SUSY SEARCH WITH PHOTONIC EVENTS AT LEP WITH $\tilde{\mathrm{G}}$ AS LSP AND $\tilde{\chi}_1^0$ AS NLSP

JEAN FAY

Institut de Physique Nucléaire de Lyon, IN2P3/CNRS and Université Claude Bernard

We present results from SUSY scenarios with the gravitino as LSP and the neutralino as NLSP. The searches, performed by the 4 LEP experiments in 1997 at $\sqrt{s}$=183 GeV, include slepton pair production, chargino pair production and photon(s) plus missing energy final states. Preliminary data obtained in 1998 at $\sqrt{s}$=189 GeV are also presented. No evidence from new physics has been found and limits on the parameters of the models have been derived.

1 Introduction

Usually, the supersymmetry breaking mechanism is supposed to occur at very high energy and the gravitino is too heavy to be produced at LEP.

On the other hand, in Gauge Mediated Susy Breaking (GMSB) models [1], the supersymmetry breaking takes place at much lower energy scale $\sqrt{\mathrm{F}}$ and the gravitino $\tilde{\mathrm{G}}$ which mass reads:

$$\mathrm{m}_{\tilde{\mathrm{G}}} = \frac{\mathrm{F}}{\sqrt{3}\,\mathrm{M_P}} \simeq 2.5 \text{ eV} \left(\frac{\sqrt{\mathrm{F}}}{100\mathrm{TeV}}\right)^2$$

becomes the Lightest Susy Particle (LSP).

The Next to Lightest Susy Particle (NLSP) can be either a right handed scalar lepton [2] $\tilde{\ell}_R^{\pm}$ or the neutralino $\tilde{\chi}_1^0$. In this latter case, which is the subject of this paper, the search for $\tilde{\ell}$, charginos $\tilde{\chi}^{\pm}$ and $\tilde{\chi}^0$ must be optimized to take the $\tilde{\chi}_1^0$ decay into account. In most cases, the branching ratio $\tilde{\chi}_1^0 \to \gamma\tilde{\mathrm{G}}$ is near 100 %.

The neutralino decay length:

$$D.L. \simeq\ (17\mu\mathrm{m})\ \frac{1}{\kappa}\ \sqrt{\frac{\mathrm{E}^2_{\tilde{\chi}_1^0}}{\mathrm{m}^2_{\tilde{\chi}_1^0}}}\ \left(\frac{\mathrm{m}_{\tilde{\mathrm{G}}}}{1\text{ eV}}\right)^2\ \left(\frac{m_{\tilde{\chi}_1^0}}{100\text{ GeV}}\right)^{-5}$$

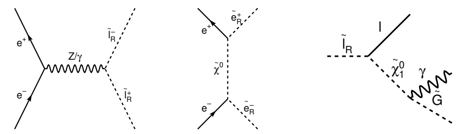
can be non negligible. Nevertheless, unless otherwise stated, we will consider that $\tilde{\chi}_1^0$ is short lived and decays near the interaction region.

ALEPH has performed a search for slepton, DELPHI and OPAL for chargino, while the 4 LEP experiments were looking for neutralino.

The main results come from data taken at $\sqrt{s}$=183 GeV. Preliminary updates at 189 GeV have already been obtained.

2 Search for slepton

The production of $\tilde{\mu}$ and $\tilde{\tau}$ proceeds via γ or Z exchange while $\tilde{\mathrm{e}}$ can also be produced via $\tilde{\chi}^0$ exchange in the t channel. The slepton dominantly decays in its partner lepton and $\tilde{\chi}_1^0$:



A dedicated search has been developed with acoplanar leptons plus photons. [3] In the case of e, μ, there must be at least 2 photons with energies greater than 3 GeV and 2 identified leptons. Additional cuts are applied in the selectron search to remove radiative Bhabha events. For acoplanar τ, the two photons must have at least 1 GeV and a τ tagging algorithm is applied.

When the mass difference $\mathrm{m}_{\tilde{\ell}}$-$\mathrm{m}_{\tilde{\chi}_1^0}$ decreases below 1 GeV, the efficiency of the previous selections becomes too low and the selection is modified in order to search for two acoplanar photons + X. Both photons must have an energy $\mathrm{E}_\gamma > 3$ GeV. Other cuts are applied on invariant mass from tracks and photons and on additionnal energy.

The results obtained from data taken at $\sqrt{s}$=161 (11.1 pb^{-1}), 172 (10.6 pb^{-1}) and 183 GeV (57.0 pb^{-1}) are displayed in Table 1.

Table 1: Efficiencies, measured and expected number of events.

	ϵ (%)	data	background
$\tilde{\mathrm{e}}$	30 - 50	0	0.6
$\tilde{\mu}$	45 - 70	0	0.8
$\tilde{\tau}$	20 - 35	1	1.1
γ + X	15 - 50	3	2.7 ($\nu\bar{\nu}\gamma(\gamma)$)

As there is no observation of any excess of events, these results lead to the exclusion regions (figure 1). The limit on $\mathrm{m}_{\tilde{\ell}}$ is derived assuming the 3 sleptons have the same mass and combining $\tilde{\mathrm{e}}$ and $\tilde{\mu}$ results.

The following mass limits at 95% confidence level are derived:

$\mathrm{m}_{\tilde{\mathrm{e}}_\mathrm{R}}$: 77 GeV, $\mathrm{m}_{\tilde{\mu}_\mathrm{R}}$: 77 GeV, $\mathrm{m}_{\tilde{\tau}_\mathrm{R}}$: 52 GeV
$\mathrm{m}_{\tilde{\ell}_\mathrm{R}}$: 82 GeV (for degenerated slepton masses)

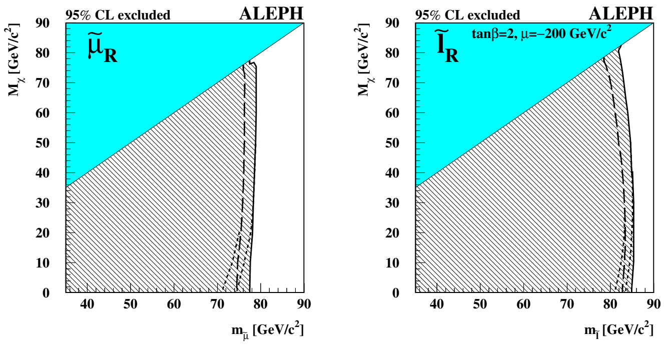


Figure 1: Mass limits for right-handed sleptons in GMSB models.

3 Search for chargino

When the neutralino is the NLSP, the chargino decay is the following:

$$e^+e^- \longrightarrow \tilde{\chi}_1^+ \, \tilde{\chi}_1^-$$

$\tilde{\chi}_1^- \longrightarrow \tilde{\chi}_1^0 \, W^{(*)-}$, with $W^{(*)-} \longrightarrow q\bar{q}'$ or $\ell^- \bar{\nu}_\ell$ and $\tilde{\chi}_1^0 \longrightarrow \gamma \, \tilde{G}$

$\tilde{\chi}_1^+ \longrightarrow \tilde{\chi}_1^0 \, W^{(*)+}$, with $W^{(*)+} \longrightarrow q\bar{q}'$ or $\ell^+ \nu_\ell$ and $\tilde{\chi}_1^0 \longrightarrow \gamma \, \tilde{G}$

The final states include isolated photons and missing energy plus jets or jets and isolated leptons or two isolated leptons.

DELPHI [4] makes no distinction on the event topology and searches for $\gamma\gamma$ + X: it requires at least 1 photon with energy $E_\gamma > 5$ GeV and angle $15° < \theta_\gamma < 165°$ and at least 1 track. Additional cuts are put on $\not{p}_t$, E_{vis} and acoplanarity, dependent on $\Delta M = m_{\tilde{\chi}_1^+} - m_{\tilde{\chi}_1^0}$.

OPAL [5] divides the events into two categories: a high multiplicity ($N_{tracks} > 4$) topology, in this case, the event must contain at least 1 photon with $E_\gamma > 15$ GeV, and a low multiplicity ($2 < N_{tracks} \leq 4$) topology where there must be at least 1 photon with $E_\gamma > 5\%$ E_{beam}. Cuts on p_t, E_{vis}, acoplanarity, γ isolation are added to remove the background.

The results obtained at $\sqrt{s}$=183 GeV and preliminary ones at $\sqrt{s}$=189 GeV are presented in Table 2.

Table 2: Efficiencies, number of events observed in data and expected from background.

	ϵ (%)	data	backgr.
DELPHI	183 GeV 50.6 pb^{-1}		
$\Delta M > 10$ GeV	35 - 45	3	4.9
$5 < \Delta M < 10$ GeV	40 - 55	0	0.9
$\Delta M < 5$ GeV	40 - 50	1	0.5
total		4	6.3
	189 GeV 34 pb^{-1}		
$\Delta M > 10$ GeV		2	3.0
$5 < \Delta M < 10$ GeV		0	0.5
$\Delta M < 5$ GeV		1	0.5
OPAL	183 GeV 56.8 pb^{-1}		
high mult.	15 - 70	2	2.1
low mult.	40 - 65	4	4.9
total	30 - 50	6	7.0
	189 GeV 32 pb^{-1}		
high mult.		2	2.2
low mult.		2	2.6

DELPHI computes the chargino cross section limits for different chargino masses (figure 2) and extracts the lower limit at 95 % confidence level for the chargino mass: 90.5 GeV in the non-degenerate case for a heavy sneutrino and 90.6 GeV in the degenerate one. The preliminary limits obtained at $\sqrt{s}$=189 GeV are respectively 93.6 and 93.7 GeV.

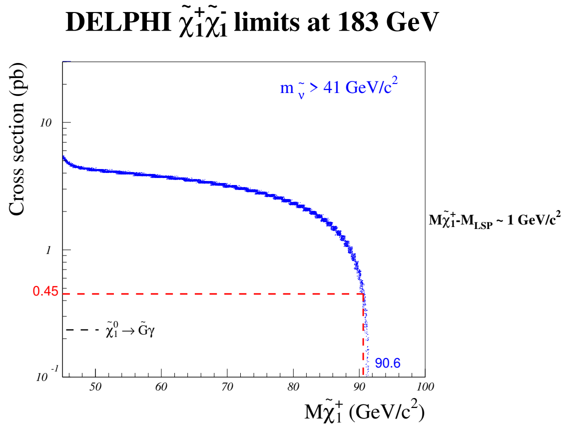


Figure 2: Expected cross section versus the chargino mass, in the degenerate case ($\Delta M \sim 1$ GeV), for different SUSY parameter values.

Production cross section limit contours are set by OPAL (figure 3).

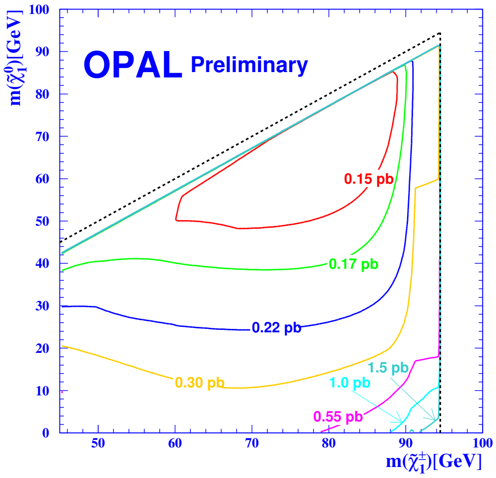


Figure 3: $\tilde{\chi}^+\tilde{\chi}^-$ production cross section upper limits (95 % confidence level) obtained at $\sqrt{s}$=189 GeV.

OPAL also presents exclusion region for non zero $\tilde{\chi}_1^0$ lifetimes (figure 4). In this case, one or both $\tilde{\chi}_1^0 \rightarrow \gamma\tilde{G}$ decay can occur outside the detector and escapes detection.

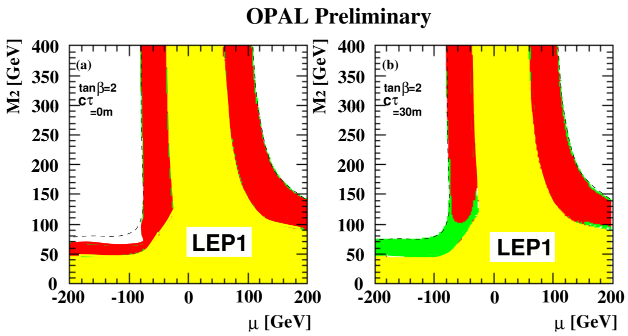


Figure 4: Excluded region for different $\tilde{\chi}_1^0$ lifetime $c\tau$. Dark shaded region is excluded from this analysis. Medium shaded region is excluded from standard $\tilde{\chi}^+\tilde{\chi}^-$ searches.

4 One and two photon final states

GMSB models predict final states with 1 γ + missing energy $e^+e^- \rightarrow \tilde{\chi}_1^0\tilde{G} \rightarrow \gamma\tilde{G}\tilde{G}$ or 2 γ + missing energy $e^+e^- \rightarrow \tilde{\chi}_1^0\tilde{\chi}_1^0 \rightarrow \gamma\gamma\tilde{G}\tilde{G}$.

These final states are also predicted by a no-scale supergravity model (LNZ) [6] which separates local ($\sqrt{\mathrm{F}}$) and global SUSY breaking (m_0, $m_{3/2}$) and predicts the $\tilde{G}$ to be the LSP. The $\tilde{\chi}_1^0$ is the NLSP and is almost purely bino. This model has only 2 free parameters, the $\tilde{G}$ and $\tilde{\chi}_1^0$ masses.

The 4 LEP experiments are looking for photon(s) plus missing energy [7] and the LEP SUSY working group (LSWG) performs a combination of the individual results.

4.1 One photon final states

The table 3 shows the results from data taken at 183 GeV. The other backgrounds ($\gamma\gamma(\gamma)$, $\mu\mu\gamma$, $\ell\ell\nu\bar{\nu}\gamma$) and the cosmic rays contamination are negligible.

Preliminary results obtained at $\sqrt{s}$=189 GeV are shown in figure 5.

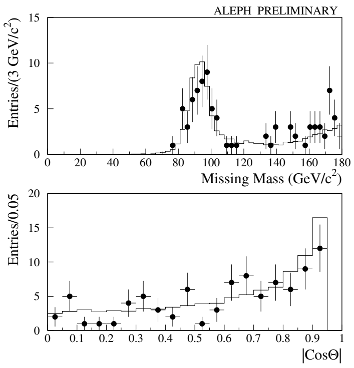


Figure 5: Missing mass spectrum and photon angular distribution. The full line shows the simulation obtained from KORALZ Monte Carlo.

Figure 6 displays the combination made by the LEP SUSY working group of all the 1 γ results.

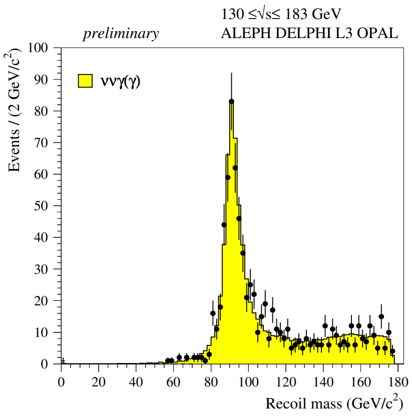


Figure 6: Recoil mass spectrum obtained by the 4 LEP collaborations in 1 γ events, compared to KORALZ predictions (from LSWG).

No evidence is observed for new physics and limits are derived. For this, additional cuts are applied: for each $\tilde{\chi}_1^0$ mass, the photon energy E_γ must be consistent with the kinematics derived from the expected signal.

Table 3: One photon search.

	ALEPH	DELPHI			L3		OPAL
Luminosity (pb^{-1})	58.5	50.2	44.3	52.0	55.3		54.5
θ_γ range (°)	18 - 162	45 - 135	11 - 30 150 - 169	3.8 - 8 172 - 176.2	43 - 137 14 - 36 144 -166	45 - 135	15 - 165
Energy cuts (GeV)	$p_t >$ $.0375\sqrt{s}$	$E_\gamma >$ $.06\sqrt{s}$	$E_\gamma >$ $.2\sqrt{s}$	$E_\gamma >$ $.6\sqrt{s}$	$E_\gamma > 5$	$10 > E_\gamma > 1.3$ $p_t > 1.3$	$E_\gamma >$ $.05 E_{beam}$
Data	195	54	58	28	195	144	191
		140					
MC $\nu\bar{\nu}\gamma(\gamma)$	187	59.5	48.1	24.7	203.2	28.2	201.3
		132.3					
MC $e^+e^-\gamma$	0	0	3.1	2.2	1.2	107.4	0
		5.3					

DELPHI, L3 (figure 7) and OPAL have derived upper limits on $e^+e^- \to \tilde{\chi}_1^0\tilde{G} \to \gamma\tilde{G}\tilde{G}$ cross section.

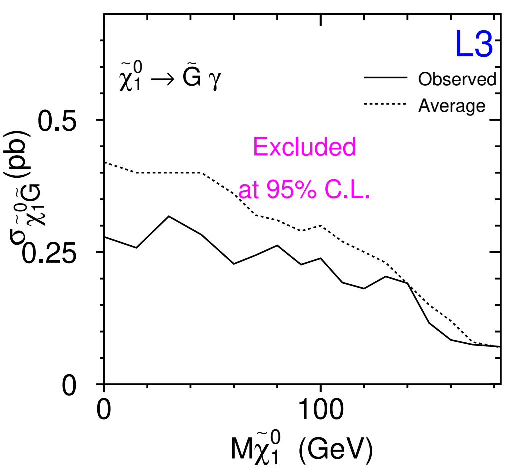


Figure 7: Upper limits at 95 % C.L. for the cross section of the process $e^+e^- \to \tilde{\chi}_1^0\tilde{G} \to \gamma\tilde{G}\tilde{G}$.

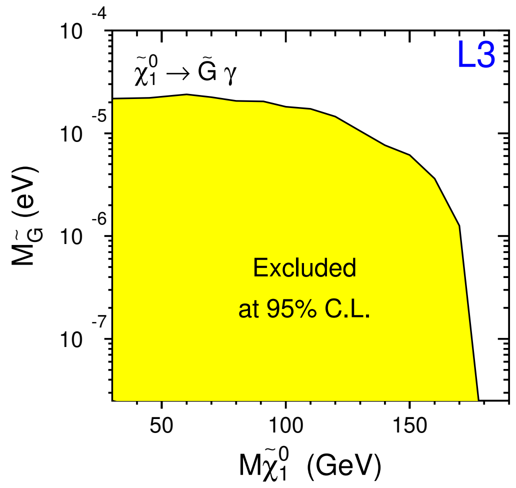


Figure 8: Upper limits at 95 % C.L. for the cross section of the process $e^+e^- \to \tilde{\chi}_1^0\tilde{G} \to \gamma\tilde{G}\tilde{G}$.

In the LNZ model, L3 has also computed the exclusion region in the plane of the 2 parameters of the model (figure 8).

If the gravitino is very light, the cross section for the process $e^+e^- \to \tilde{G}\tilde{G}\gamma$ can be sizeable. This scenario, with all other SUSY particles too heavy to be produced, has been recently studied. [8] The total cross section is given by:

$$\sigma = \frac{\alpha\ s^3}{320\pi^2|F|^4}\ \mathrm{I}(E_{\gamma,\min}, |\cos\theta_\gamma|_{\max})$$

where integral I is dependent on the cuts on photon energy and angle. One can derive a lower limit on the gravitino mass:

$$m_{\tilde{G}} > 3.8\ 10^{-6}\mathrm{eV}\left[\frac{\sqrt{s}(\mathrm{GeV})}{200}\right]^{\frac{3}{2}}\left[\frac{\mathrm{I}}{\sigma_{\exp}(\mathrm{pb})}\right]^{\frac{1}{4}}$$

Mass limits have been set by three experiments:

	$m_{\tilde{G}}$ (eV)
ALEPH	$8.3\ 10^{-6}$
DELPHI	$6.6\ 10^{-6}$
L3	$8.0\ 10^{-6}$

4.2 Two photon final states

The results from data collected at $\sqrt{s}$=183 GeV are displayed in table 4. The other backgrounds are negligible.

Table 4: Search for acoplanar two photon final states.

	ALEPH	DELPHI	L3	OPAL
$\theta_\gamma$range (°)	18 - 162	γ_1 : 10 - 170 γ_2 : 25 - 155	43 - 137 14 - 36 144 -166	15 - 165
Energy cuts (GeV)	$E_\gamma > 1$	$E_\gamma > .05E_{beam}$	$E_\gamma > 1$	$E_\gamma > .05E_{beam}$ $E_\gamma > 1.5$ if $\lvert\cos\theta\rvert < 0.8$
Acopl. (°)	3.	3.	2.4	2.5
Data	9	10	14	9
MC ($\nu\bar{\nu}\gamma\gamma$)	10.8	10.2	13.3	8.2

Figure 9, from the LEP SUSY working group, displays the events selected by the 4 experiments.

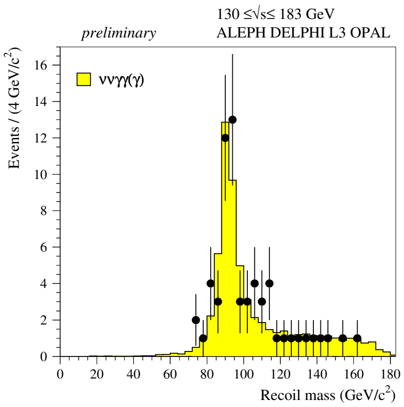


Figure 9: Recoil mass spectrum obtained by the 4 LEP collaborations in acoplanar 2 γ events (from LSWG).

No anomaly is found and limits are derived, imposing additional cuts to improve signal to background ratio. An upper limit on $\gamma\gamma\tilde{G}\tilde{G}$ cross section has been computed by the LEP SUSY working group (figure 10).

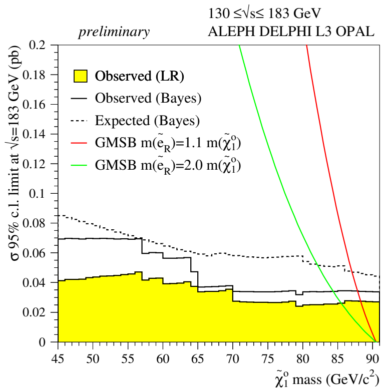


Figure 10: Upper limit cross section for the process $e^+e^- \to \tilde{\chi}^0_1\tilde{\chi}^0_1 \to \gamma\gamma\tilde{G}\tilde{G}$ (from LSWG).

The interpretation of the CDF event in $q\bar{q} \to \tilde{e}\tilde{e} \to e^+e^-\tilde{\chi}^0_1\tilde{\chi}^0_1 \to e^+e^-\gamma\gamma\tilde{G}\tilde{G}$ leads to specific region in the $m_{\tilde{e}}$, $m_{\tilde{\chi}^0_1}$ plane. Exclusion region (figure 11) in this plane can be derived from 2 γ plus missing energy results.

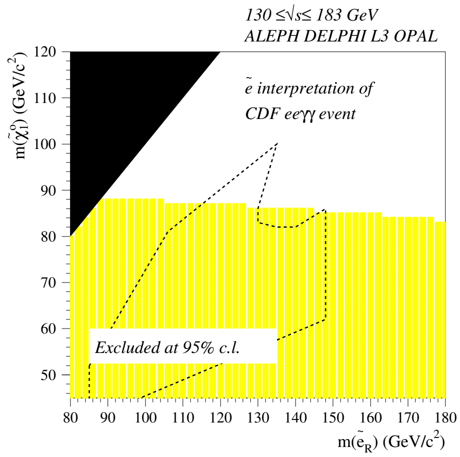


Figure 11: Exclusion mass plot from 2 γ and missing energy data (from LSWG).

5 Conclusion

No evidence for production of events compatible with Susy models predicting a $\tilde{G}$ as LSP and $\tilde{\chi}^0_1$ as NLSP has been reported by any of the four LEP experiments. CDF event interpretation in $\tilde{e}$ $\tilde{e}$ is almost ruled out.

References

1. P. Fayet, *Phys. Lett.* B117 (1982) 423,
   C. Kolda *Nucl. Phys.* B Proc. Suppl (1998) 62.
2. G. Wolf, these Proceedings.
3. ALEPH Coll., CERN-EP/98-077, ICHEP98#950.
4. DELPHI Coll., DELPHI 98-66, ICHEP98#201.
5. OPAL Coll., OPAL PN-332, ICHEP98#332.
6. J.L. Lopez et al., *Phys. Rev.* D55 (1997) 5813.
7. ALEPH Coll., *Phys. Lett.* B429 (1998) 201, ICHEP98#953,
   DELPHI Coll., DELPHI 98-76, ICHEP98#206,
   DELPHI Coll., DELPHI 98-59, ICHEP98#207,
   L3 Coll., L3 Note 2289, ICHEP98#494,
   OPAL Coll., OPAL PN-351, ICHEP98#275.
8. A. Brignole et al., CERN-TH/97-339.