New Production Mechanism of Higgs Bosons with $\tilde{\nu}_R$ as the LSP

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SM

no $\nu_R \Rightarrow m_\nu = 0$

MSSM

$$W = \mu H_u H_d + H_u Q U + H_d Q D + H_d L E$$

no $\nu_R \Rightarrow m_\nu = 0$ & no $\tilde{\nu}_R$

ν-oscillation data $\Rightarrow$ $m_\nu \neq 0$

SeeSaw in GUT

$$\begin{pmatrix} 0 & v \\ v & M \end{pmatrix} \Rightarrow \begin{pmatrix} \frac{v^2}{M} & 0 \\ 0 & M \end{pmatrix}$$

↑ Majorana ν_R

$v \sim \frac{246\ \text{GeV}}{\sqrt{2}} = 174\ \text{GeV}$

$M \sim 10^{14}\ \text{GeV}$

$\frac{v^2}{M} \sim 10^{-1}\ \text{eV} \sim m_\nu$

⇓

M is too large to have observable effect at colliders other than ν-oscillation

SUSY GUT seeSaw

$$W = \mu H_u H_d + H_u Q u + H_d Q D + H_u L N + H_d L E + \tfrac{1}{2} M N N$$

$$\begin{pmatrix} 0 & \lambda v_u \\ \lambda v_u & M \end{pmatrix}$$

ν_R heavy $(\sim M)$

⇒ Because of SUSY GUT $\tilde{\nu}_R$ heavy $(\sim M)$

⇒ No observable new effects with the inclusion of ν_R & $\tilde{\nu}_R$ fields

SM

Add ν_R ⇒ Dirac mass

$\left(\frac{m_\nu}{v}\right) h \bar{\nu}_L \nu_R$

↑ $\frac{0.1\,\text{eV}}{174\,\text{GeV}} \sim 10^{-12}$

(tiny)

⇓

No observable new effect.

MSSM ⊕ N

N: SU(3) × U(1) × SU(2) singlet superfield

Add ν_R ⇒ Add $\tilde{\nu}_R$

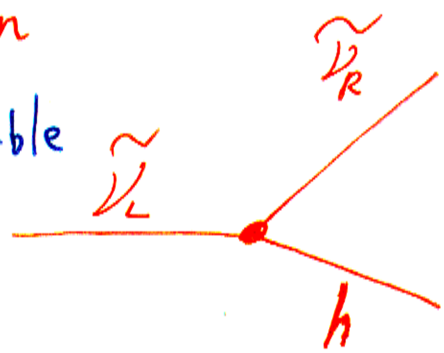
① Can $\tilde{\nu}_R$ be light?

② Can the coupling of $(H_u \tilde{L} \tilde{N})$ be large?

↑ A-term

If Yes, then

Can have a sizable



⇒ Interesting Collider phenomenology

A. Arkani-Hamed, L.J. Hall, H. Murayama
D. Smith, N. Weiner

hep-ph/0006312

Can generate

① a light $\tilde{\nu}_R$

& ② a large A-term

by applying Giudice-Masiero mechanism

e.g. $\langle X \rangle = \sqrt{F} + \theta^2 F$, with $F \sim (10^{11}\,\mathrm{GeV})^2$

$$\int d^4\theta \, \frac{X^\dagger N N}{M_{Pl}} \Rightarrow \frac{F}{M} \nu_R \nu_R$$

$$\int d^2\theta \, \frac{X L H N}{M_{Pl}} \Rightarrow \frac{\sqrt{F}}{M} H \nu_L \nu_R$$

$\Rightarrow (m_\nu)_{LR} = \begin{pmatrix} 0 & \frac{v\sqrt{F}}{M} \\ \frac{v\sqrt{F}}{M} & \frac{F}{M} \end{pmatrix}$

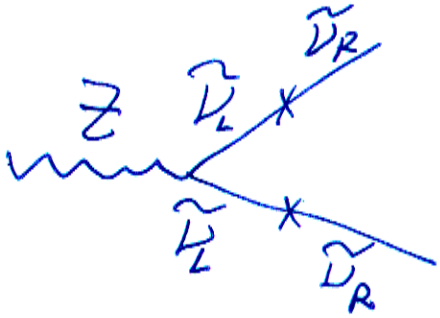
$\Rightarrow m_\nu = \frac{v^2}{M}$

$$\frac{F}{M} H_u \tilde{\nu}_L \tilde{\nu}_R$$

(large A term)

light $\tilde{\nu}_R$ ⇐ Weak Scale

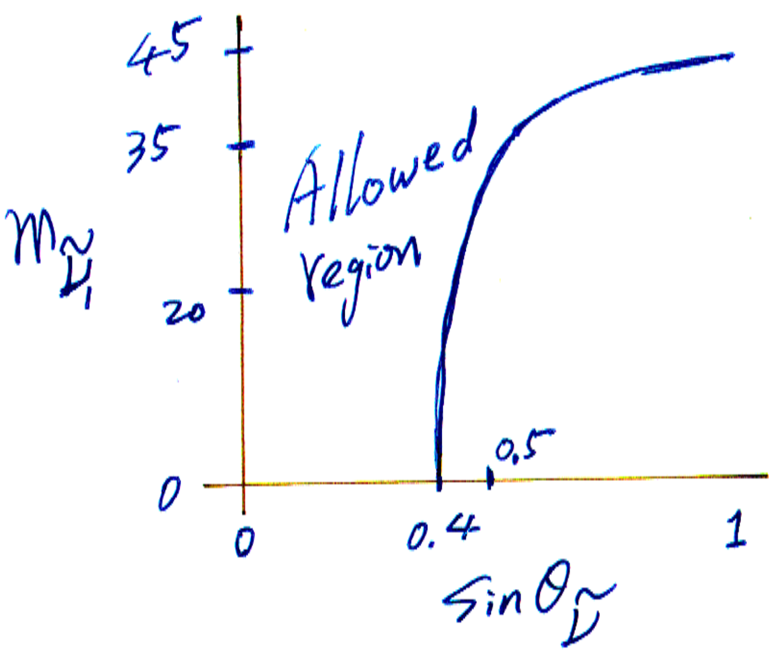
Constraint from Z-pole



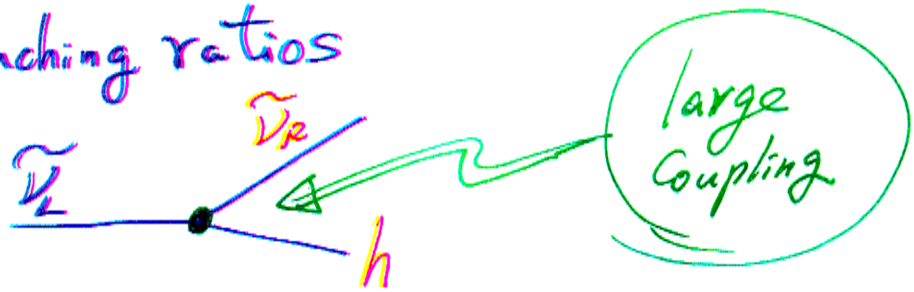
$\sim \sin^4\theta_{\tilde{\nu}}$

$\Rightarrow$ If $\sin\theta_{\tilde{\nu}} < 0.4$

then $m_{\tilde{\nu}_1} < \frac{m_Z}{2}$ is allowed.



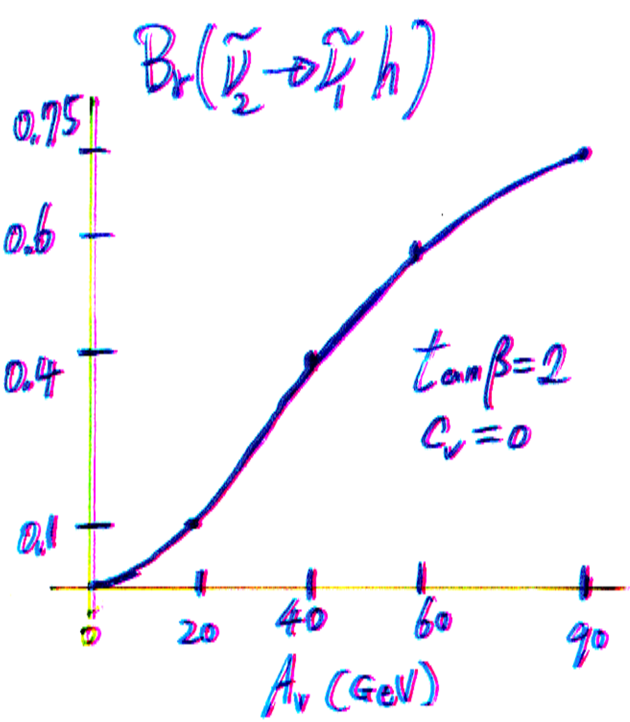
Decay branching ratios

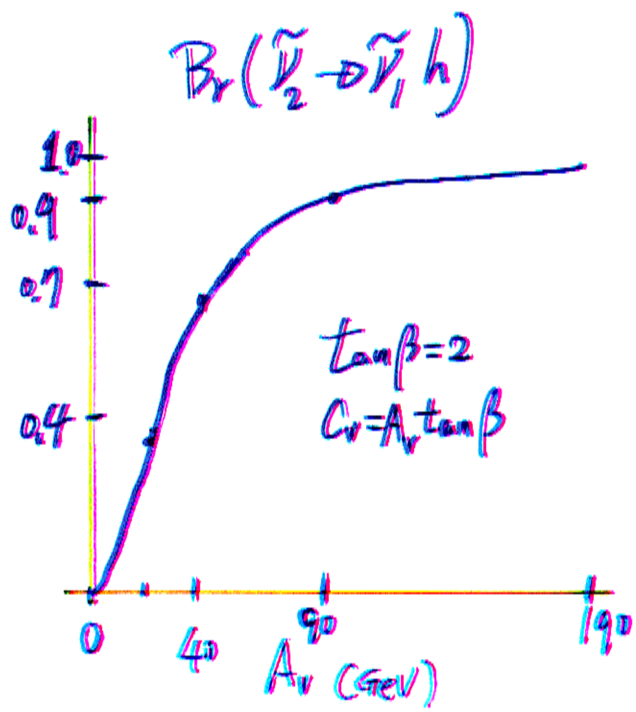


depend on the soft breaking parameters.

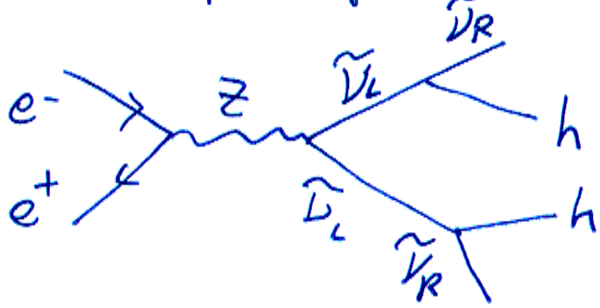
e.g. $m_{\tilde{\nu}_2} = 200$, $m_{\tilde{\nu}_1} = 20$, $m_h = 130$ GeV

$(M_1 = 200,\ M_2 = 400,\ \mu = -100)$

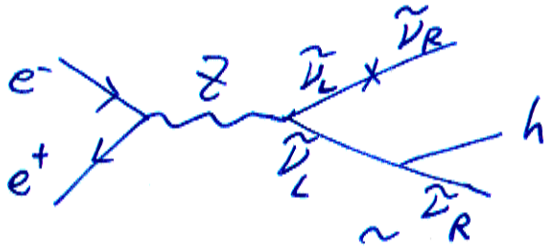




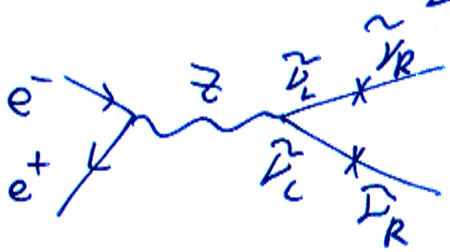
$\tilde{\nu}_1$- LSP at the LC



$(2h + \not{E}_T)$



$(h + \not{E}_T)$



$(\not{E}_T)$

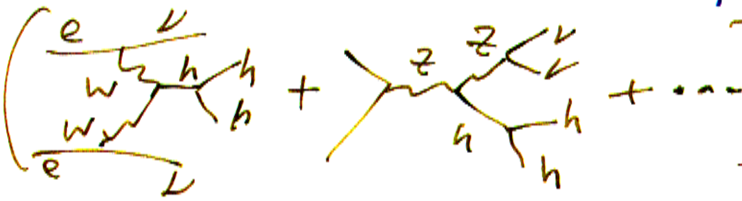
which modes are open is model dependent.

e.g. For $m_{\tilde{\nu}_2} = 200$ GeV, $\sin\theta_{\tilde{\nu}} \simeq 0$

$\sigma(e^- e^+ \to \tilde{\nu}_2 \tilde{\nu}_2) \simeq 12$ fb for $\sqrt{s} = 500$ GeV

with $Br(\tilde{\nu}_2 \to \tilde{\nu}_1 h) \simeq 0.9$ (for $A_\nu = 90$, $\tan\beta = 2$).

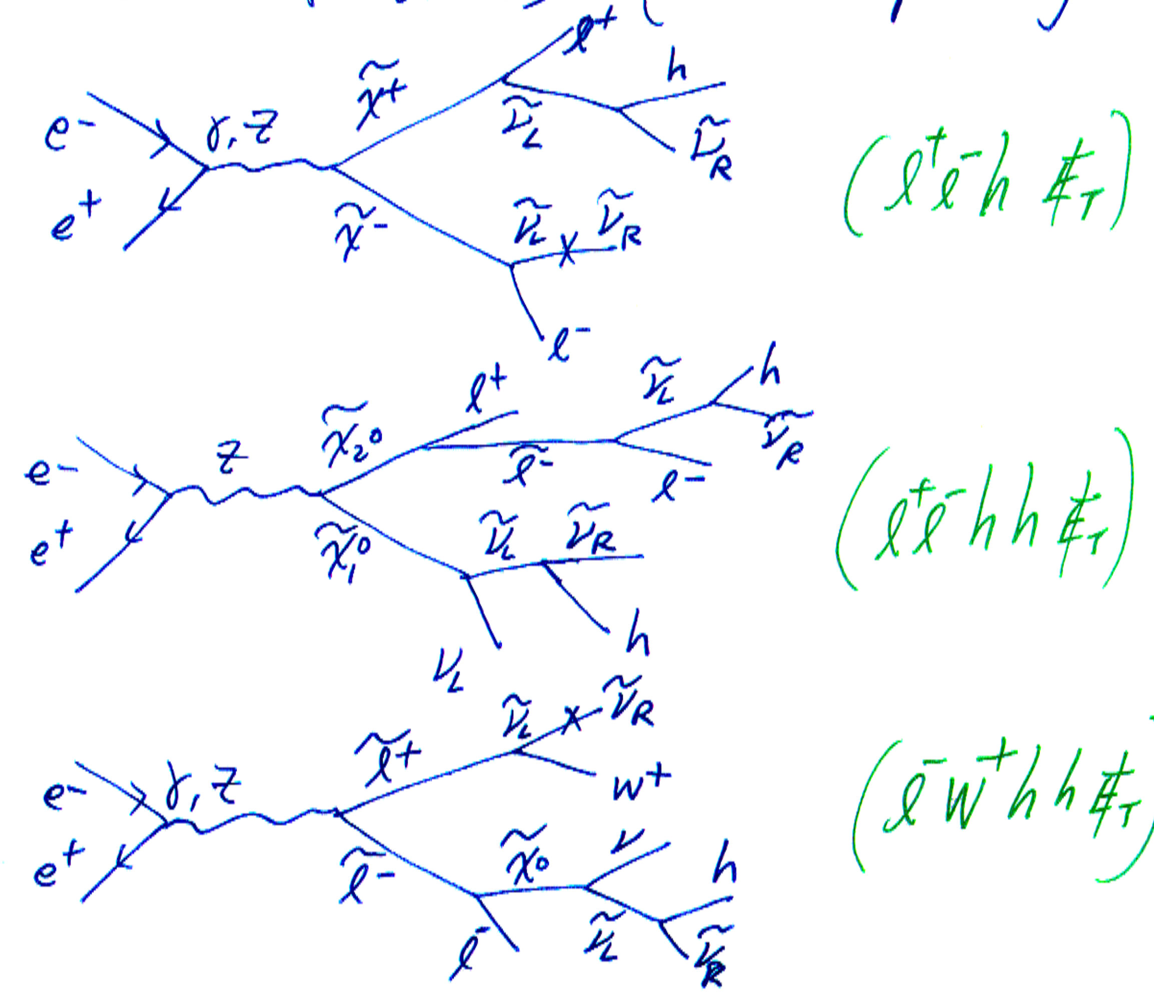
cf. $\sigma^{(SM)}$ (



)

$\simeq 0.03$ fb

Other Possibilities (Model dependent)



⇒ Very different collider phenomenology from the usual MSSM.

$m_\nu \neq 0$ ⇒ Collider phenomenology drastically altered

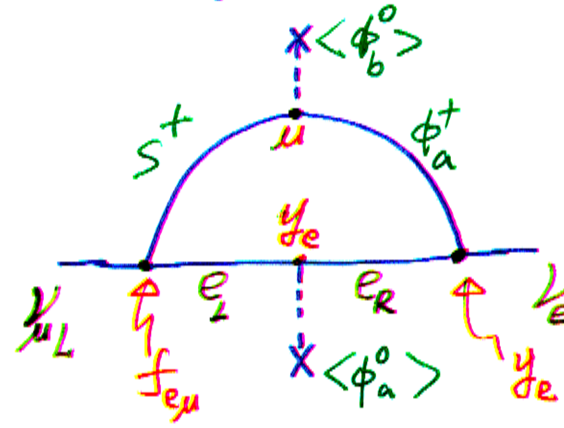
Generate Small Majorana m_ν through radiative corrections

e.g. Zee model — A. Zee, PLB 93 (1980) 339; 161 (85) 141.

(2 Higgs doublets ⊕ 1 charged Higgs singlet s^+) ⟹ two charged Higgs bosons S_1^+, S_2^+

$$M_\nu = \begin{pmatrix} 0 & m_{12} & m_{13} \\ m_{12} & 0 & m_{23} \\ m_{13} & m_{23} & 0 \end{pmatrix},$$

with $m_{ij} = f_{ij}\,(m_j^2 - m_i^2)\,\frac{\mu \cdot v_b}{v_a}\,F(m_{S_1}^2, m_{S_2}^2)\,\frac{1}{16\pi^2}$



$i, j = 1, 2, 3$ (flavor index)

$a, b = 1, 2$ (2 Higgs doublet)

Need $\left\{ \begin{array}{l} \mu\,\phi_1\phi_2 S^+ \\ f_{ij}\,L_i L_j S^+ \quad (f_{ij} = -f_{ji}) \\ \phi_1^+\phi_2 \end{array} \right\}$

to break lepton number.

Zee Model & Neutrino Oscillations

C. Jarlskog, M. Matsuda, S. Skadhauge, M. Tanimoto

hep-ph/0005147

Atmospheric & solar neutrino data

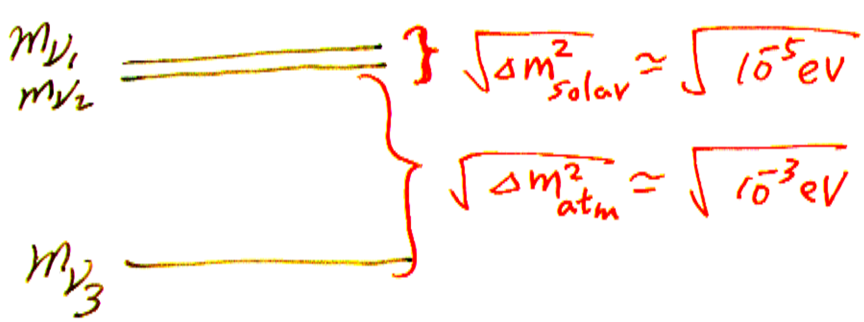
⇒ Bi-maximal mixing solution in Zee-type mass matrix

$$M_\nu = \begin{pmatrix} 0 & m_{e\mu} & m_{e\tau} \\ m_{e\mu} & 0 & \epsilon \\ m_{e\tau} & \epsilon & 0 \end{pmatrix}, \qquad (\epsilon \ll m_{e\mu}, m_{e\tau})$$

⇒ Mixing matrix

$$U = \begin{pmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & 0 \\ \frac{-1}{2} & \frac{1}{2} & \frac{1}{\sqrt{2}} \\ \frac{1}{2} & \frac{-1}{2} & \frac{1}{\sqrt{2}} \end{pmatrix}$$

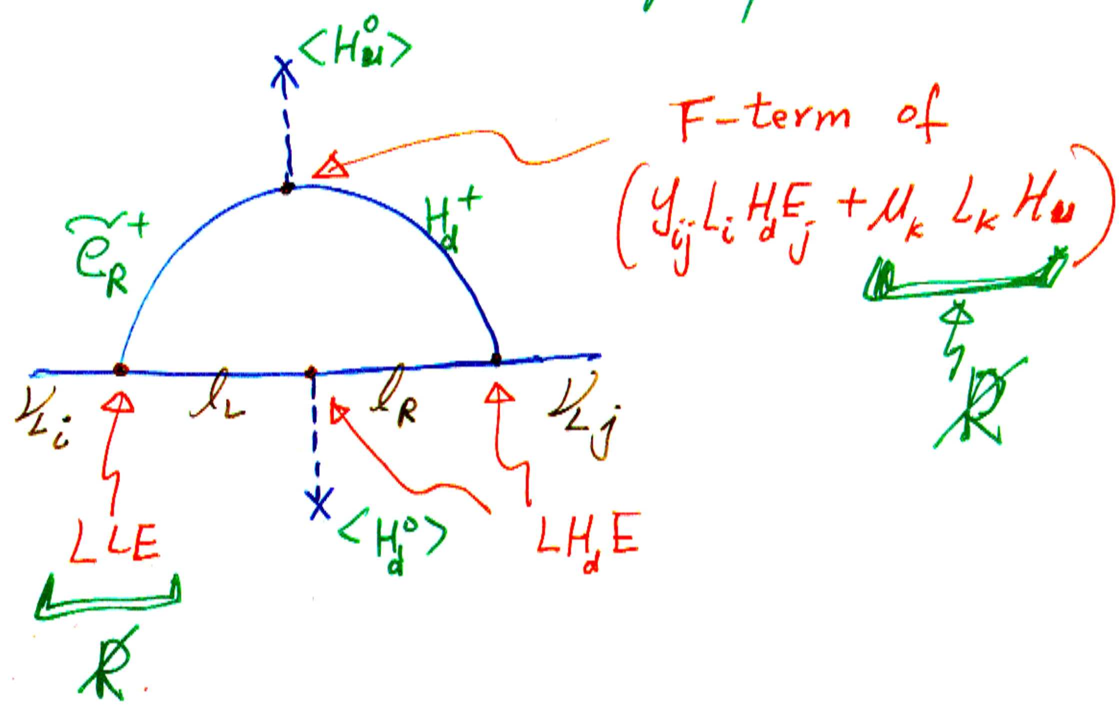
⇒ $|f_{12}| \gg |f_{13}| \gg |f_{23}|$



(MSW large angle solution)

Supersymmetric Version can be realized in $\not{R}$ - SUSY

K. Cheung, O. Kong   hep-ph/0003276



($\tilde{e}_R$ plays the role of S^+ in Zee-model.)

↑ weak singlet field

$m_\nu \neq 0 \Rightarrow$ Collider phenomenology

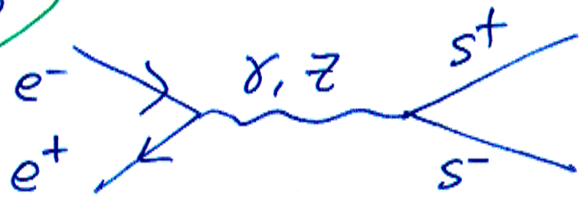
S. Kanemura, T. Kasai, G.L. Lin, Y. Okada, T.J. Tseng, C.-P. Yuan

hep-ph/0010233

e.g. Zee-type model

$m_\nu \neq 0 \Rightarrow$ SU(2) singlet S^+
(not SU(2) doublet H^+)

LEP



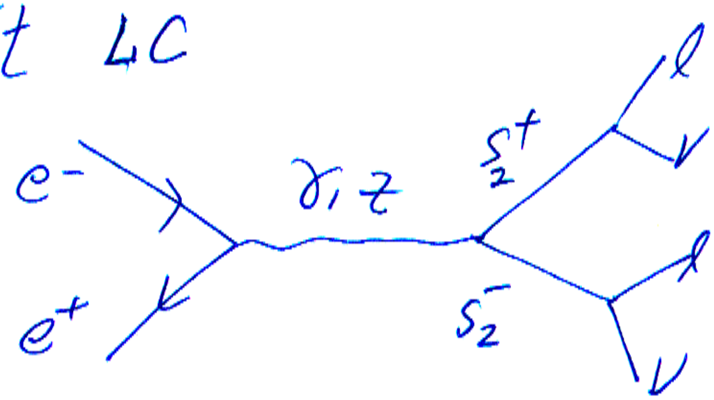
$\Rightarrow \left(\begin{array}{l} e^+ e^- \not{E}_T \\ \mu^+ \mu^- \not{E}_T \\ e^\pm \mu^\mp \not{E}_T \end{array} \right)$ ← not $\tau^\pm$

$$Br(S^+ \to e^+ \not{E}_T) \simeq 0.5$$
$$Br(S^+ \to \mu^+ \not{E}_T) \simeq 0.5$$
$$Br(S^+ \to \tau^+ \not{E}_T) \simeq \mathcal{O}\left(\frac{m_\mu^4}{m_\tau^4}\right) \sim 10^{-5}$$

$\Rightarrow$ New physics effects only show up in $e^- e^+ \not{E}_T$, $e^\pm \mu^\mp \not{E}_T$, $\mu^- \mu^+ \not{E}_T$ modes.

$\Rightarrow$ LEP needs New Analysis on their data (with $e^\pm$ or $\mu^\pm$, not $\tau^\pm$) to probe this type of S^+.

At LC



$Br(S^+ \to e^+ \not{E}_T) = 0.5$

$Br(S^+ \to \mu^+ \not{E}_T) = 0.5$

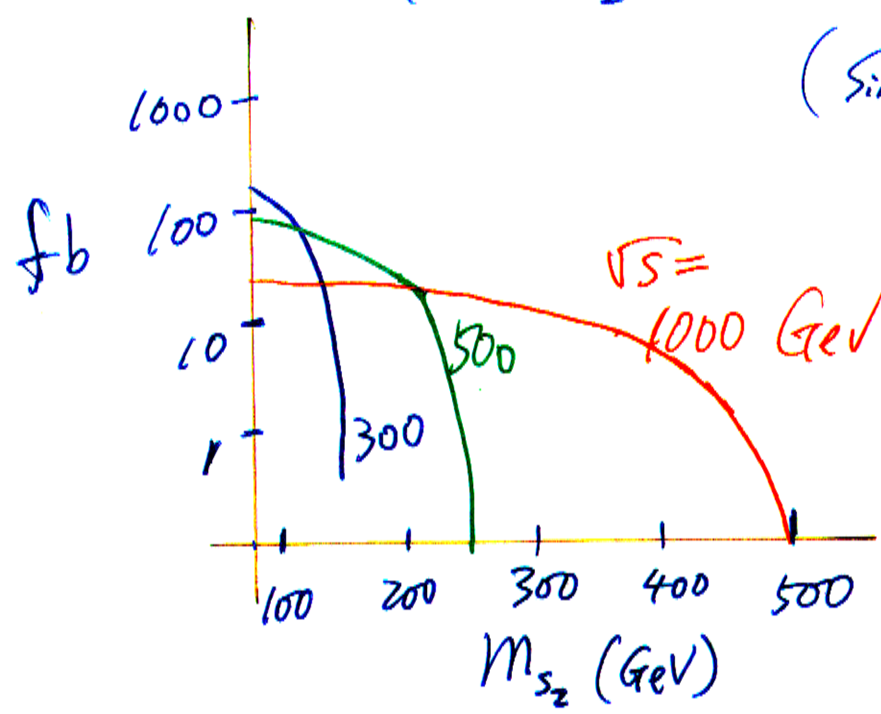
$Br(S^+ \to \tau^+ \not{E}_T) \simeq 0$

$S^- = S_1^- \sin\chi + S_2^- \cos\chi$

$\sin\chi$ ← mixing between two mass eigenstate charged Higgs bosons

$\sigma(e^- e^+ \to S_2^- S_2^+)$

$(\sin\chi = 0)$



Conclusions

- $m_\nu \neq 0 \Longrightarrow$ MSSM $\oplus$ $(\nu_R, \tilde{\nu}_R)$
- $\tilde{\nu}_R$ can be light (at weak scale) & A-term $(H_u \tilde{\nu}_L \tilde{\nu}_R)$ can be large (at weak sale)
- Collider phenomenology can be dramatically altered.
- LEP need New Analysis to probe the Zee-type charged SU(2) singlet Higgs boson in their $\not{E}_T$ data with $e^\pm$ or $\mu^\pm$ (but not $\tau^\pm$ or jets)
- LC can clearly test the scenarios:
  - MSSM $\oplus$ light $\tilde{\nu}_R$ (LSP)
  - Zee-type model with a weak singlet S^+ or $\not{R}$-SUSY