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Search for resonant $\tilde{\nu}$ production at $\sqrt{s} = 189$ GeV

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Abstract

Searches for $\tilde{\nu}$ resonant production in e^+e^- collisions at center-of-mass energy of 189 GeV have been performed on 1998 DELPHI data, under the assumption that R-parity is not conserved and that the dominant R-parity violating coupling is λ_{121}. No deviation with respect to the Standard Model predictions was observed, therefore upper limits were derived on the λ_{121} coupling.

Note for Moriond

Introduction

In the Minimal Supersymetric Standard Model (MSSM), R parity $R_p = (-1)^{3B+L+2S}$ is assumed to be conserved and therefore supersymetric particles can only be produced by pairs. On the contrary, in the R_p violating scenario, single sparticle production is allowed, via additionnal couplings usually called λ_{ijk}, λ'_{ijk} and λ''_{ijk}, where i, j, k are family indices.

At LEP the only resonant sparticle production which is allowed is the sneutrino ($\tilde{\nu}$) production via the couplings λ_{121} or λ_{131}. The cross section for a sneutrino (J=0) can be expressed as [1]:

$$\sigma(e^+e^- \to \tilde{\nu} \to X)(s) = \frac{4\pi s}{M_{\tilde{\nu}}^2} \frac{\Gamma(ee)\Gamma(X)}{(s - M_{\tilde{\nu}}^2)^2 + M_{\tilde{\nu}}^2 \Gamma_{\tilde{\nu}}^2}$$

where $\Gamma(ee) = \Gamma(\tilde{\nu}_j \to e^+e^-) = \frac{\lambda_{1j1}^2}{16\pi} M_{\tilde{\nu}_j}$, $j = 2, 3$, and $\Gamma(X)$ denotes the partial width for $\tilde{\nu}$ decay to final state X, with $X = e^+e^-$ ("direct decay"), $X = \tilde{\chi}^0\nu$ or $X = \tilde{\chi}^{\pm} l^{\mp}$ ("indirect decays" of the sneutrino).

Given the present (indirect) upper limits on λ_{121} and λ_{131} ($\lambda_{121} < 0.04$, $\lambda_{131} < 0.05$ at 1σ C.L. [2]), the e^+e^- decay channel ($\sigma \propto \lambda^4$) is suppressed compared to the other two ($\sigma \propto \lambda^2$), unless both the neutralino and chargino are heavier than the sneutrino.

DELPHI has already studied sneutrino resonant production in both direct and indirect decay channels at center of mass energies up to 183 GeV.

The direct decay mode was investigated by looking for deviations to the Standard Model in the cross sections and asymetries of $e^+e^- \to l^+l^-$ [3] (see also equivalent analyses by L3 [4] and OPAL [5]). The results were obtained from data up to 172 GeV assuming a 1 GeV width for the sneutrino and presented as an upper limit on λ as a function of the sneutrino mass.

The indirect decay channels $\tilde{\nu} \to \tilde{\chi}^0\nu$ and $\tilde{\nu} \to \tilde{\chi}^{\pm} l^{\mp}$ were analysed explicitely. First in up to 172 GeV data assuming $M_{\tilde{\nu}} = \sqrt{s}$ and $\Gamma_{\tilde{\nu}} = 8$ GeV [6]. Then in 183 GeV data taking into account any mass and the actual width of the $\tilde{\nu}$ as a function of the MSSM parameters [7] (there is also a very preliminar ALEPH analysis of 183 GeV data, presented at ICHEP98 [8], looking for the indirect decay of the sneutrino).

In the present note, we use for 189 GeV data the same method as for 183 GeV data; all the results are still preliminary.

1 Data samples

The data recorded in 1998 at $\sqrt{s} \simeq 189$ GeV (processing 98C2) have been analysed. The integrated luminosity was 158 pb^{-1}. For the Standard Model processes, we have used as MC generators:

- $\gamma\gamma$ events: `BDK`[9] for $\gamma\gamma \to l^+l^-$ processes, and `TWOGAM`[10] for $\gamma\gamma \to$ hadrons processes.
- two-fermion processes: `BABAMC` and `BHWIDE` for Bhabhas, `DYMU3`[11] for $e^+e^- \to \mu^+\mu^-(\gamma)$, and `KORALZ`[12] for $e^+e^- \to \tau^+\tau^-(\gamma)$ and $e^+e^- \to q\bar{q}(\gamma)$ events.
- four-fermion processes: `EXCALIBUR`[13] and `GRC4F` for all types of four fermion processes: non resonant ($f\bar{f}f'\bar{f}'$), simply resonant ($Zf\bar{f}$, $Wf\bar{f}'$) and doubly resonant (ZZ, WW) (`PYTHIA` was used also for cross checks).

For the signal simulation, we have used the `SUSYGEN 2.20/03` program [14] (followed by the full DELPHI simulation and reconstruction program) with the R-parity violating coupling λ_{121} set at 0.05 and $M_{\tilde{\nu}} = m_0$. A faster simulation (`SGV` [15]) was used to check that there was no efficiency "accident" in the points where we did not have full simulation.

2 Selection criteria

With a non zero λ coupling, the neutralinos and charginos can decay into three leptons, charged or neutral (R_p violating decays). Therefore if one takes into account all the decays, violating or not R-parity, of the neutralinos and charginos, the possible final states for both processes $\tilde{\nu} \rightarrow \tilde{\chi}^0 \nu$ and $\tilde{\nu} \rightarrow \tilde{\chi}^{\pm} l^{\mp}$ are of two kinds, either purely leptonic: two leptons and missing energy, and four leptons (with or without missing energy), or multi-lepton multi-jet and missing energy. Whereas the cross section for the chargino is much higher than for the neutralino, the cross sections for the purely leptonic and for the multi-lepton multi-jet final states are of the same order, so that it is necessary to look for all kinds of topologies.

In order to select these final states, we first apply a serie of preselection cuts:

- At least two charged tracks of standard quality;
- a vast majority of the recorded events consists in $\gamma\gamma$ events, we get rid of most of them by requiring:
  - total transverse momentum p_T greater than 5 GeV,
  - charged energy E_{ch} greater than $0.1 \times \sqrt{s}$,
  - thrust axis not parallel to the beam pipe: abs($cos\theta_{th}$) less than 0.9,
  - polar angle of the missing momentum θ_{miss} between 20^o and 160^o;
- two-fermion events are the second kind of standard physics processes being source of background events in the leptonic final states, we reject them by demanding
  - dividing the event in two hemispheres with respect to the sphericity axis: acolinearity greater than 5^o,
  - forcing the event to two jets: acoplanarity less than 175^o,
  - the total transverse momentum p_T had to be greater than 15 GeV;
- in the multijet final state preselection, we demand
  - visible mass M_{vis} more than $0.2 \times \sqrt{s}$,
  - event sphericity S_{ph} greater than 0.02.

Then we designed three more series of cuts, in order to select the three kinds of topologies that we search for. Electrons and muons are identified at least at the level of 'loose' identification; in the following, isolated means that there must be no other charged track or neutral shower in a 5^o half-cone.

- Two leptons plus missing energy final states:

  - we required the charged track multiplicity N_{ch} to be two,
  - two leptons, the leading one being isolated,
  - the acoplanarity below 160^o,
  - not two muons identified,
  - the missing energy E_{miss} greater than $0.45 \times \sqrt{s}$,
  - the angle α between the two charged tracks between 20^o and 120^o,
  - the momentum of the non-leading track p_2 had to be less than 35 GeV,
  - the invariant mass of the two leptons, M_{ll}, lower than 45 GeV,
  - the difference between the missing momentum and the invariant mass greater than 5 GeV.

- Four leptons (with or without missing energy) final states:
  - we asked for $3 \leq N_{ch} \leq 6$,
  - at least three identified leptons (electrons or muons), the leading one being isolated.

- Multi-lepton multi-jet final states:
  - there must be at least 7 charged tracks, and at most 20,
  - there must be at least two identified leptons (electrons or muons), the leading one being isolated,
  - the y_{cut} Durham 'distance' (scaled invariant mass) for which the event flips from four to three jets y_{34} had to be bigger than 10^{-3},
  - the transverse momentum of the second lepton $p_T(l_2)$ had to be above 10 GeV,
  - $n_{tot}(j_1)$, the total multiplicity of the leading jet (when the number of jets was forced to 4) could not exceed 4,
  - the invariant mass of the two leading leptons had to be above 15 GeV.

The average efficiency of these selections was 28%, 47% and 28% respectively on two-lepton, four-lepton and multi-lepton multi-jet signals.

The step by step comparison of the number of data and of SM Monte Carlo events after these selections is shown in table 1. The background composition in each channel is displayed in table 2.

The agreement between data and Monte-Carlo is not excellent at early stages, because of known, still uncorrected for, inacuracies of the SM generators. Nevertheless, there is clearly no excess of data in any of the 3 channels.

3 Interpretation of the results

Given that no excess of data is found, it is possible to derive limits on the parameters of the model, namely the MSSM with R-parity violation.

$2l$-selection	# of data evts	Nb of SM MC evts
Preselection	805	861.7
$N_{ch} = 2$	578	657.6
2 id. leptons	104	126.1
Acoplanarity$< 160^o$	72	96.5
not 2μ	39	50.5
$E_{miss} \geq 0.45 \times \sqrt{s}$	28	36.1
$20^o \leq \alpha \leq 120^o$	15	22.6
$p(l_2) < 35$ GeV	12	18.2
$M_{ll} \leq 45$ GeV	11	12.3
$p_{miss} - M_{ll} > 5$ GeV	10	$9.5 \pm 1.$

$4l$-selection	# of data evts	Nb of SM MC evts
Preselection	805	861.7
$3 \leq N_{ch} \leq 6$	227	204.
≥ 3 id. leptons	2	2.9 ± 0.5

Multi-l multi-j selection	# of data evts	Nb of SM MC evts
Preselection	6061	5822.
$7 \leq N_{ch} \leq 20$	2908	2831.2
≥ 2 id. leptons	259	301.5
$y_{34} > 10^{-3}$	119	150.1
$p_T(l_2) > 10$ GeV	10	11.7
$n_{tot}(j_1) < 5$	6	5.8
$M_{ll} > 15$ GeV	5	4.8 ± 0.5

Table 1: Data/MC comparison at each step of the event selection.

	$\tau\tau(\gamma)$	$\gamma\gamma \to ll$	$l\nu l\nu$	All
$2l$	0.1	2.	7.4	9.5

	Bhabha	$ll(\gamma)$	$\gamma\gamma \to \tau\tau$	$llll$	WW-like	All
$4l$	0.8	0.7	0.15	0.9	0.35	2.9

	$q\bar{q}(\gamma)$	WW-like	$llq\bar{q}$	All
leptons+jets	0.3	2.1	2.4	4.8

Table 2: Background composition.

3.1 Method

The results of this kind of analysis are usually presented as a limit on λ as a function of the sneutrino mass, assuming a fixed width for the sneutrino. This is an over simplification given that $\Gamma_{\tilde{\nu}}$ changes with μ, M_2, $\tan\beta$, m_0 (and λ in case of a very small $\Gamma_{\tilde{\nu}}$) and enters directly in the production. We therefore explored the robustness of the limits against this assumption and present also the results as a function of both the mass and the total width of the sneutrino, for a low and for a high value of $\tan\beta$.

We have used the `SUSYGEN 2.20/03` program to scan a wide portion of the MSSM parameter space (111,848 points for each $\tan\beta$) and compute all the cross sections of our final states. The parameter ranges were:

- $\tan\beta = 1.5$ or 30.,
- $m_0 = 60$ to 220 GeV in steps of 10 GeV ($m_0 = 170$ to 200 GeV in steps of 1 GeV),
- $M_2 = 5$ to 405 GeV in steps of 10 GeV,
- $\mu = \pm 5$ to ± 305 GeV in steps of 10 GeV.

This scan gave $m(\chi_1^0) \leq 210$ GeV and $45 \leq m(\chi_1^+) \leq 315$ GeV.

Several sets of MSSM parameters lead to the same ($M_{\tilde{\nu}}$, $\Gamma_{\tilde{\nu}}$) couple. In order to derive parameter independent limits, one should then use the minimum cross section obtained in a given ($M_{\tilde{\nu}}$, $\Gamma_{\tilde{\nu}}$) bin for a given λ. In other words, the highest value of the upper limit obtained on λ was kept in each bin.

3.2 Existing limits

During the scan, one should not consider parameter combinations that have already been excluded by other DELPHI or LEP studies. One process that has been very precisely measured recently is the Z resonance parameters.

At the resonance, $\sigma(e^+e^- \rightarrow Z \rightarrow X) = 12\pi \frac{\Gamma_{ee}\Gamma_X}{M_Z^2 \Gamma_Z^2}$.

Using the LEP lineshape data and the SLD left-right asymmetry, a limit on the decay width of the Z into unpredicted modes has been derived: $\Gamma_Z^{new} < 6.3$ MeV at 95% CL [16].

Under the assumption that the unpredicted modes are pair production via the s-channel, using the measured values of Γ_Z and Γ_{ee}, this limit on Γ_Z^{new} can be converted into an upper limit on the cross section for new decay modes of the Z: $\sigma_Z^{new}(\sqrt{s} \simeq M_Z) < 150$ pb at 95% CL.

Pair production of neutralinos and charginos was chosen to exclude some SUSY parameter combinations thanks to the limit on σ_Z^{new}. In neutralino or chargino pair production, the t-channel contribution affects significantly the cross section only for low values of m_0 (light sfermions), and only when the s-channel alone cross section is small, much below 150 pb. Thus our assumption does not bias the result.

3.3 Results

The three channels being totally independant thanks to the charged multiplicity criterion, they could be summed: the number of candidates was then 17, whereas the number of expected events was 16.3. This gives an upper limit on the number of signal events at 95% C.L. of 10.4.

The resulting exclusion plots are shown in figure 1: for each scanned sneutrino mass and width, an upper limit on λ_{121} is given at 95% C.L.

One can also derive an upper limit on λ_{121} as a function of $M_{\tilde{\nu}}$ only, assuming a not too small sneutrino width, e.g. $\Gamma_{\tilde{\nu}} \geq 0.2$ GeV[1]; this is shown in figure 2.

In principle, this allows to compare the result of this analysis with the $e^+e^- \to l^+l^-$ analyses ([3]–[5]). DELPHI's reaches the level of $\lambda_{121} < 0.02$ at 95% CL with 172 GeV data, whereas L3's and OPAL's go approximately down to $\lambda_{121} < 0.015$ with 183 GeV data (five times more statistics). The present analysis gives at the best point, namely $M_{\tilde{\nu}} \simeq \sqrt{s}$, with 189 GeV data $\lambda_{121} < 0.0015$ at 95% CL.

Conclusion

Although preliminary, this analysis already gives stronger limits than those fitting the $e^+e^- \to l^+l^-$ cross section, as expected. It will still improve in the next few months, first by analysing reprocessed data, using the latest alignments and calibrations, and also thanks to a better understanding of the Monte Carlo generators for Standard Model processes.

[1]this implies $m(\chi_1^0) \leq 130$ GeV and $45 \leq m(\chi_1^+) \leq 200$ GeV

References

[1] V.Barger et al, Phys. Rev. **D40** (1989) 2987

[2] F. Ledroit and G. Sajot, GDR–S–008 (http://qcd.th.u-psud.fr/GDR_SUSY/GDR_SUSY_PUBLIC/entete_note_publique)

[3] P.J.Holt and P. Renton, DELPHI 97-116 CONF 98, submitted to HEP'97 (abstract # 467) and DELPHI collaboration, CERN-EP/99-05

[4] M. Acciari et al., L3 collaboration, Phys. Lett. **B414** (1997) 373;
updated with 183 GeV data in the contribution of L3 coll. to ICHEP 98: L3 Note 2235

[5] OPAL collaboration, CERN-EP/98-108

[6] DELPHI collaboration, DELPHI 97-119 CONF 101, submited to HEP97 (abstract # 589)

[7] F. Ledroit-Guillon and R. López-Fernández, DELPHI 98-165 PHYS 805

[8] ALEPH collaboration, ALEPH 98-070, submitted to ICHEP 98 (Abstract Number 949)

[9] F.A. Berends, P.H. Davervelt, R. Kleiss, Comp. Phys. Comm. **40** (1986) 271

[10] S. Nova, A. Olchevski, T. Todorov, DELPHI 90-35 PROG 152

[11] J.E. Campagne, R. Zitoun, Z. Phys. **C43** (1989) 469

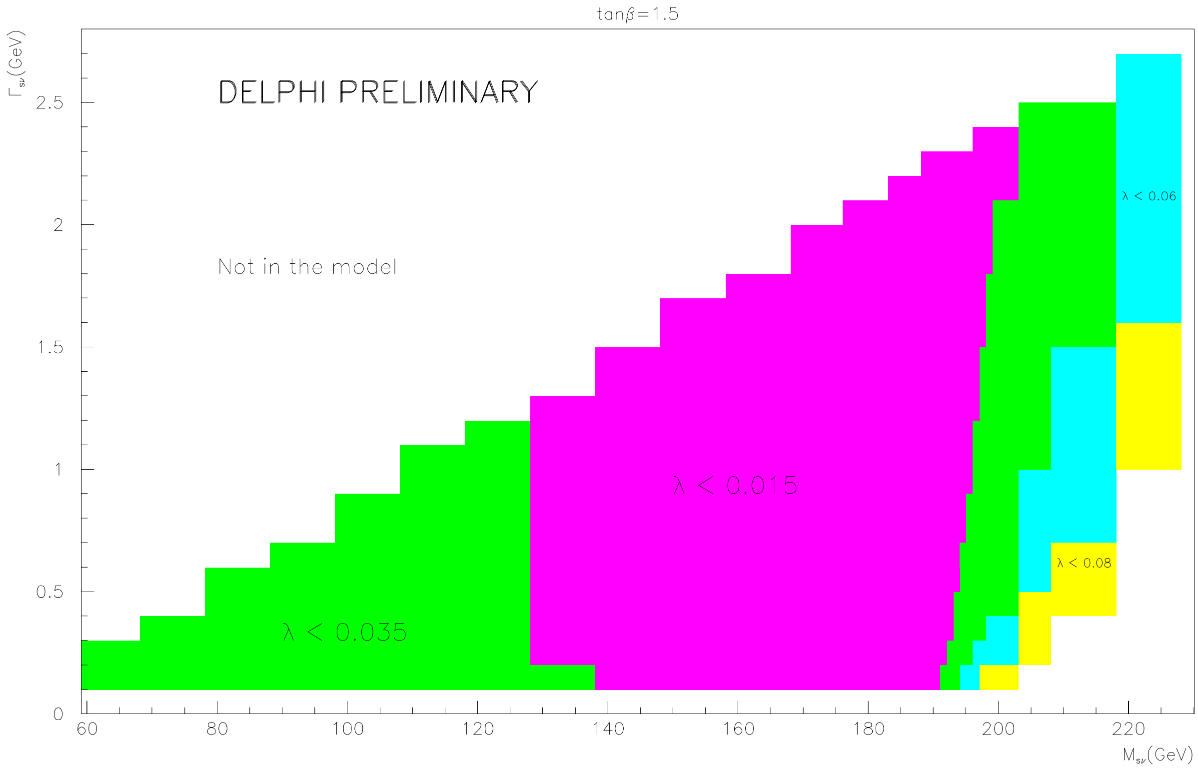
[12] S. Jadach, Z. Was, Comp. Phys. Comm. **79** (1994) 503

[13] F.A. Berends, R. Kleiss, R. Pittau, Comp. Phys. Comm. **85** (1995) 437

[14] S. Katsanevas, P. Morawitz, Comp. Phys. Comm. **112** (1998) 227

[15] http://home.cern.ch/ berggren/sgv.html

[16] K. Mönig, "Model Independent Limit of the Z-Decay-Width into Unknown Particles", DELPHI 97-174 PHYS 748



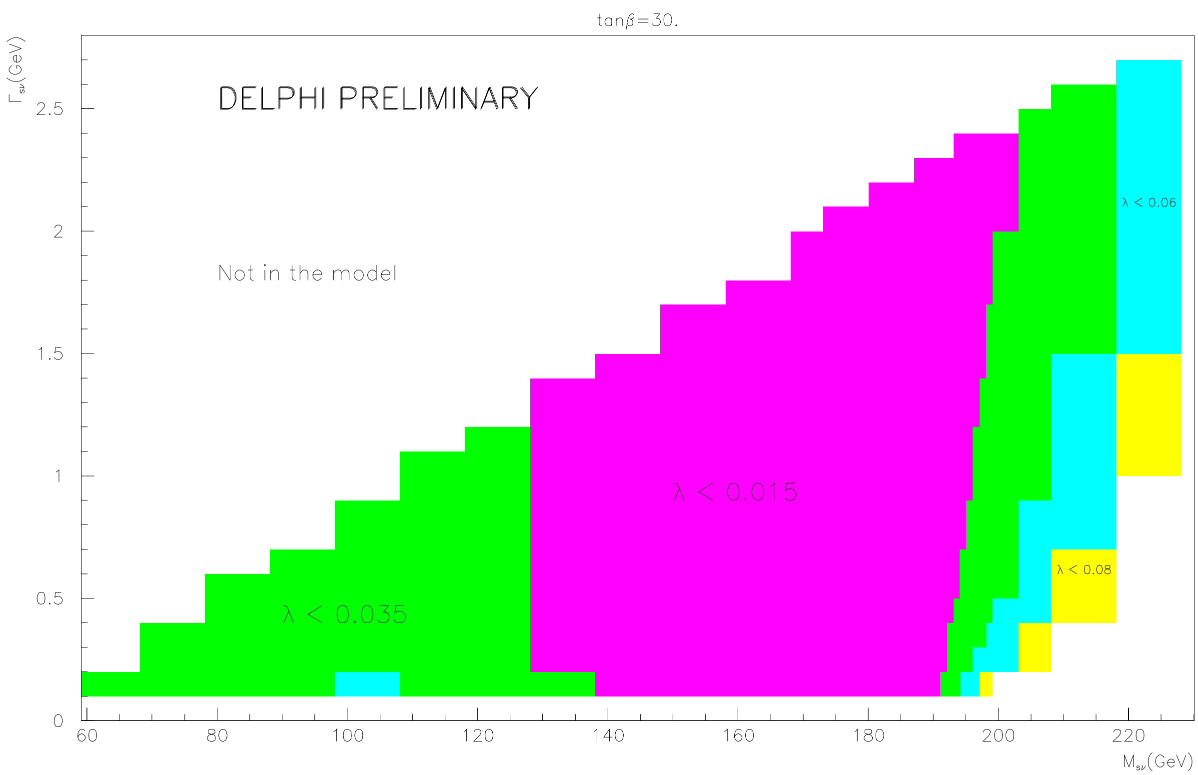


Figure 1: For $\tan\beta = 1.5$ (top) and $\tan\beta = 30.$ (bottom), upper limit on λ_{121} as a function of $M_{\tilde{\nu}}$ and $\Gamma_{\tilde{\nu}}$.

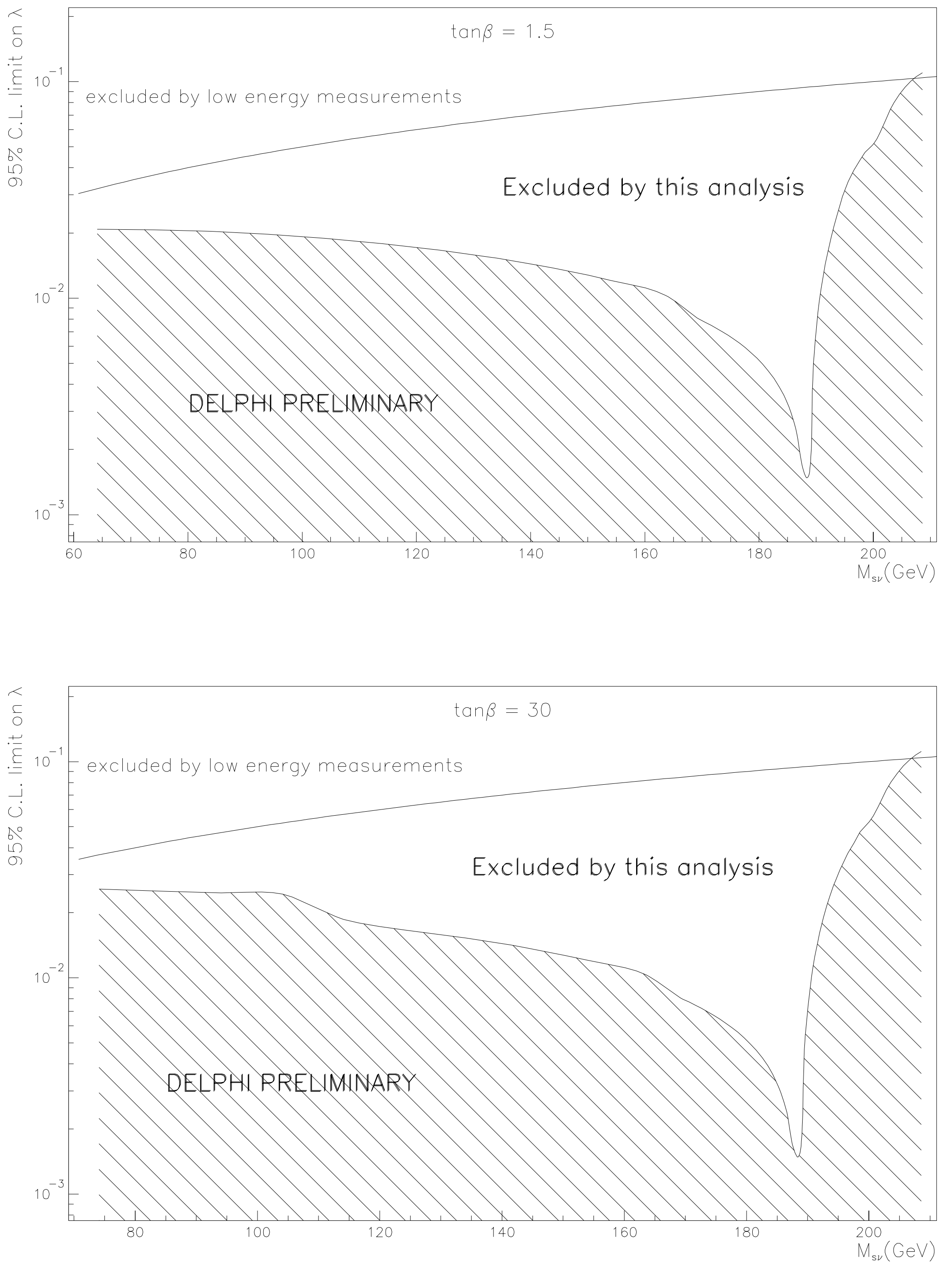


Figure 2: For $\tan\beta = 1.5$ (top) and $\tan\beta = 30.$ (bottom), upper limit on λ_{121} as a function of $M_{\tilde{\nu}}$, assuming $\Gamma_{\tilde{\nu}} > 0.2$ GeV. The indirect limit given by low energy measurements is given assuming $M_{\tilde{\nu}} = M_{\tilde{e}}$.