Precision Measurements, Extra Generations and Heavy Neutrino.

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$$\boxed{N_f = 3} \quad ?$$

Extra quark-lepton generations and precision measurements

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A. N. Rozanov, M. I. Vysotsky

[redacted].

Phys. Lett. B 476 (2000), 107–115.

Question:

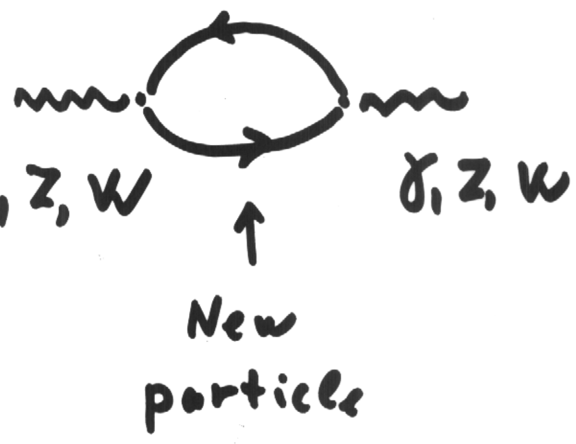
⇒ **Are new generations of fermions still allowed by experimental data?**

N. Evans, Phys. Lett. B 340 (1994) 81;
P. Bamert, C. Burgess, Z. Phys. C 66 (1995), 495;
T. Inami et al., Mod. Phys. Lett. A 10, (1995) 1471;
A. Masiero et al., Phys. Lett. B 355 (1995) 329;
N.O.R.V., Mod. Phys. Lett. A 10, (1995) 1975;

Answer:

- No
- Yes
- We should look

Indirect bounds on New Physics



"Oblique" corrections

~20 observables at LEP 1 } ~ 10^{-3}

New generation: $\begin{pmatrix} N \\ E \end{pmatrix}_L$ $\begin{pmatrix} U \\ D \end{pmatrix}_L$ $\begin{pmatrix} N_R, E_R \\ U_R, D_R \end{pmatrix}$

- No decoupling from low-energy (from LEP 1)

- $m_U, m_D \to \infty$; $m_U - m_D$ - finite

$$\left.\begin{aligned} \delta V_m &= -\frac{16}{9} s^2 \\ \delta V_A &= 0 \\ \delta V_R &= -\frac{8}{9} \end{aligned}\right\} + \frac{16}{9}\left(\frac{m_U - m_D}{m_Z}\right)^2 + \dots$$

- $|m_U - m_D| \gg m_Z$

$$\delta V_i = \frac{|m_U^2 - m_D^2|}{m_Z^2} + \frac{1}{3}\frac{|m_N^2 - m_E^2|}{m_Z^2}$$

Low-energy observables

- $$m_W/m_Z = c\left\{1 + \frac{3\bar{\alpha}}{32\pi s^2(c^2-s^2)} V_m\right\}$$

$$g_A^\ell = -\frac{1}{2}\left\{1 + \frac{3\bar{\alpha}}{64\pi s^2 c^2} V_A\right\}$$

$$R^\ell = \frac{g_V^\ell}{g_A^\ell} = (1-4s^2) + \frac{3\bar{\alpha}}{4\pi(c^2-s^2)} V_R$$

Γ_Z, σ_h, R_e .... (18 observables)

where $c = \cos\theta$; $s = \sin\theta$

$$\sin^2 2\theta = \frac{4\pi}{\sqrt{2}} \frac{\bar{\alpha}}{G_\mu m_Z^2}$$

Table 1. LEPTOP fit of the precision observables.

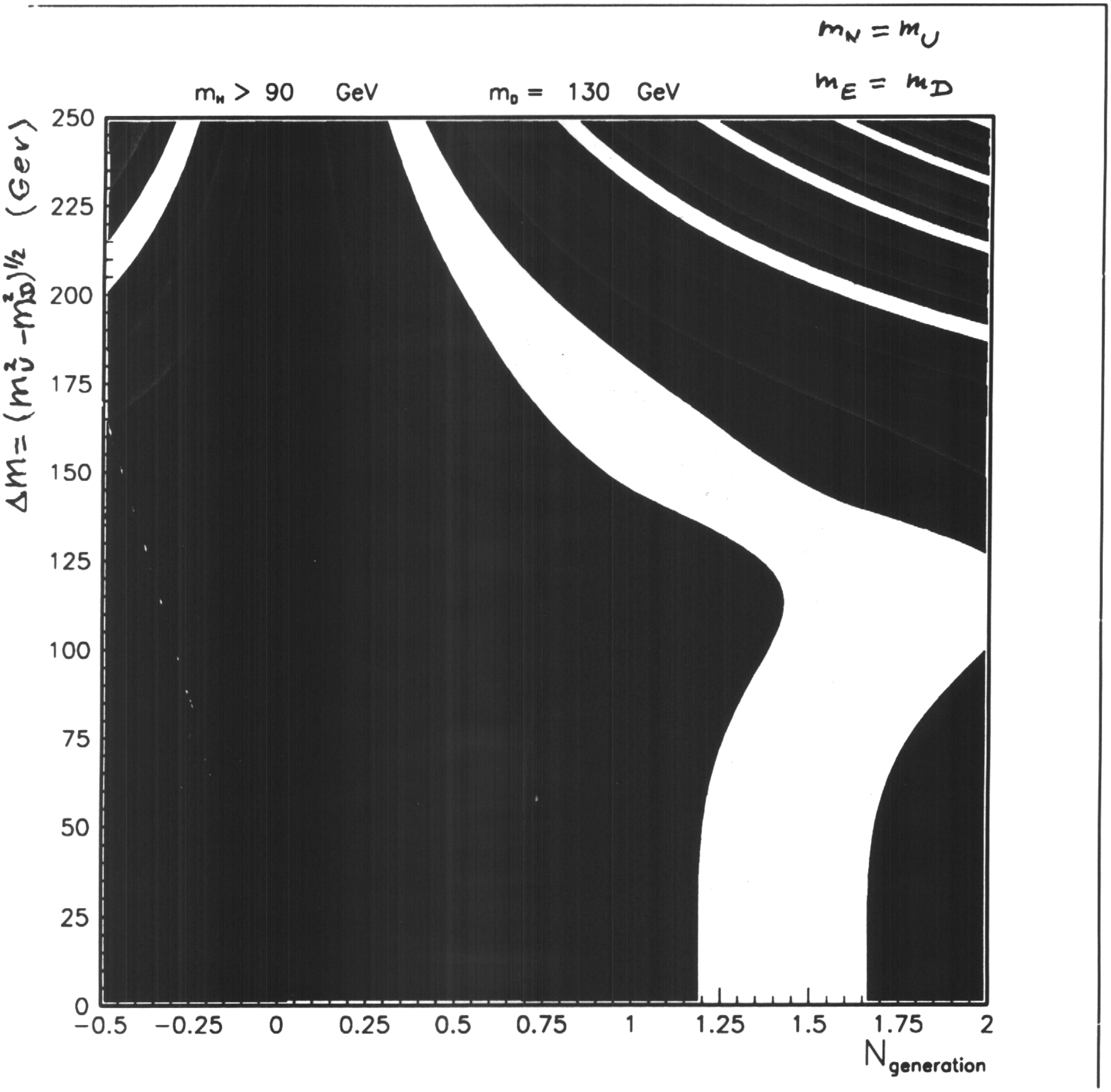
Observ.	Exper. data	LEPTOP fit	Pull
Γ_Z [GeV]	2.4952(23)	2.4964(16)	-0.5
σ_h [nb]	41.541(37)	41.479(15)	1.7
R_l	20.767(25)	20.739(18)	1.1
A^l_{FB}	0.0171(10)	0.0164(3)	0.7
A_τ	0.1439(42)	0.1480(13)	-1.0
A_e	0.1498(48)	0.1480(13)	0.4
R_b	0.2165(7)	0.2157(1)	1.2
R_c	0.1709(34)	0.1723(1)	-0.4
A^b_{FB}	0.0990(20)	0.1038(9)	-2.4
A^c_{FB}	0.0689(35)	0.0742(7)	-1.5
s^2_l (Q_{FB})	0.2321(10)	0.2314(2)	0.7
s^2_l (A_{LR})	*0.2310(3)*	*0.2314(2)*	-1.5
A_b	0.911(25)	0.9349(1)	-1.0
A_c	0.630(26)	0.6683(6)	-1.5
m_W [GeV]	80.434(37)	80.397(23)	1.0
s^2_W (νN)	0.2255(21)	0.2231(2)	1.1
m_t [GeV]	174.3(5.1)	174.0(4.2)	0.1
m_H [GeV]		55^{+45}_{-26}	
$\hat{\alpha}_s$		0.1183(27)	
$\bar{\alpha}^{-1}$	128.88(9)	128.85(9)	0.3
χ^2/n_{dof}		21.4/14	

For $\bar{\alpha}^{-1} = 128.945(60)$ (BES)

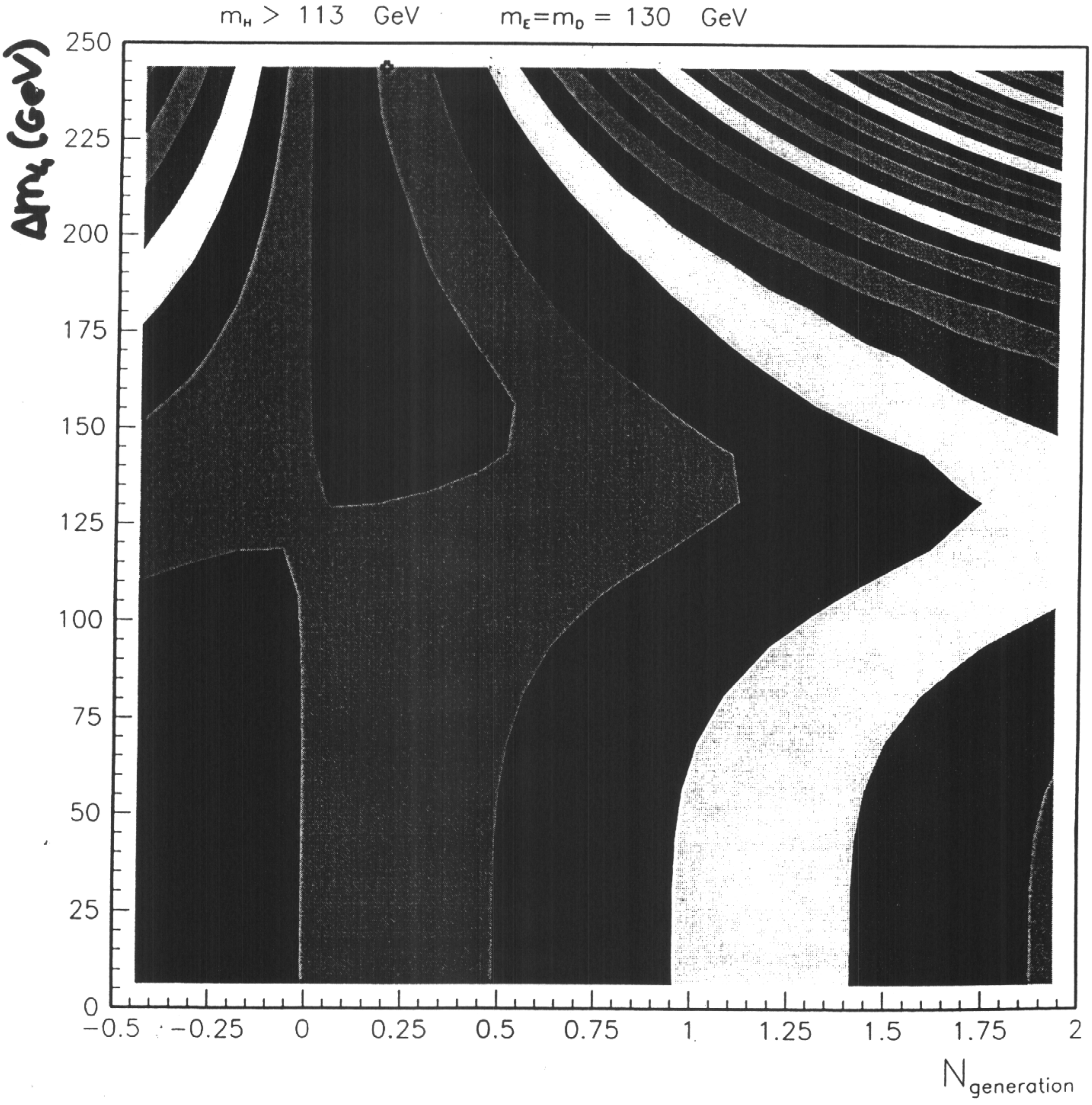
⇓

$m_H = 78^{+53}_{-32}$ GeV

$N_g = 1$ is excluded 2.5σ



$N_g = 1$ is excluded 2σ

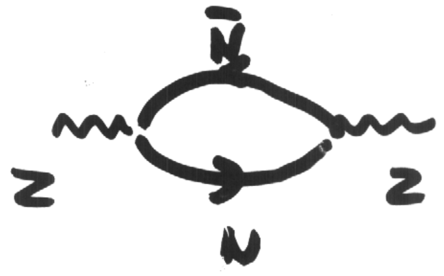


Conclusion

The existence of extra generations with all fermions heavier M_Z is strongly disfavoured by precision data.

"Light" heavy neutrinos N

$$m_N \simeq \frac{m_Z}{2}$$



Degenerate perturbative theory

⇓

Large mixing, i.e. large corrections to wave function renormalization

- $m_N \gtrsim m_Z/2$

- $m_N > 45$ GeV } DELPHI (if $\theta < 10^{-6}$)
  N - Dirac

$m_N \gtrsim 70$–80 GeV $\theta \gtrsim 10^{-6}$

$m_{E^\pm} > 93.5$ GeV } LEP II

$m_Q > 130$ GeV $p\bar{p}$

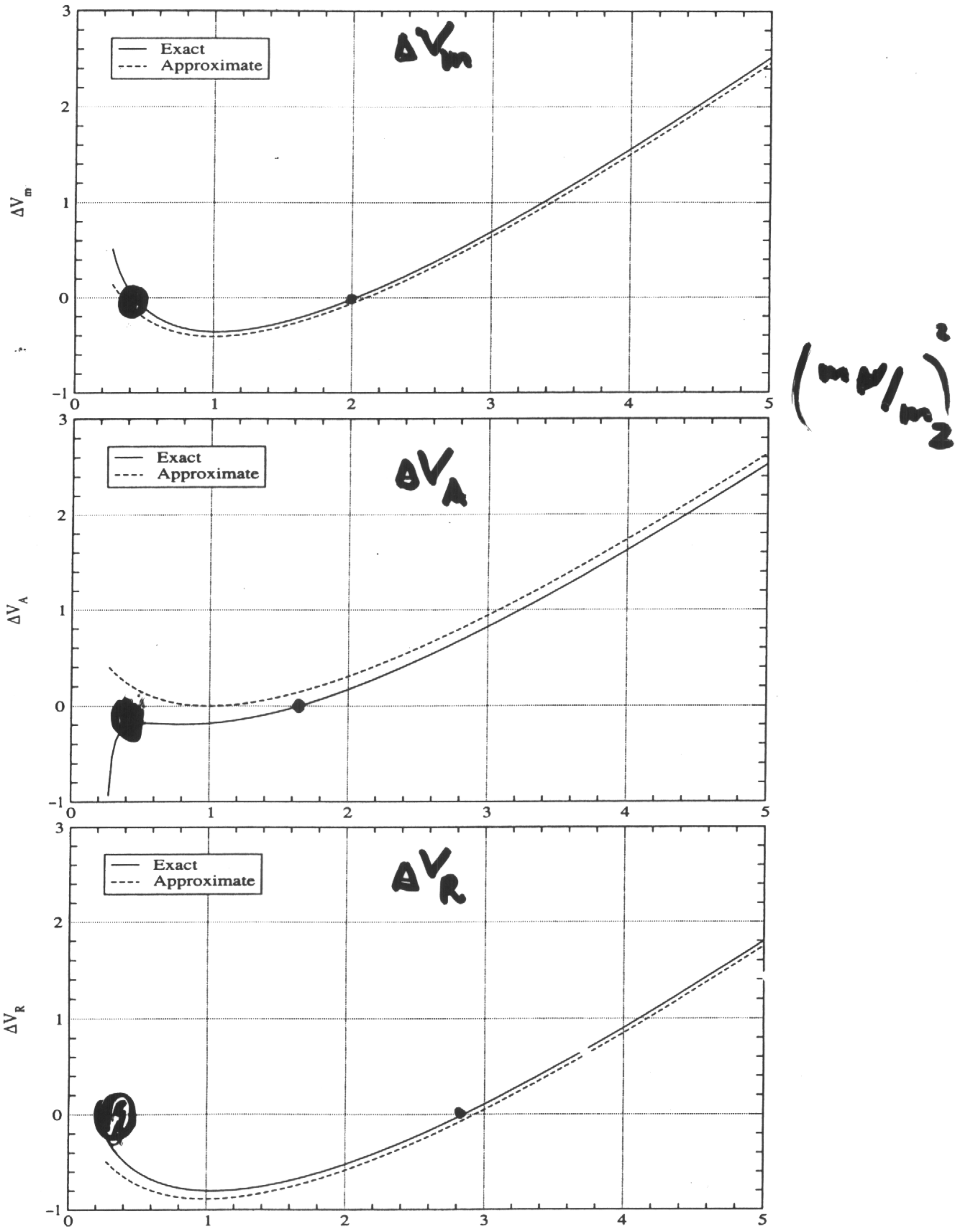


Figure 1: Contributions of a fourth generation of fermions to ΔV_i as a function of $u \equiv (m_U/m_Z)^2$. We assume $m_N = m_U$ and $m_E = m_D = m_Z$. Solid lines correspond to exact eq (4); dashed lines correspond to approximation given in eq(15). These plots help to study accuracy of approximation (12 - 14) outside its formal domain of validity, that is why we neglect experimental bounds on m_D and m_U.

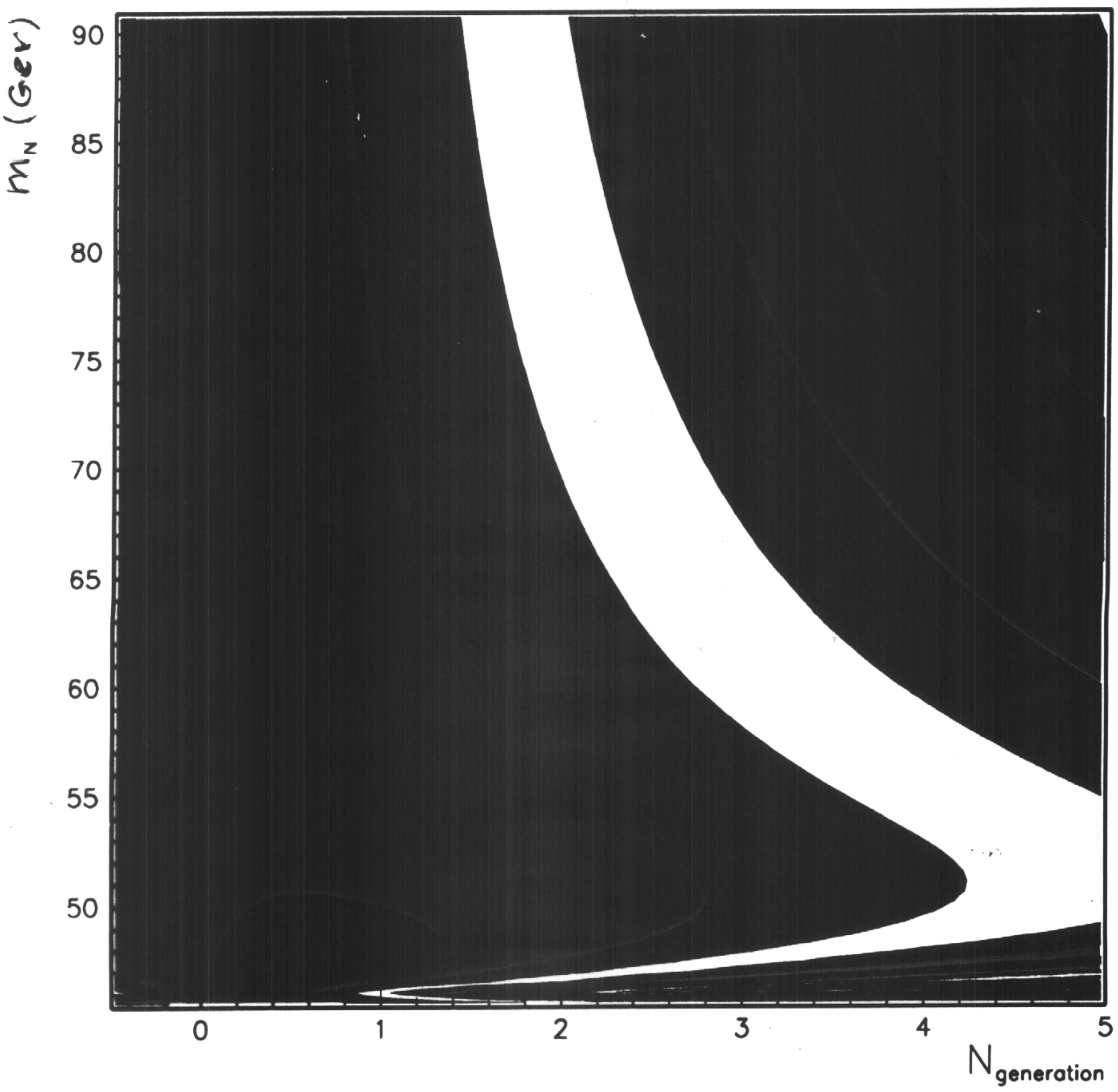
$m_U = 220$ GeV

$m_D = 200$ GeV

$m_E = 100$ GeV

$m_H > 90$ GeV

Forth generation with $m_N \simeq 50$ GeV is not worse than the SM!!



Conclusions

- The existence of extra generations with all fermions heavier M_Z is strongly disfavoured by precision data

- If neutral lepton is light

$$m_N \simeq 50\,\text{GeV}$$

new generations are not excluded

- Additional generation is less forbidden if

$$m_{\chi^+} \simeq m_{\chi^0} \simeq 60\ \text{GeV}$$

$$|m_{\chi^+} - m_{\chi^0}| \lesssim 1\ \text{GeV}$$

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On the search for 50 GeV neutrinos

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Abstract

Using the computer code CompHEP we estimate the number of events and the background, at LEP II and TESLA, for the reaction $e^+e^- \to N\bar{N}\gamma$, where N is a hypothetical Dirac neutrino with mass of the order of 50 GeV.

The direct search for "light" $M_N \sim 50$ GeV neutrino

$e^+e^- \to$ invisible state
⇓
$e^+e^- \to \gamma$ + "nothing"
"lonely" photon

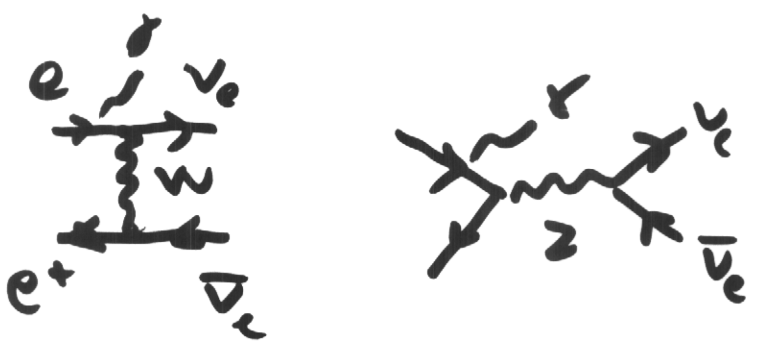
} Dolgov, Okun, Zakharov 1972

Heavy neutrino (signal) Ⓢ

$e^+e^- \to \gamma Z^* \to \gamma N\bar{N}$

Background Ⓑ

$e^+e^- \to \gamma \underset{(Z)}{Z^*} \to \gamma \nu_i \bar{\nu}_i$ $i = \mu, \tau$



- Logarithmic approximation M.V. & V.N.
- Numerical CompHep

S/B signal ~ 7-10%

50 GeV Neutrinos at LEP2

4 groups $\quad e^+e^- \to \gamma + $ "Nothing"

"Nothing" $\equiv$ (1) SUSY

(2) Gravity with extra dimensions

$\Downarrow$

| (3) Heavy N

1997-99 $\quad \sqrt{s} = 182 - 202$ GeV

$\mathcal{L} \sim 1830\ pb^{-1}$

2000 $\quad \sqrt{s} = 200 - 210$ GeV

$\mathcal{L} \sim 800\ pb^{-1}$

$\mathcal{L} \sim 2600\ pb^{-1}$

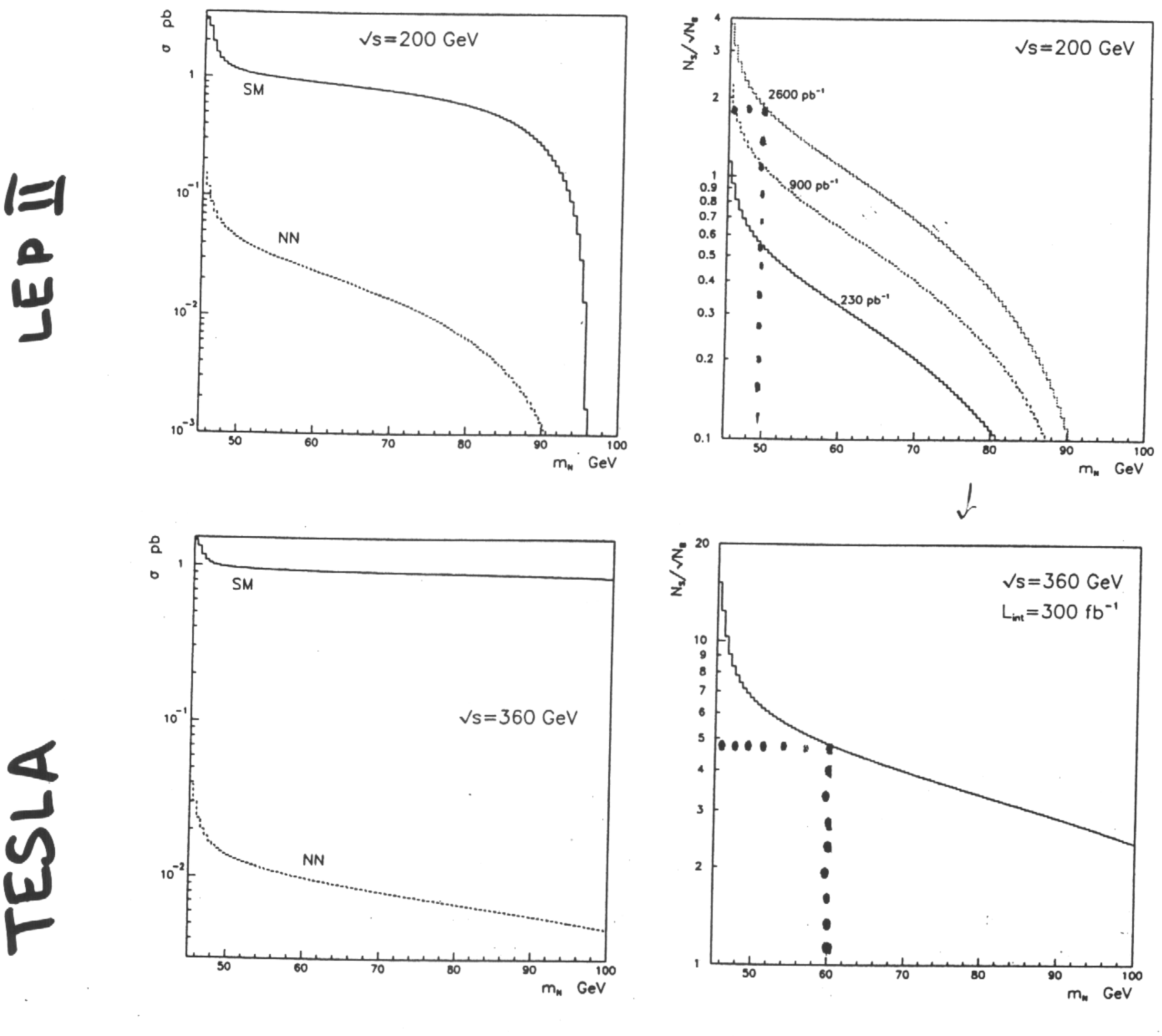


Figure 3: Cross sections for the $N\bar{N}$ signal and SM background (left side plots) and $N\bar{N}$ signal significances at different statistics (right side plots) as function of the neutrino mass. Cuts applied: $M_{inv} > 2m_N$, $|\cos\vartheta_\gamma| < 0.95$ and $p_T^\gamma > 0.0375\sqrt{s}$. For the significance the photon detection efficiency 74% is assumed.

Example:

$\mathcal{L} \sim 230\ pb^{-1}$ ⇒ (212) Background events per experiment

$m_N = 48$ GeV ⇒ (9) events with $N\bar{N}$

Significance of the $N\bar{N}$ signal } $N_S / \sqrt{N_B}$

⇓

Total ~ 2600 pb^{-1} from LEP II can exclude at 95% CL the $m_N \leq 50$ GeV

We need spesial post-LEP II run!

Figures

LEP II LEP II

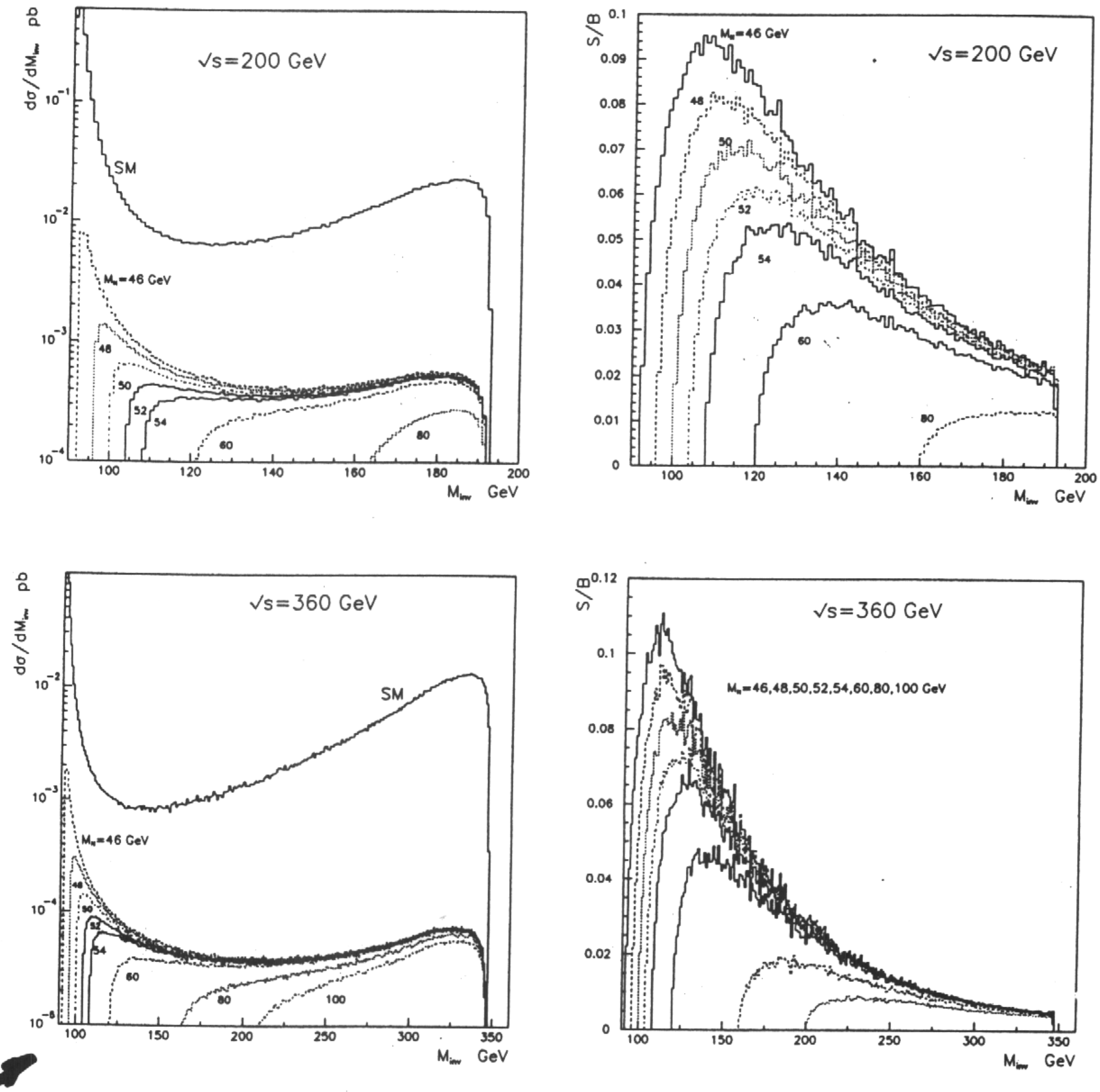


Figure 1: The left side plots: $d\sigma/dM_{inv}$ (in pb) for Standard Model and for the differen values of m_N. The right side plots: the *Signal/Background* ratio as a function of M_{inv} Cuts applied: $|\cos\vartheta_\gamma| < 0.95$ and $p_T^\gamma > 0.0375\sqrt{s}$. The photon detection efficiency 74% is assumed.

Tesla

50 GeV neutrinos at TESLA

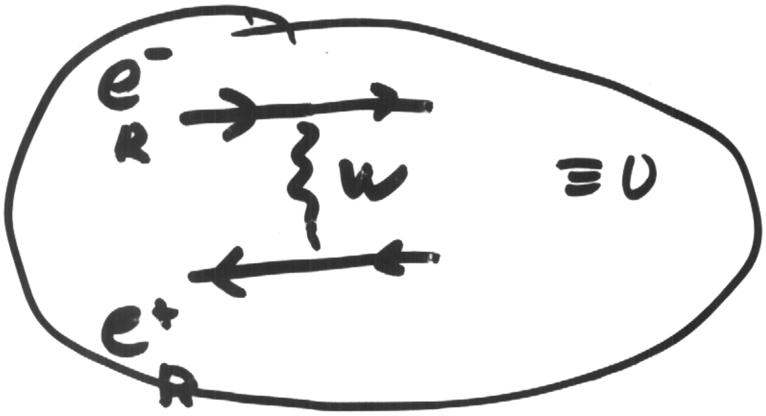
- First stage: $\sqrt{s} = 360$ or 500 GeV

  $\mathcal{L} = 300\ fb^{-1}$ per year

$\sigma_{N\bar{N}}$, $\sigma_{\nu\bar{\nu}}$ $\sim \frac{1}{s}$ | But luminosity compensates this decrease of σ.

- Polarized beams

  80% e^-
  60% e^+



Suppress $e^+e^- \to \nu_e \bar{\nu}_e \gamma$ background

- Example: B $3 \cdot 10^5\ \gamma$ with $M_{inv} > 100$ GeV

  S $N\bar{N}$ (4000)

(5σ) significance for $m_N < 60$ GeV within (one year) work!!

Conclusion

- LEP II excludes at 95% CL

  $m_N \lesssim 50$ GeV

- TESLA in one year run
  can exclude at 95% CL
  all range of m_N

  or

  discover with <u>5 σ</u> significance

  $m_N < 60$ GeV.