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HINTS FOR NEW PHYSICS AT COLLIDERS

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Abstract

Searches for new physics at LEP, FERMILAB and HERA are presented. In particular the limits on the Higgs (standard model and supersymmetric) and on supersymmetry ("standard" and "non-standard") with R-parity conservation are reviewed. The results on supersymmetry with R-parity violation and the search for leptoquarks are summarised.

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1 Introduction

The results presented in this review are based on the data recorded until the end of 1996 at LEP, CERN's large e^+e^- collider, at the TEVATRON, Fermilab's $p\bar{p}$ collider, and HERA, DESY's ep collider. ALEPH, DELPHI, L3 and OPAL have recorded each about 6 pb^{-1} at centre-of-mass energies of 130 GeV and 136 GeV, referred to as LEP1.5 hereafter, 11 pb^{-1} and 10 pb^{-1} at centre-of-mass energies beyond the W pair production threshold at 161 GeV and 172 GeV, called LEP2 hereafter. CDF and D0 each have recorded about 120 pb^{-1} at the TEVATRON at $\sqrt{s} = 1.8$ TeV. At HERA the experiments H1 and ZEUS have recorded in total 37 pb^{-1} in ep collisions at $\sqrt{s} = 300$ GeV.

The results of the search for the Higgs boson(s) will be described first. The non-minimal Higgs sector leads naturally to a discussion of supersymmetric extensions of the standard model. Results on "standard" and "non-standard" supersymmetry with R-parity conservation will be presented. Supersymmetry with R-parity violation and the search for leptoquarks are discussed in parallel afterwards.

In the following all limits will be reported at 95% C.L., unless explicitly stated otherwise. References to theoretical papers are restricted to review articles. Experimental results without an explicit reference were given to the conference as private communications.

2 Higgs Bosons

2.1 Standard Model Higgs Boson

In the minimal standard model masses are generated by the introduction of a complex scalar doublet via the Higgs-Kibble mechanism. Three degrees of freedom are absorbed by the massive $W^\pm$ and Z bosons. The remaining degree of freedom is the Higgs boson,[1] whose mass cannot be predicted.

At LEP the standard model Higgs boson is predominantly produced in the bremsstrahlung process. The ultimate limit derived from the negative searches at LEP1, i.e., at energies at and around the Z resonance, combined for the four experiments at Warsaw, was 66 GeV/c^2.[2]

The following final states are searched for, classified according to the Z boson decay: H(Z$\rightarrow \nu\bar{\nu}$) with a branching ratio of $\mathcal{B} = 20\%$, H(Z$\rightarrow \ell^+\ell^-$) with $\mathcal{B} = 6.7\%$, H(Z$\rightarrow \tau^+\tau^-$) with $\mathcal{B} = 3.4\%$, H(Z$\rightarrow q\bar{q}$) with $\mathcal{B} = 69.9\%$. The dominant decay mode of the Higgs boson in the LEP reach is the $b\bar{b}$ decay ($\mathcal{B} = 85\%$), followed by the decay to $\tau^+\tau^-$ with $\mathcal{B} = 8\%$ (for a Higgs boson mass of 70 GeV/c^2). Since the final states H($\rightarrow \tau^+\tau^-$)$q\bar{q}$ and H($\rightarrow q\bar{q}$)$\tau^+\tau^-$ exhibit a similar topology, they are usually treated jointly.

The H$q\bar{q}$ channel was not used at LEP1 due to the overwhelming background from $q\bar{q}$ production, the dominant background for this analysis. The $q\bar{q}$ production cross section is reduced from about 30 nb ($\sqrt{s} = 91$ GeV) to 0.15 nb at 161 GeV. Therefore it is now possible, in combination with powerful b-tagging, to include this final state in the analyses for the first time. Typical efficiencies and backgrounds are shown in

Table 1: Efficiencies and background for the standard model Higgs search at $\sqrt{s} = 172$ GeV.

	$H\nu\bar{\nu}$	$H\ell^+\ell^-$	$H\tau^+\tau^-$	$H(\not{\tau}^+\tau^-)q\bar{q}$	$\tau^+\tau^-q\bar{q}$
ϵ	43%	75%	20%	22%	17.4%
BG	0.09	0.11	0.02	0.23	0.03

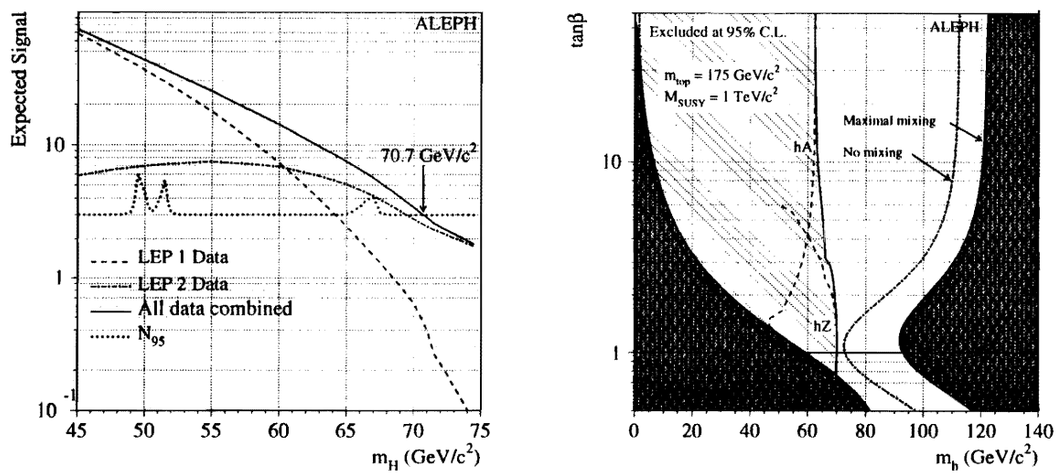


Figure 1: Left: Limit on the standard model Higgs boson mass (70.7 GeV/c^2) from ALEPH. Right: Excluded region in the ($\tan\beta$,m_h) plane in the MSSM from ALEPH.

Table 1.[3] The highest efficiency with a very low background is obtained, when the Z decays to $\ell^+\ell^-$, suffering however from the low branching ratio of the Z to $\ell^+\ell^-$. The Z boson, in contrast to LEP1, is on-shell at LEP2, which is used as a constraint in the analyses.

Although candidate events were observed by the collaborations, the total number and their distribution agreed with the expectation from the standard model background. In the absence of a signal, lower mass limits of 70.7 GeV/c^2, 66.2 GeV/c^2, 69.5 GeV/c^2 and 69.4 GeV/c^2 for ALEPH,[3] DELPHI,[4] L3[5] and OPAL[6] respectively were reported. The number of expected signal events as a function of the Higgs boson mass is shown in Figure 1 (Left) by ALEPH. Without the LEP1 data sample, the lower mass limit would be weaker by about 1 GeV/c^2. The combined sensitivity of all experiments is expected to be about 77 GeV/c^2.

2.2 Neutral Higgs Bosons in the MSSM

The introduction of a second complex scalar doublet in the minimal supersymmetric extension of the standard model (MSSM), which is necessary to give masses to up and down type particles, leads to an enlarged particle spectrum consisting of two CP-even neutral Higgs bosons (h, H), one CP-odd neutral Higgs boson (A) and the charged Higgs ($H^\pm$) bosons. In a general two-doublet model, there are six param-

eters, the particle masses (m_h, m_H, m_A, $m_{H^\pm}$), the ratio of the vacuum expectation values of the two Higgs doublets ($\tan\beta$) and the mixing angle in the CP-even sector (α). Supersymmetry introduces relationships among the parameters, so that only two independent parameters remain, which are usually chosen to be $\tan\beta$ and m_h.

The Higgs boson h is produced in the bremsstrahlung process as is the standard model Higgs boson, but with a cross section reduced by $\sin^2(\beta-\alpha)$. The reduction of the cross section can be compensated by an additional process, the associated production of h and A, if kinematically accessible, since here the cross section is proportional to $\cos^2(\beta-\alpha)$.

The associated production leads to final states $b\bar{b}b\bar{b}$ with a branching ratio of $\mathcal{B}$ = 84% and $\tau^+\tau^-b\bar{b}$ with $\mathcal{B}$ = 14% for m_h= 60 GeV/c^2 and $\tan\beta$= 10. The efficiencies are of the order 55% and 45% respectively with about one event expected from the standard model background.[7] The excluded region in the plane (m_h,$\tan\beta$) is shown in Figure 1 (Right) from ALEPH.[7] The limit is mainly due to the associated production for large $\tan\beta$, while for small $\tan\beta$ the limit is essentially equal to the limit from the bremsstrahlung process alone. Shown also is the impact of stop (the supersymmetric partner of the top quark) mixing, entering via radiative corrections, on the theoretically allowed region for two extreme scenarios: no mixing and maximal mixing. A neutral Higgs boson of mass less than 62.5 GeV/c^2 is excluded, independent of theoretical assumptions.

2.3 Charged Higgs Bosons

In the MSSM the charged Higgs boson is expected to be heavier than the W boson. However, in a non-minimal standard model containing two Higgs doublets, no such lower boundary exists.

A limit on the charged Higgs boson mass can be determined via the measurement of the branching ratio $b \to s\gamma$,[8] leading to excluded masses of 250 GeV/c^2 and more.[9] The limit is not valid in general in the MSSM.

The direct search for the $H^\pm$ is performed at the TEVATRON and at LEP. CDF searches for the tau decay of the charged Higgs boson via the decay of the top quark. As the branching ratio to tau is large for large $\tan\beta$, a Higgs mass of up to 160 GeV/c^2 is excluded for $\tan\beta$ of the order of 100.[10] For small $\tan\beta$ the branching ratio of the top quark to $H^\pm$ is large and the subsequent decay is predominantly to cs ($c\bar{s}$ and $s\bar{c}$). The charged Higgs boson can be detected by a suppression of the leptonic branching ratio of the top quark, which, in the absence of the charged Higgs boson, is expected to be equal to that of the W boson. The excluded region is shown in Figure 2 (Left).

The search for the charged Higgs boson at LEP is designed to be independent of the decay modes. DELPHI[4] and ALEPH searched for the three final states of Higgs boson pair production, the four jet final state, the mixed final state $\tau\nu$cs and $\tau\nu\tau\nu$. A lower mass limit of 52 GeV/c^2, shown in Figure 2 (Right), was achieved, independent of the branching ratio.

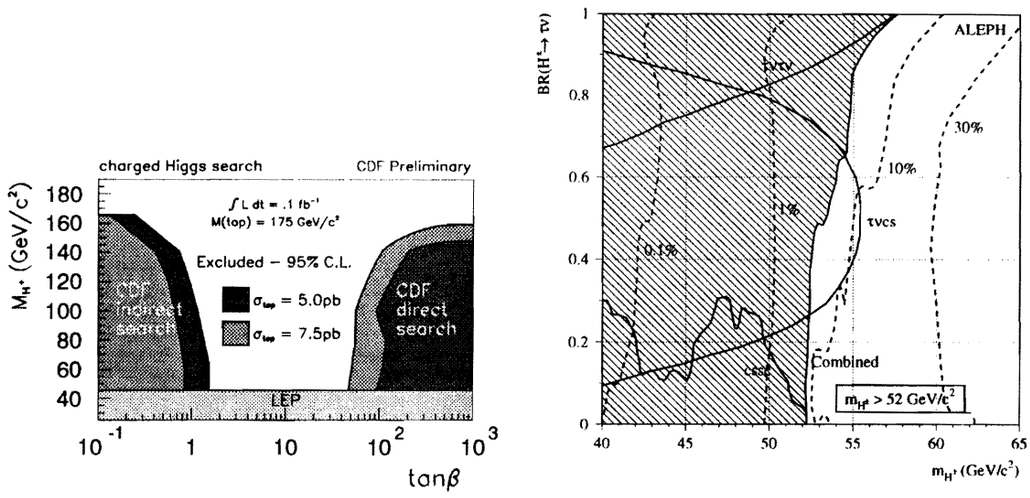


Figure 2: Limit on the charged Higgs boson mass, Left: from CDF as a function of tan β. Right: from ALEPH as a function of the branching ratio to $\tau\nu$

2.4 *The Four-Jet Events*

ALEPH reported a peak in the dijet mass sum distribution in an analysis of the four-jet final state at LEP1.5. [11] This excess was not confirmed by the other three experiments. [12,13,14] Including the data from LEP2, ALEPH still sees an excess centred at 105 GeV/c^2. DELPHI, L3 and OPAL confirmed their non-observation of any deviation from the standard model background expectation.

The discrepancy was studied extensively by a LEP working group. [15] The studies included treating ALEPH's events as Monte Carlo input and passing them through the detector simulation of the four experiments. Since all experiments observe a peak after this procedure, one has to conclude that, if these events had been present in the data samples of DELPHI, L3 and OPAL, they would have been observed. The probability to observe a fluctuation as large as the ALEPH data for any one of the four experiments was determined to be $7 \cdot 10^{-4}$. The probability that ALEPH and DELPHI, L3, OPAL are simultaneously compatible with a signal is $7 \cdot 10^{-4}$. The working group concluded: The origin has not been identified.

3 Supersymmetry

The main phenomenological consequence of a supersymmetric theory is the doubling of the particle spectrum. Each bosonic degree of freedom receives a fermionic partner and vice versa. The particle content of the MSSM [16] is summarised in Table 2. The partners of the neutral gauge and Higgs bosons mix to form the mass eigenstates called neutralinos ($\chi,\chi',\chi'',\chi'''$), the charged gauge and Higgs bosons mix to form the mass eigenstates called charginos ($\chi^{\pm},\chi_2^{\pm}$).

Exact supersymmetry implies the degeneracy of the masses of supersymmetric par-

Table 2: The (s)particle content of the MSSM

spin–0	spin–1/2	spin–1
$\tilde{q}_R$, $\tilde{q}_L$	q	
	$\tilde{g}$	g
$\tilde{\ell}_R$, $\tilde{\ell}_L$	ℓ	
	$\tilde{\gamma}$	γ
H	$\tilde{H}$, $\tilde{Z}$	Z
h A	$\tilde{h}$	
$H^\pm$	$\tilde{H}^\pm$, $\tilde{W}^\pm$	$W^\pm$

ticles and their standard model partners. In the absence of a discovery so far, supersymmetry must be a broken symmetry. The commonly used technique is the introduction of soft supersymmetry breaking parameters.

The MSSM then contains the following parameters: M_1, M_2 and M_3, the soft supersymmetry breaking parameters associated with the U(1), SU(2) and SU(3) groups. These are reduced to one single parameter by invoking the GUT relationship: $M_1 = \frac{5}{3}\tan^2\theta_W M_2 = \frac{5}{3}\frac{\alpha}{\alpha_s \cos^2\theta_W} M_3$. The sfermion sector can be simplified, motivated by minimal supergravity scenarios, by using only one common m_0 at the GUT scale to break the degeneracy of fermion and sfermion masses. A_f are the trilinear couplings, where usually only A_t is considered to be important. μ is the supersymmetric Higgs mass parameter and $\tan\beta$ is the ratio of the vacuum expectation values of the two Higgs doublets. The region, where $|\mu| \ll M_2$ is called the Higgsino region and $M_2 \ll |\mu|$ is called the gaugino region, referring to the dominant field content of the lightest neutralino and chargino.

R-parity, a new multiplicative quantum number, distinguishes ordinary from supersymmetric particles. R-parity will be assumed to be conserved for the following. As a consequence, supersymmetric particles must be produced in pairs. They (cascade) decay to the lightest supersymmetric particle (LSP), which is stable. Motivated by cosmology, the LSP is to be neutral. This leaves as candidates the neutralino, the gravitino or a sneutrino. The lightest neutralino will be used as the LSP in the following, unless explicitly stated otherwise.

3.1 Search for "standard" Supersymmetry

Charginos are produced in pairs at LEP via the s channel (γ,Z) and the t channel ($\tilde{\nu}_e$) exchange. When the $\tilde{\nu}_e$ is light, destructive interference reduces the production cross section. For heavy $\tilde{\nu}_e$ the typical cross section is several picobarn. Neutralinos are produced in association ($\chi\chi'$) via s channel (Z) and t channel ($\tilde{e}$) exchange. The interference is constructive when the $\tilde{e}$ is light.

The decay proceeds either via a virtual $W^\pm$ (Z) for charginos (neutralinos) or via a sfermion propagator. This leads to the following topologies for charginos: hadronic $q\bar{q}'\chi q\bar{q}'\chi$, semileptonic $q\bar{q}'\chi\ell^+\nu\chi$, leptonic $\ell^-\bar{\nu}\chi\ell^+\nu\chi$, and neutralinos: hadronic $q\bar{q}\chi\chi$, leptonic $\ell^+\ell^-\chi\chi$. The common signature of all final states is missing energy due to

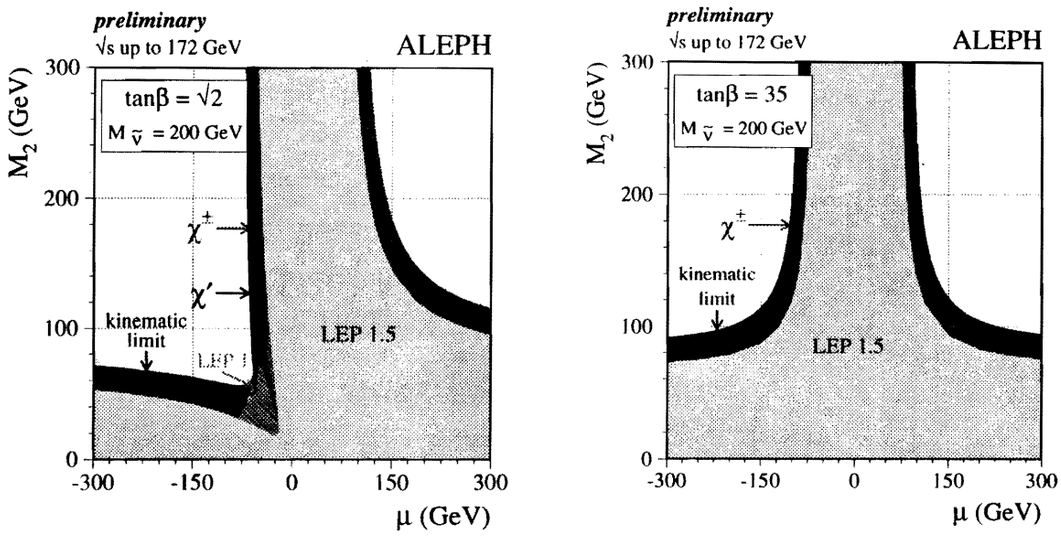


Figure 3: Limits in the (μ/M_2) plane for $\tan\beta = \sqrt{2}$ (Left) and $\tan\beta = 35$ (Right) for a $\tilde{\nu}_e$ mass of 200 GeV/c^2 from ALEPH

the undetected LSP. Since the decays of charginos and neutralinos can also proceed via a virtual sfermion, a scenario with light sleptons but heavy squarks increases the leptonic branching ratios.

Efficiency and background depend, in first approximation, only on the mass difference between the mother particle and the LSP. For small mass differences the typical backgrounds are untagged $\gamma\gamma$ processes, whereas for large mass differences the W pair production, with at least one W decaying leptonically, constitutes the major background. In order to cope with these topologies in an optimal way, the analyses were designed depending on mass difference and topology.

In Figure 3 the excluded regions in the (μ,M_2) plane are shown for $\tan\beta = \sqrt{2}$ and $\tan\beta = 35$ with $M_{\tilde{\nu}} = 200$ GeV/c^2. One can see that in this scenario almost no room is left for charginos to be discovered below the kinematic limit of 86 GeV/c^2. For large parts of the parameter space, the results from the search for charginos alone are sufficient to exclude a given point. However, for small $\tan\beta$ and negative μ the neutralino search extends the excluded region, which translates into an exclusion of charginos up to 90 GeV/c^2, beyond the kinematic limit. For small $\tan\beta$ the inclusion of LEP1 data still has a small impact.

Stated quantitatively (DELPHI): If the mass difference is large ($\Delta M > 10$ GeV/c^2) and the sneutrino heavy (> 300 GeV/c^2), the kinematic limit is almost reached at 84 GeV/c^2. If the $\tilde{\nu}_e$ is light, then the limit is reduced to 68 GeV/c^2. These are the results typical for the gaugino region. In the higgsino region the mass difference is small and the limit is 80 GeV/c^2.

Combining the excluded regions for $m_0 = 500$ GeV/c^2 and varying $\tan\beta$ leads to a mass lower limit on the lightest neutralino of 24.6 GeV/c^2, reported by L3, which is shown in Figure 4 (Left). If one allows m_0 to vary also and includes the limits from

the search for sleptons and sneutrinos, one can deduce the following result (ALEPH LEP1.5 [17]), shown in Figure 4 (Right): a massless neutralino is excluded almost everywhere. The preliminary result for LEP2 is: a massless neutralino is excluded everywhere.

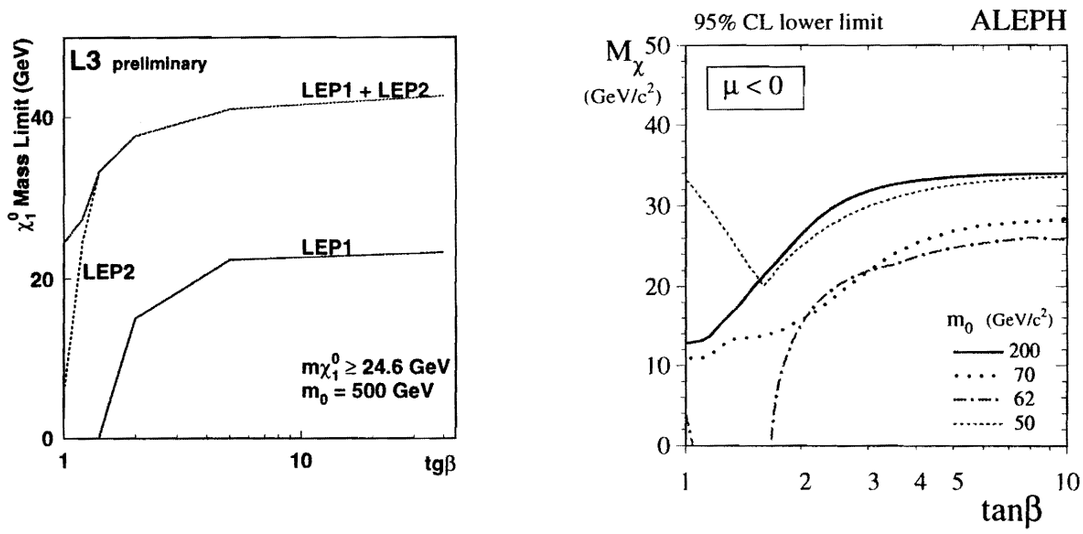


Figure 4: Left: L3 neutralino limit for $m_0 = 500$ GeV/c^2. Right: ALEPH (LEP1.5) with free m_0

At the TEVATRON, CDF and D0 search for the associated production of chargino and next to lightest neutralino in the purely leptonic decay mode, i.e., $\chi^\pm\chi' \to \ell\nu\chi\ell\ell\chi$, where $\ell = e, \mu$. In the most optimistic case, i.e., leptonic branching ratio 100% for the neutralino and the chargino, chargino masses of up 104 GeV/c^2 can be excluded when chargino and next to lightest neutralino have about equal masses and are twice as heavy as the LSP (with 95 pb^{-1}). [18] However for branching ratios of chargino and neutralino equal to the branching ratios of the $W^\pm$ and Z boson respectively, the limit does not improve on LEP.

Sleptons are produced in pairs at LEP via s channel γ,Z exchange, in addition to which selectrons can also be produced via neutralino t channel exchange. Sleptons are searched for in the decay to their standard model partner and the LSP, i.e., search for acoplanar leptons. All limits quoted here are for a massless LSP. Smuons are excluded for masses up to 64 GeV/c^2 by OPAL. ALEPH reported a limit of 53 GeV/c^2 for staus. [19] In the gaugino region the selectron cross section is enhanced due to the t channel neutralino exchange. For $\mu = -200$ GeV/c^2 and $\tan\beta = 2$ a selectron of mass up to 75 GeV/c^2 is excluded, as shown in Figure 5 (Left).

At HERA the associated production of selectrons and squarks proceeds via a t channel neutralino exchange. Selectrons and squarks then decay to their standard model partners and the LSP. For $\mu = -50$ GeV/c^2 under the assumption of equal selectron (right and left) and squark masses (four degenerate flavours), a mass lower limit of 70 GeV/c^2 was determined by ZEUS, shown in Figure 5 (Right).

The best limit for selectrons is obtained by the single photon counting analyses at

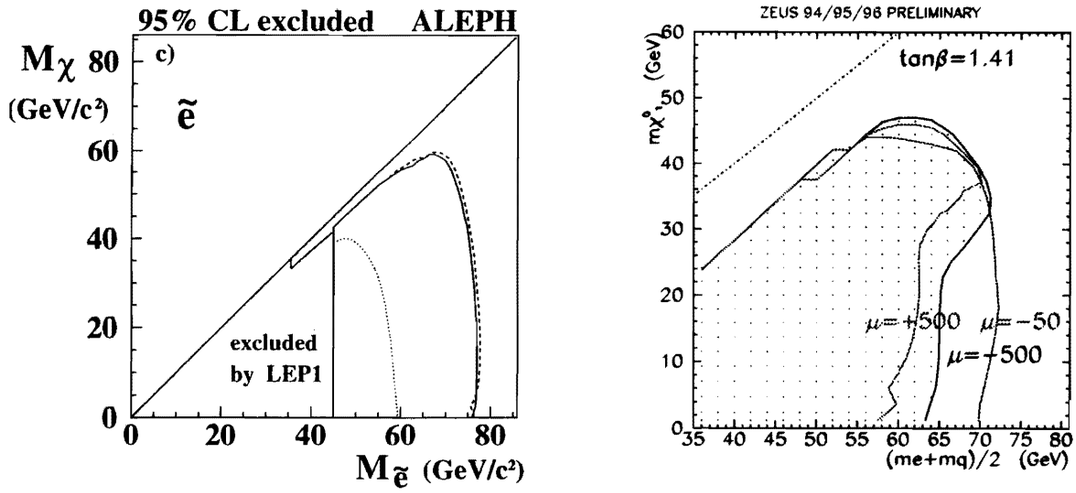


Figure 5: Left: ẽ limit from ALEPH for $\mu = -200$ GeV/c^2, $\tan\beta = 2$. Right: Limit on associated ẽq̃ production from ZEUS.

PEP + PETRA + TRISTAN, where the "invisible" $\chi\chi$ production is tagged via initial state radiation. The final limit is 79.3 GeV/c^2 at 90% C.L., assuming degenerate left and right selectrons. [23]

The analysis for multijets with missing energy by CDF in search of gluino and/or squark production leads to a limit of 215 GeV/c^2 for equal squark and gluino masses (D0: 260 GeV/c^2). The excluded region in the ($M_{\tilde{q}}/M_{\tilde{g}}$) plane is shown in Figure 6 (Left). [20] In this particular example five degenerate squark flavours and $\tan\beta = 4$ are assumed. A limit on the parameter M_2 can be translated, via the GUT relationship mentioned before, into a limit on M_3, which in turn is equal to the gluino mass. The excluded region derived by OPAL [21] this way is shown in Figure 6 (Right) for several values of $\tan\beta$. Assuming a common m_0 at the GUT scale, the masses of the sfermions are calculated from renormalization group equations. In the region below the diagonal there is no solution, i.e., this region is theoretically forbidden.

The top squark plays a special role due to the large top mass. The off-diagonal elements of the stop mass matrix are proportional to the top quark mass, leading potentially to non-negligible mixing and a light top squark. If the top squark is lighter than the top quark, its decay must proceed via loop diagrams, which causes a lifetime longer than the hadronization time. In the most unfavourable case mixing can lead to a decoupling of the lightest top squark from the Z boson, reducing the production cross section at LEP as only the γ production channel remains. At the TEVATRON, the production proceeds via a virtual gluon, therefore the decoupling has no influence on the cross section. In Figure 7 (Left) current limits from OPAL [22] on stop quarks are shown for the decay channel $c\chi$ and in Figure 7 (Right) the corresponding limit from D0. It can be clearly seen that the mass reach of D0 is much larger than that of LEP (the mass lower limit of 100 GeV/c^2 is beyond the kinematic limit of LEP2), but there is room for improvement for LEP, when the mass difference is small.

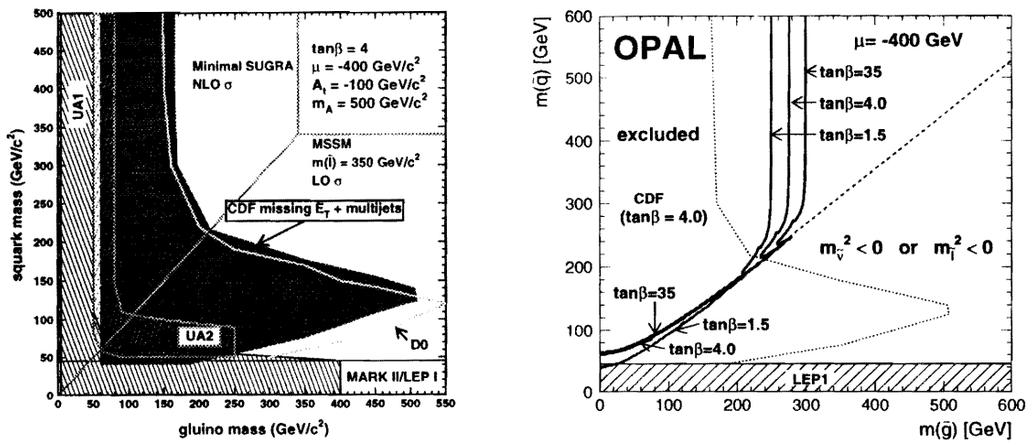


Figure 6: Left : CDF limit in the $(M_{\tilde{q}}/M_{\tilde{g}})$ plane. Right: OPAL limit on M_2 translated into a limit on $M_{\tilde{g}}$

3.2 "Non-standard" Supersymmetry

The observation of an event by CDF consisting of two electrons, two hard photons and missing transverse energy has generated interest in "non-standard" supersymmetric models. Two roads are followed to explain this one (!) event in the context of supersymmetry.

The first possibility is very close to standard supersymmetry, the event is interpreted as selectron pair production with a subsequent cascade decay via the second lightest neutralino, which decays to a photon plus the lightest neutralino, i.e., $\tilde{e}\tilde{e} \to ee\chi'\chi' \to ee\gamma\gamma\chi\chi$. This explanation necessitates a lightest neutralino that is predominantly higgsino and a second lightest neutralino that is predominantly gaugino, otherwise the selectrons would decay directly to χ. The only difference to the MSSM, as defined in the previous section, is that the GUT relationship between M_1 and M_2 no longer holds, $M_1 \approx M_2$.[24]

In models motivated by gauge mediated supersymmetry the LSP no longer is the lightest neutralino, but the gravitino ($\tilde{G}$). The lightest neutralino can then decay to gravitino and photon. In these models the interpretation of the CDF event is pair production of selectrons, which decay to lightest neutralino and electron, and the subsequent neutralino decay, i.e., $\tilde{e}\tilde{e} \to ee\chi\chi \to ee\gamma\gamma\tilde{G}\tilde{G}$.

All of the models predict also other processes characterised by hard photons. D0 searched for the production of $\gamma\gamma$ + X + missing E_T with negative results,[25] which was translated into a lower limit, fairly independent of the production process, of $\sigma \cdot B(p\bar{p} \to \gamma\gamma \not{E}_T + X) < 185$ fb.

DELPHI has performed an extensive study of the light gravitino scenario. The limits, as an example shown in Figure 8 for the chargino analysis ($e^+e^- \to \chi^+\chi^- \to X\chi\chi \to X\tilde{G}\tilde{G}\gamma\gamma$), are at least as constraining as the limits in the standard supersymmetry searches.

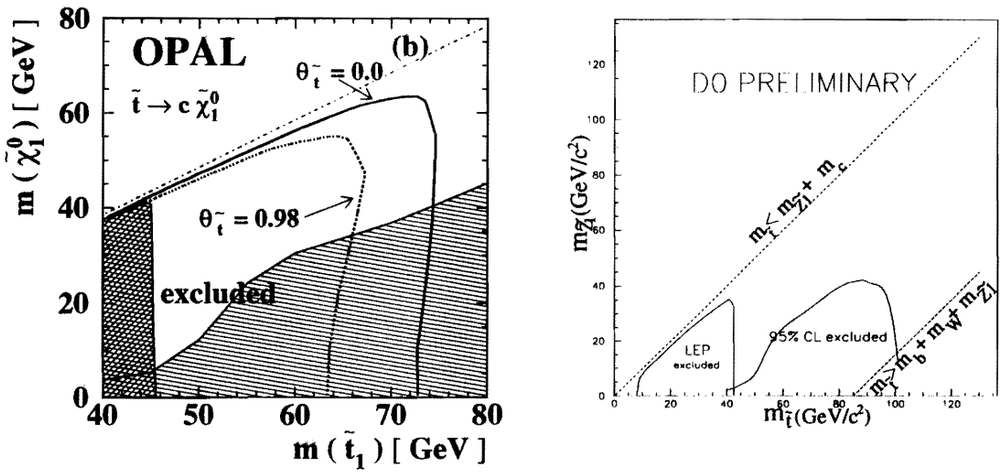


Figure 7: Left: Limit on the top squark by OPAL for no-mixing (θ = 0rad) and the decoupled top squark (θ = 0.98rad). The hatched area shows the limit from D0. Right: Limit from D0

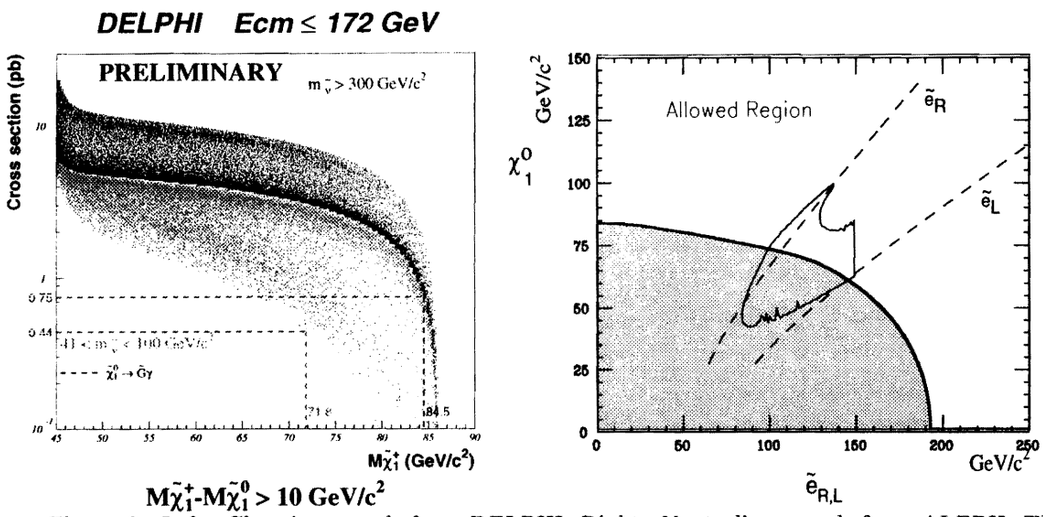
Searching for neutralinos ($e^+e^- \to \chi\chi \to \tilde{G}\tilde{G}\gamma\gamma$) ALEPH reported in Figure 8 the experimentally excluded region in dark shade. The dashed lines are the solutions for a no-scale supergravity model.[26] The region kinematically accessible for the CDF event is delineated by the solid curve. About half of the region of interest is now excluded.

4 R-parity Violation and Leptoquarks

The most general supersymmetric Lagrangian contains R-parity violating interactions via $\lambda_{ijk}L_iL_jE_k$, $\lambda'_{ijk}L_iQ_jD_k$ and $\lambda''_{ijk}U_iD_jD_k$, where L, E denote the left-handed lepton doublet, right-handed lepton singlet superfields, Q, U, D the left-handed quark doublet, right-handed quark singlet superfields and i, j, k denote the generation indices. The simultaneous presence of λ' and λ'' can lead to a proton decay incompatible with current experimental limits, which can be avoided by assuming that only one type of coupling dominates, further simplified by the assumption that only one coupling dominates. The main experimental difference with respect to supersymmetry with R-parity conservation is that the LSP decays, therefore missing energy no longer is the characteristic sign of supersymmetry.

If the LLE term is present, a multi-lepton final state is expected. The excluded regions for chargino and neutralino production are shown in Figure 9 (Left) in the (μ/M$_2$) plane as reported by ALEPH. In general the limits derived from these searches are as good as the limits with R-parity conservation.

The unusual events observed by H1 [27] and ZEUS [28] at HERA, [29] have led to a renewed interest in leptoquarks (LQ), [30] which are now often interpreted as squarks with LQD R-parity violation. They are produced as resonance in the s channel at HERA ($e^+q \to LQ \to e^+ + jet$, $e^+q \to \tilde{q} \to e^+ + jet$).



$M_{\tilde{\chi}_1^+}-M_{\tilde{\chi}_1^0} > 10$ GeV/c²

Figure 8: Left: Chargino search from DELPHI. Right: Neutralino search from ALEPH. The solid curve denotes the region kinematically accessible to the CDF event.

Leptoquarks are objects that carry lepton number, baryon number and colour. Their branching ratio to charged leptons (β) is 1, 0.5 or 0. Due to the constraints from flavour changing currents, a leptoquark couples only to one generation. The coupling ℓq(LQ) is a free parameter (λ).

The differences between leptoquarks and squarks with LQD are that vector leptoquarks and/or leptoquarks of charge 4/3 or 5/3 could exist, on the other hand, depending on the supersymmetric parameters, additional supersymmetric decay channels might be open for squarks, leading to a deviation of β from the values given above.

If the HERA events are due to the production of leptoquarks, a coupling of order 0.04 can be deduced,[32] if the production proceeds via a collision with a valence quark in the proton. The mass region of interest is around 200 GeV/c^2. In the squark sector one remains with two possibilities: $\tilde{c}$ or $\tilde{t}$, $\tilde{u}$ is excluded due to the stringent limits on the λ'_{111} coupling from the neutrinoless double beta decay.[33] For the leptoquarks in the context of grand unified theories, a first generation leptoquark with β=1 is the most interesting possibility, since $\beta = 0$ leptoquarks cannot be produced at HERA and the $\beta = 0.5$ leptoquarks would lead to a large signal in the e$^-$p data sample,[34] which has not been observed.

At LEP the squarks with R-parity violation or leptoquarks lead to an additional t channel diagramme. By measuring the total q$\bar{\text{q}}$ cross section, OPAL set limits on the coupling strength as a function of the mass of the exchanged particle.[31] In the region of interest around 200 GeV/c^2 in mass, the limits on the couplings are about 0.4, which is about an order of magnitude too weak.

At the TEVATRON, leptoquarks are produced in pairs via gluon fusion. The production cross section is therefore independent of λ, which affects only the decay of the particles. The analyses are valid for couplings as small as 10^{-12}. It should be noted that the production cross section for leptoquarks is identical to the production cross section for squarks, if one restricts oneself to scalar leptoquarks and on the supersym-

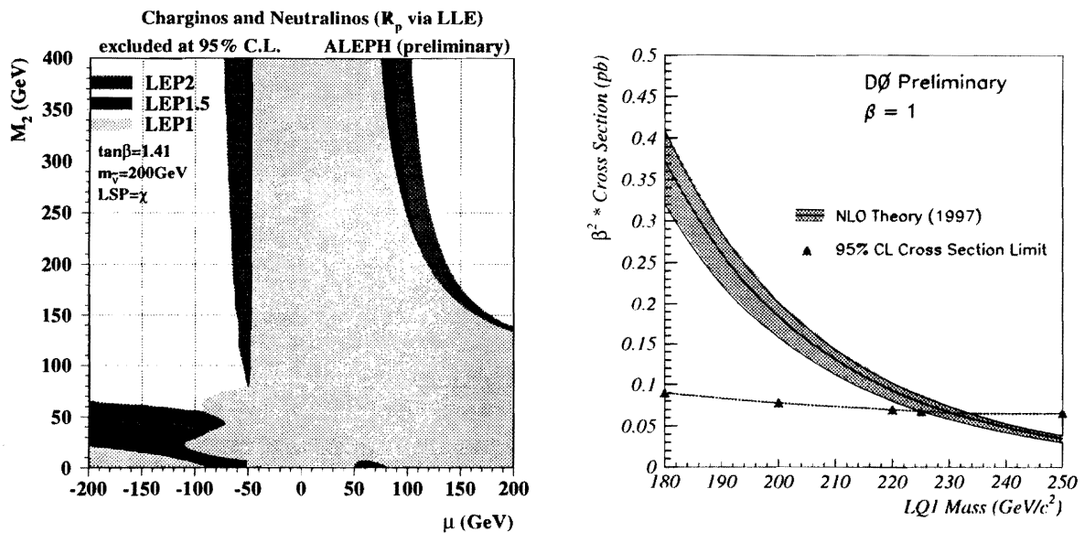


Figure 9: Left: ALEPH search for charginos and neutralinos with LLE. Right: D0 limit on first generation leptoquarks ($\beta = 1$)

metric side to models with heavy gluinos. First generation leptoquarks with $\beta = 1$ are excluded up to 213 GeV/c^2 and 225 GeV/c^2 by CDF [35] and D0 [36] respectively as shown for D0 in Figure 9 (Right). One must therefore conclude that it is not possible to explain the HERA events with first generation leptoquark production with $\beta = 1$.

5 Conclusions

Many topics could not be covered in depth due to the lack of time and space, among which are: Excited fermions, where OPAL reported limits of $M_{\ell^*} > 84$ GeV/c^2 and $M_{\nu^*} > 84$ GeV/c^2. ZEUS determined limits on the ratio of coupling constant to scale (f/Λ) for excited electrons and quarks.[37] These limits are complementary to the search for excited quarks as dijet resonances at the TEVATRON.[38]

In conclusion, the limits on the standard model and supersymmetric neutral Higgs bosons have been improved to 70.7 GeV/c^2 and 62.5 GeV/c^2 respectively. No explanation for the unusual four-jet events seen by ALEPH has been found. No hints for supersymmetry with R-parity conservation have been observed. The CDF event remains the only unusual event in the search for "non-standard" supersymmetry. Leptoquarks ($\beta = 1$) are ruled out as explanation of the HERA events.

With LEP's energy increase to about 183 GeV, the low $\tan\beta$ scenario can be explored in the Higgs sector and a new energy regime is opened for all searches. From HERA one can expect a doubling of the integrated luminosity, which will help to clarify the situation.

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