gravitino mass. Masses between 45 GeV/c^2 and 68 (65) GeV/c^2 can be excluded for left-handed (right-handed) smuons and staus.

3.5 Search for excited charged and neutral leptons

Excited leptons can be single or pair produced in e^+e^- interactions. They promptly decay to their ground state by radiating a γ, Z^0 or W. Many final state topologies have been searched for in DELPHI [11]: $\gamma\gamma\nu\nu$, $ll\nu\nu$, $ll\gamma$, $ll\gamma\gamma$, $llll$, $l\nu jj$, $lljj$, $ll\nu jj$ and $l\nu\nu\nu jj$. Data from the runs at 130/136 and 161 GeV have been analyzed, without finding any evidence of excesses above the

Table 2: Upper limits (in GeV/c^2) at the 95% CL on the masses of the excited leptons for both left and right-handed (only left-handed) components. f and f' are the ratios of the $SU(2)$ and $U(1)$ couplings for excited and standard leptons.

	$f = f'$		$f = -f'$	
e^*	79.6	(77.9)	70.9	(44.6)
μ^*	79.6	(78.4)	70.9	(44.6)
τ^*	79.4	(77.4)	70.9	(44.6)
ν^*	56.4	(44.9)	77.6	(64.4)

SM expectations. This leads to the limits on the mass of the excited leptons reported in table 2.

4 Conclusions

The 1995-96 LEP runs at high energy where very successfull. DELPHI collected an integrated overall luminosity of about 26 pb^{-1} that was used in the search for new physics in several channels, mainly in the MSSM framework. No excess has been found above the SM expectations in any of the channels explored: the data could then be used to set constraints on the possible new physics parameters and new particles masses.

In 1997 LEP is expected to increase the centre-of-mass energy up to 184 GeV, thus enlarging the window for the production of massive new particles. The aim is to provide, after the start of the physics runs foreseen for mid june, an integrated luminosity of about 100 pb^{-1} per experiment, that is four time what has been collected so far. In that case the experiments will be more sensitive also to low efficiency or low cross section processes.

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