

Wide Scalar Neutrino Resonance and $b\bar{b}$ Production at the CERN Collider LEP

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In supersymmetric models with R -parity violation, scalar neutrinos $\tilde{\nu}$ may be produced as s -channel resonances in e^+e^- colliders. We note that within current constraints the scalar neutrino may have a width of several GeV into $b\bar{b}$ and be produced with large cross section, leading to a novel supersymmetry discovery signal at the CERN collider LEP II. In addition, if $m_{\tilde{\nu}} \approx m_Z$, such a resonance necessarily increases R_b and reduces $A_{FB}(b)$, significantly improving the fit to electroweak data. Bounds from B meson and top quark decays are leading constraints, and we stress the importance of future measurements. [S0031-9007(97)03014-7]

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One of the important goals of future collider experiments is to search for and possibly discover supersymmetry. In the most widely analyzed supersymmetric extension of the standard model (SM), the superpotential is assumed to be $W = h_E H_1 L E^c + h_D H_1 Q D^c - h_U H_2 Q U^c - \mu H_1 H_2$, where the lepton and quark superfields $L = (N, E)$, E^c , $Q = (U, D)$, U^c , and D^c contain the SM fermions f and their scalar partners \tilde{f} , and generation indices have been omitted. This superpotential conserves R parity, $R_P = (-1)^{2J+3B+L}$, where J , B , and L are spin, baryon number, and lepton number, respectively. R_P conservation strongly restricts the phenomenology, as it implies that superpartners must be produced in pairs and that the lightest supersymmetric particle (LSP) is stable.

The superpotential above, however, is not the most general allowed by gauge invariance and renormalizability. In particular, as the superfields H_1 and L have the same quantum numbers, the R_P -violating (\mathcal{R}_P) terms

$$W_{\mathcal{L}} = \lambda L L E^c + \lambda' L Q D^c \quad (1)$$

are allowed. We will consider these couplings, the most general trilinear \mathcal{R}_P terms that violate lepton number but not baryon number. (Note that proton stability requires only approximate conservation of either lepton or baryon number.) Such terms have a number of interesting properties, including the possibility of providing new avenues for neutrino mass generation [1,2], which otherwise must be attributed to some grand-scale sector of the theory, as in, e.g., see-saw models. Here, we focus on another implication of these terms, namely, the possibility of sneutrino resonances at e^+e^- colliders [3,4]. Such resonances offer the unique opportunity to probe supersymmetric particle masses up to \sqrt{s} , which, at LEP II, is well into the range typically predicted for slepton masses.

The superpotential of Eq. (1) generates couplings

$$\begin{aligned} \mathcal{L}_{\mathcal{L}} = & \lambda_{ijk} [\tilde{e}_L^i \bar{e}_R^k \nu_L^j + \tilde{\nu}_L^j \bar{e}_R^k e_L^i + (\tilde{e}_R^k)^* (\bar{e}_L^i)^c \nu_L^j] \\ & - \lambda_{ijk} [\tilde{\nu}_L^i \bar{e}_R^k e_L^j + \tilde{e}_L^j \bar{e}_R^k \nu_L^i + (\tilde{e}_R^k)^* (\bar{\nu}_L^i)^c e_L^j] \\ & + \lambda'_{lmn} V_{CKM}^{*pm} [\tilde{e}_L^l \bar{d}_R^m u_L^p + \tilde{u}_L^p \bar{d}_R^m e_L^l + (\tilde{d}_R^m)^* (\bar{e}_L^l)^c u_L^p] \\ & - \lambda'_{lmn} [\tilde{\nu}_L^l \bar{d}_R^m d_L^m + \tilde{d}_L^m \bar{d}_R^m \nu_L^l + (\tilde{d}_R^m)^* (\bar{\nu}_L^l)^c d_L^m], \quad (2) \end{aligned}$$

where V_{CKM} is the Cabibbo-Kobayashi-Maskawa matrix, we assume f - \tilde{f} alignment, $i < j$, and the other generation indices are arbitrary. As we will concentrate on the sneutrino $\tilde{\nu}$, we have chosen the basis in which NDD^c is diagonal; implications of choosing another basis will be discussed below.

The interactions of Eq. (2) imply that sneutrinos may be produced as s -channel resonances with cross section

$$\sigma(e^+e^- \rightarrow \tilde{\nu} \rightarrow X) = \frac{8\pi s}{m_{\tilde{\nu}}^2} \frac{\Gamma_{\tilde{\nu} \rightarrow e^+e^-} \Gamma_{\tilde{\nu} \rightarrow X}}{(s - m_{\tilde{\nu}}^2)^2 + m_{\tilde{\nu}}^2 \Gamma_{\tilde{\nu}}^2}. \quad (3)$$

(Lepton pair production may also receive contributions from t -channel $\tilde{\nu}$ exchange.) If the sneutrino is the LSP, it decays to pairs of charged leptons or down-type quarks with width

$$\Gamma_{\tilde{\nu} \rightarrow f\bar{f}} = N_c \frac{g^2}{16\pi} m_{\tilde{\nu}}, \quad (4)$$

where N_c is the color factor and g is the relevant \mathcal{R}_P coupling. Decays to neutrinos and up-type quarks are prohibited by gauge invariance. On the other hand, if the LSP is the lightest neutralino χ^0 , the sneutrino may also decay through $\tilde{\nu} \rightarrow \nu \chi^0$, with partial width $\sim 0.1 - 1$ GeV for $m_{\tilde{\nu}} \sim 100 - 200$ GeV [4]. The neutralino χ^0 then decays to three SM fermions through \mathcal{R}_P interactions.

In this study, motivated by the Yukawa renormalization of the scalar spectrum, which typically leaves the third generation scalar fields lighter than the first two, we focus on the possibility of a $\tilde{\nu}_\tau$ resonance. In addition, we

concentrate on $\tilde{\nu}_\tau$ decays to $b\bar{b}$ pairs, as the possibility of a wide resonance will be evident from considerations of this channel alone. We therefore consider the scenario in which the nonzero couplings of Eq. (2) are λ_{131} and λ'_{333} , and, for simplicity, we take these to be real. Note, however, that a $\tilde{\nu}_\mu$ resonance and decays to other final states, e.g., $b\bar{d}$, and $b\bar{s}$, though more highly constrained, are also possible in principle.

Bounds on λ_{131} and λ'_{333} , taken individually, have been considered previously, and the strongest of these are $\lambda_{131} < 0.10 [m_{\tilde{e}_R}/100 \text{ GeV}]$ from $\Gamma(\tau \rightarrow e\nu\bar{\nu})/\Gamma(\tau \rightarrow \mu\nu\bar{\nu})$ [4], and $\lambda'_{333} < 0.6\text{--}1.3 (2\sigma)$ from R_τ [5], where the range is for $m_{\tilde{q}} = 2m_{\tilde{l}} = 300 \text{ GeV--}1 \text{ TeV}$. These and the new bounds derived below are collected in Table I.

In the limit of large scalar masses, the interactions of Eq. (2) induce many four-fermion operators, some of which mediate meson decays. A competitive bound on λ'_{333} arises from $B \rightarrow \tau\bar{\nu}X$ through the \mathcal{R}_P operator $-\frac{\lambda'_{333}}{m_{\tilde{b}_R}^2} V_{cb}[(\bar{\nu}_{\tau L})^c b_L](\bar{c}_L(\tau_L)^c)$. After a Fierz transformation, this is seen to interfere constructively with the SM operator to give

$$-V_{cb} \left[\frac{4G_F}{\sqrt{2}} + \frac{\lambda'_{333}}{2m_{\tilde{b}_R}^2} \right] \bar{c}_L \gamma_\mu b_L \bar{\tau}_L \gamma^\mu \nu_\tau. \quad (5)$$

The experimental bound and SM prediction for $B(B \rightarrow \tau\bar{\nu}X)$ are $2.68\% \pm 0.34\%$ [6] and $2.30\% \pm 0.25\%$ [7], respectively. Simply combining these errors in quadrature and demanding that the \mathcal{R}_P -enhanced rate be below the current upper bound, we find the constraint $\lambda'_{333} < 0.96 [m_{\tilde{b}_R}/300 \text{ GeV}]$.

Meson decays also bound the product $\lambda_{131}\lambda'_{333}$, which enters in the cross section of Eq. (3). The operator $-\frac{\lambda_{131}\lambda'_{333}}{m_{\tilde{\tau}_L}^2} V_{pb}(\bar{e}_R\nu_L)(\bar{u}_L b_R)$ is most stringently bounded by taking $p = u$ and considering $B^- \rightarrow e^-\bar{\nu}$. The SM contribution to this decay is helicity suppressed and negligible. The \mathcal{R}_P decay width may be calculated using $\langle 0|\bar{u}\gamma^5 b|B^- \rangle = -if_B m_B^2/m_b$ [8] to be

$$\Gamma = \frac{1}{64\pi} |V_{ub}|^2 \lambda_{131}^2 \lambda_{333}^2 \frac{1}{m_{\tilde{\tau}_L}^4} \frac{f_B^2 m_B^5}{m_b^2}. \quad (6)$$

Applying the current bound $B(B^- \rightarrow e^-\bar{\nu}) < 1.5 \times 10^{-5}$ [9], and taking $V_{ub} > 0.0024$, $f_B > 140 \text{ MeV}$, and $m_b = 4.5 \text{ GeV}$, we find the upper bound $\lambda_{131}\lambda'_{333} < 0.075 [m_{\tilde{\tau}_L}/100 \text{ GeV}]^2$.

The \mathcal{R}_P couplings are also constrained by other B decays, Y decays, and the collider bound on m_{ν_τ} . These bounds, however, are not competitive with those discussed above.

TABLE I. Upper bounds on the couplings λ_{131} and λ'_{333} .

Coupling	Upper Bound	Process
λ_{131}	$0.10 [m_{\tilde{e}_R}/100 \text{ GeV}]$	$\frac{\Gamma(\tau \rightarrow e\nu\bar{\nu})}{\Gamma(\tau \rightarrow \mu\nu\bar{\nu})}$ [4]
λ'_{333}	$0.6\text{--}1.3 (2\sigma)$	R_τ ($m_{\tilde{q}} = 0.3\text{--}1 \text{ TeV}$) [5]
λ'_{333}	$0.96 [m_{\tilde{b}_R}/300 \text{ GeV}]$	$B \rightarrow \tau\bar{\nu}X$
$\lambda_{131}\lambda'_{333}$	$0.075 [m_{\tilde{\tau}_L}/100 \text{ GeV}]^2$	$B^- \rightarrow e^-\bar{\nu}$

In addition, under the assumption that only λ'_{333} is nonzero, there are no contributions to $K^0 - \bar{K}^0$ and $B^0 - \bar{B}^0$ mixing, and $D^0 - \bar{D}^0$ mixing gives an extremely weak constraint. If we had worked in the basis in which EUD^c is diagonal and considered the possibility of only λ'_{333} nonzero, the \mathcal{R}_P interactions would contribute to neutral K and B meson mixing, as well as to $\Delta B = 1$ neutral current decays. The bound from $B^0 - \bar{B}^0$ mixing is stronger than the one from $K^0 - \bar{K}^0$ mixing, and is $\lambda'_{333} < 1.1$ for scalar masses of 100 GeV [10]. $B(B^0 \rightarrow e^+e^-) < 5.9 \times 10^{-6}$ [9] and $B(B^0 \rightarrow K^0 e^+e^-) < 3 \times 10^{-4}$ [9] both imply $\lambda_{131}\lambda'_{333} \lesssim 0.03 [m_{\tilde{\nu}_\tau}/100 \text{ GeV}]^2$. We see then that numerically the bounds are fairly basis independent.

An independent set of constraints arises from the exotic top quark decay mode $t_L \rightarrow b_R \tilde{\tau}_L^+$, assuming it is kinematically allowed. [Note that $SU(2)$ invariance requires $m_{\tilde{\tau}_L} \approx m_{\tilde{\nu}_\tau}$.] For $m_t = 175 \text{ GeV}$,

$$R_t \equiv \frac{\Gamma_{t \rightarrow b\tilde{\tau}}}{\Gamma_{t \rightarrow bW}} = 1.12 \lambda_{333}^2 \left[1 - \left(\frac{m_{\tilde{\tau}_L}}{175 \text{ GeV}} \right)^2 \right]^2. \quad (7)$$

If the sneutrino is the LSP, the three-body decays $\tilde{\tau} \rightarrow \tilde{\nu}_\tau f \bar{f}'$ and $\tilde{\tau} \rightarrow W b \bar{b}$ are sufficiently phase space suppressed that the dominant decay mode is either $\tilde{\tau} \rightarrow \bar{c} b$ or $\tilde{\tau} \rightarrow e \bar{\nu}_e$. The former is suppressed by $|V_{cb}|^2 \lambda_{333}^2$, and the latter by λ_{131}^2 . As top constraints will be important only for large λ'_{333} , we first assume that the $\bar{c} b$ mode is dominant. This new decay mode alters the number of $t\bar{t}$ events expected in each channel, both through an enhancement of the percentage of hadronic decays and through the increased probability of b -tagging events with b -rich $\tilde{\tau}$ decays. For each channel, we denote the number of events expected in the presence of $\tilde{\tau}$ decays relative to the number expected in the SM as

$$R_B(x) \equiv \frac{B(t\bar{t} \rightarrow X; x)}{B(t\bar{t} \rightarrow X; x=0)}, \quad (8)$$

where $x = B(t \rightarrow b\tilde{\tau}) = R_t/(1 + R_t)$. The expressions for these ratios are given in Table II, where $\varepsilon_{m,n}$ denotes the probability of tagging at least m of n b jets. The SVX b -tagging efficiency for $t\bar{t}$ events is $\varepsilon_{1,2} = 41 \pm 4\%$ [11]. Crudely neglecting the dependence of b -tagging efficiencies on the number of jets and jet momenta, the remaining b -tagging efficiencies are then determined by $\varepsilon_{1,2}$ to be, e.g., $\varepsilon_{1,3} \approx 55\%$ and $\varepsilon_{1,4} \approx 65\%$. This approximation is conservative when $m_{\tilde{\tau}}$ approaches m_t , as the soft b jets lower $\varepsilon_{1,n}$, but we will ignore this effect here.

Based on an event sample of 110 pb^{-1} , the production cross section has been measured by CDF to be $\sigma[t\bar{t}]_{\text{exp}} =$

TABLE II. The ratios $R_B(x)$, where H is the W hadronic branching fraction, and $\varepsilon_{m,n}$ are b -tagging efficiencies.

Channel	$R_B(x)$
Dilepton	$(1 - x)^2$
Lepton + jets	$(1 - x)^2 + \frac{\varepsilon_{1,3}}{\varepsilon_{1,2}} \frac{1}{H} x(1 - x)$
All-hadronic	$(1 - x)^2 + \frac{\varepsilon_{1,3}}{\varepsilon_{1,2}} \frac{1}{H} 2x(1 - x) + \frac{\varepsilon_{1,4}}{\varepsilon_{1,2}} \frac{1}{H^2} x^2$

$8.3^{+4.3}_{-3.3}$, $6.4^{+2.2}_{-1.8}$, and $10.7^{+7.6}_{-4.0}$ pb in the dilepton, SVX lepton + jets, and all-hadronic channels, respectively [11]. The SM theoretical expectation for $m_t = 175$ GeV is $\sigma[t\bar{t}]_{\text{QCD}} = 5.5^{+0.1}_{-0.4}$ pb [12]. The coupling λ'_{333} may then be bounded by requiring that $R_B(x)$ lie within the measured range of $\sigma[t\bar{t}]_{\text{exp}}/\sigma[t\bar{t}]_{\text{QCD}}$ for each channel. The 2σ upper bound from the dilepton channel is $\lambda'_{333} < 1.3$ for $m_{\tilde{\tau}_L} = 100$ GeV and is degraded to $\lambda'_{333} < 3.2$ for $m_{\tilde{\tau}_L} = 150$ GeV. Significantly weaker constraints arise from the other channels. We see that these counting experiments currently give weak constraints. In addition, given the number of $t\bar{t}$ candidate events at present and the low probability of tagging three or more b jets, there are no available limits from such multi- b -tagged events; eventually, these limits may strongly constrain λ'_{333} [10].

A more promising approach is to examine kinematic parameters in $t\bar{t}$ events, e.g., the reconstructed W mass in lepton + jets events with a second loosely tagged b [11]. (The two untagged jets define m_W .) In a sample of N such events, an upper bound of three events outside the m_W peak would imply $\varepsilon_{2,3}/\varepsilon_{2,2}[R_t/H] < 3/N$, where we have ignored differences between the usual and loose b -tag efficiencies. Currently, with just ten events, this gives $\lambda'_{333} \lesssim 0.4(1.0)$ for $m_{\tilde{\tau}_L} = 100(150)$ GeV. Such kinematic analyses may, therefore, provide strong constraints on R_P couplings in the future.

If λ_{131} is large enough that the decay mode $\tilde{\tau} \rightarrow e\bar{\nu}_e$ dominates, the R_P decay violates e - μ universality in t decays [10], leading to the constraint $\lambda'_{333} < 0.35(0.90)$ for $m_{\tilde{\tau}_L} = 100(150)$ GeV. Finally, we briefly comment on the neutralino LSP case, which was discussed in Ref. [10]. In our case, the decay $\tilde{\tau} \rightarrow \tau\chi^0 \rightarrow \tau\nu b\bar{b}$ may be constrained by counting experiments as above, but with the substitutions $\varepsilon_{1,3} \rightarrow \varepsilon_{1,4}$ and $\varepsilon_{1,4} \rightarrow \varepsilon_{1,6}$ in $R_B(x)$. The dilepton channel again gives the strongest bounds, and, as these are independent of b -tagging efficiencies, we again find $\lambda'_{333} < 1.3(3.2)$ for $m_{\tilde{\tau}_L} = 100(150)$ GeV. With more $t\bar{t}$ candidate events, one could also constrain the τ excess in the different channels.

We conclude, therefore, that couplings $\lambda_{131} \sim \mathcal{O}(0.1)$ and $\lambda'_{333} \sim \mathcal{O}(1)$ are consistent with all of the constraints considered above. With such couplings, a sneutrino with $m_{\tilde{\nu}} \lesssim 190$ GeV will be singly produced at LEP II and may be observed as a resonance with $\Gamma_{\tilde{\nu}} \approx 6.0 \text{ GeV} \times \lambda'^2_{333}[m_{\tilde{\nu}}/100 \text{ GeV}]$. (Of course, if light enough, sneutrinos may also be pair produced at LEP II and will be easily discovered through their b quark signature [13].) Such a resonance could be discovered as a peak in the initial state radiation (ISR)-induced tails of $\sqrt{s_{\text{eff}}}$ distributions in two jet events. For fixed values of $m_{\tilde{\nu}}$, λ_{131} , and λ'_{333} , one may estimate the effective luminosity at $\sqrt{s_{\text{eff}}} \approx m_{\tilde{\nu}}$ required to discover such a peak. We demand a 5σ $b\bar{b}$ excess in a bin centered at $m_{\tilde{\nu}}$ of width $\max\{2 \text{ GeV}, 2\Gamma_{\tilde{\nu}}\}$ and assume a tagging efficiency of 40% for $b\bar{b}$ events. The required luminosities have nontrivial dependences on the various parameters; a sample of results is given in Table III. Examples D and F are already probed, in prin-

TABLE III. The effective integrated luminosity \mathcal{L}_{eff} per 1 GeV bin required to discover a sneutrino resonance with $m_{\tilde{\nu}}$, λ_{131} , and λ'_{333} as given.

	A	B	C	D	E	F
$m_{\tilde{\nu}}$ (GeV)	110	110	110	145	145	145
λ_{131}	0.01	0.005	0.005	0.01	0.005	0.005
λ'_{333}	1.0	1.0	0.1	1.0	1.0	0.1
\mathcal{L}_{eff} (pb $^{-1}$ /GeV)	1.1	18	1.3	0.45	7.1	0.43

ciple, by the luminosity available in the ISR tails of the $\sqrt{s} = 130$ – 174 GeV runs, provided that the data of the four experiments are combined. A total integrated luminosity of $\sim 500 \text{ pb}^{-1}$ per detector at $\sqrt{s} \approx 190$ GeV will yield an effective luminosity sufficient to probe examples A and C . Coverage of the parameter space may be further improved by runs at lower beam energies with a luminosity of $\mathcal{O}(10 \text{ pb}^{-1})$, which would probe examples B and E . Such runs would also probe the parameter space if the neutralino is the LSP and $\tilde{\nu} \rightarrow \nu\chi^0 \rightarrow \nu\nu b\bar{b}$, as the final state in this case is still characterized by an excess of b jets, but with a smeared $\sqrt{s_{\text{eff}}}$ spectrum. We conclude that values of $\lambda_{131}\lambda'_{333}$ more than two orders of magnitude below current bounds could be probed by the LEP experiments. These analyses and searches therefore offer exciting, if unconventional, possibilities for the discovery of supersymmetry.

Finally, a most interesting window for the sneutrino resonance exists near the Z pole, illustrating the possibility of new physics hidden by the Z resonance [14]. It is intriguing that a $\tilde{\nu}$ resonance in this window necessarily increases R_b and decreases $A_{\text{FB}}(b)$, in accord with current measurements [15]. In addition, gauge invariance prohibits the $\tilde{\nu}$ from directly affecting $c\bar{c}$ production, and we have explicitly confirmed that direct effects on leptonic observables, e.g., the t -channel $\tilde{\nu}$ contribution to $A_{\text{FB}}(e)$, are negligible given the constraints on λ_{131} . We have performed a Z line shape fit including the sneutrino resonance in the sneutrino LSP scenario. Our treatment and approximations follow closely those described in Ref. [14], where four-fermion operators with cross sections depending linearly on s were studied; here, we superimpose a second s resonance on that of the Z .

We restricted our line shape fit to the published data of only one LEP group (L3) [16] from the years 1990–1992. This will suffice, as here we are interested in the changes caused by the introduction of a sneutrino with $m_{\tilde{\nu}} \approx m_Z$. We also included the SLD Collaboration's determination of the left-right polarization asymmetry A_{LR} , recorded during 1992–1995 [17], and results of the LEP and SLD heavy flavor groups, as reported in Ref. [15]. The latter include the $Z \rightarrow b\bar{b}$ branching ratio R_b , which we interpret as a relative measurement of cross sections, and the b quark forward-backward asymmetry $A_{\text{FB}}(b)$ at three center of mass energies on peak and approximately ± 2 GeV off peak. In addition, we incorporated bounds from the DELPHI Collaboration on the ratio of $\sim \pm 2$ GeV

off-peak to on-peak values of R_b : $R_b^{-2}/R_b^0 = 0.982 \pm 0.015$ and $R_b^{+2}/R_b^0 = 0.997 \pm 0.016$ [18]. These constraints are stringent, as systematic errors cancel in the ratios. Aside from the standard line shape variables, namely, m_Z , Γ_Z , $\Gamma(Z \rightarrow e^+e^-)$, and the hadronic peak cross section, σ_{had}^0 , we simultaneously fit to the $\tilde{\nu}$ mass and to its partial decay widths into e^+e^- and $b\bar{b}$ pairs.

We find that a sneutrino near the Z resonance is not excluded by the high precision scans of the Z line shape. After introducing the three fit parameters associated with the sneutrino, the overall χ^2 improves significantly. We find one minimum with $m_{\tilde{\nu}} = 91.79 \pm 0.54$ GeV, $\Gamma_{\tilde{\nu}} = 1.7_{-1.4}^{+2.0}$ GeV, $\lambda_{131} = 0.013_{-0.006}^{+0.004}$, $\lambda'_{333} = 0.56_{-0.30}^{+0.27}$, and $\chi^2/\text{d.o.f.} = 54.1/51$, relative to 60.6/54 in the SM. The improvement in the fit comes primarily from R_b and $A_{\text{FB}}(b)$ as may be seen in Table IV. The sneutrino width is dominated by the partial decay width into $b\bar{b}$, which in turn is strongly correlated with the width into e^+e^- pairs. The reason for this, and for the large error range, is that the $\tilde{\nu}$ peak cross section for $b\bar{b}$ pairs is, for a given $m_{\tilde{\nu}}$, roughly determined by the R_b data and given by

$$\sigma_{b\bar{b}}^0 = \frac{8\pi\Gamma_{\tilde{\nu} \rightarrow e^+e^-}\Gamma_{\tilde{\nu} \rightarrow b\bar{b}}}{m_{\tilde{\nu}}^2\Gamma_{\tilde{\nu}}^2} \approx \frac{8\pi\Gamma_{\tilde{\nu} \rightarrow e^+e^-}}{m_{\tilde{\nu}}^2\Gamma_{\tilde{\nu} \rightarrow b\bar{b}}} \quad (9)$$

The extracted Z line shape parameters are almost identical to the SM, except that σ_{had}^0 is reduced by $\frac{2}{3}$ of a standard deviation, slightly lowering the extracted α_s .

Fits with comparable χ^2 also exist for $m_{\tilde{\nu}}$ below the Z peak. In fact, an even better fit exists with $m_{\tilde{\nu}} = 90.28$ GeV, $\Gamma_{\tilde{\nu}} = 0.003$ GeV, $\lambda_{131} = 0.027$, $\lambda'_{333} = 0.016$, and $\chi^2/\text{d.o.f.} = 53.6/51$. This narrow width minimum is made possible by initial state radiation, which has the effect of broadening the $\tilde{\nu}$ resonance, allowing it to improve the χ^2 for scan points with $\sqrt{s} > m_{\tilde{\nu}}$.

It is important to note that the location of $m_{\tilde{\nu}}$ and the size of the allowed window is largely dictated by the DELPHI off-peak results for R_b . Omitting them would enlarge the window and also allow an improvement in the prediction for $A_{\text{FB}}(b)$ at the peak + 2 GeV position. We would like to encourage the other LEP groups to perform a similar analysis of their off-peak data.

In conclusion, we have discussed the possibility of \tilde{R}_P sneutrino resonances at LEP. We find that the relevant \tilde{R}_P operators are only moderately constrained at present, leaving open the possibility of a sneutrino width of several GeV. Such a resonance is the unique opportunity to directly probe supersymmetric masses up to \sqrt{s} , greatly extending the reach in supersymmetry parameter space, and could be discovered at LEP II either through analyses

TABLE IV. Total $\chi^2/\text{d.o.f.}$ and χ^2 contributions from R_b and $A_{\text{FB}}(b)$ below, on, and above peak, for our fit to the SM with and without the $\tilde{\nu}$ resonance.

	$\chi^2/\text{d.o.f.}$	R_b^{-2}	R_b^0	R_b^{+2}	$A_{\text{FB}}^{-2}(b)$	$A_{\text{FB}}^0(b)$	$A_{\text{FB}}^{+2}(b)$
SM	60.6/54	1.2	4.5	0.0	1.1	2.6	2.3
SM + $\tilde{\nu}$	54.1/51	0.5	0.1	0.2	1.1	1.4	1.7

of $\sqrt{s_{\text{eff}}}$ distributions or through additional low luminosity runs at strategically chosen beam energies. Furthermore, a window with $m_{\tilde{\nu}} \approx m_Z$ exists and is currently preferred by the data. We encourage the search for peaks in the $\sqrt{s_{\text{eff}}}$ distributions of the forthcoming hadronic event samples, and the serious consideration of the proposed additional low luminosity runs at LEP II energies.

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