1-loop radiative corrections to the ρ-parameter in the left-right twin Higgs Model

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Contents

Introduction

- Hierarchy problem : one of the main problem in particle physics
- Solution to H.P. : Supersymmetry ExtraDimensions Little Higgs models, etc.
- Twin Higgs models : Introducing discrete symmetry to protect the Higgs mass from quadratic divergence

Z.Chacko, H. Goh and R. Harnik,
PRL96,231802(2006), JHEP 0601:108,2006
H. Goh and S. Su,
PRD75, 075010, 2007

- Global U(4)symmetry

$$V(H) = -m^2 H^\dagger H + \lambda (H^\dagger H)^2$$

Spontaneous Symmetry breaking,

U(4) → U(3) with $\langle |H| \rangle = m/\sqrt{2\lambda} \equiv f$

CW effective potential, for H=(H_A,H_B),

$$\Delta V = \frac{9 g_A^2 \Lambda^2}{64\pi^2} H_A^\dagger H_A + \frac{9 g_B^2 \Lambda^2}{64\pi^2} H_B^\dagger H_B + \ldots$$

- If we take two gauge couplings equal, i.e. $g_A = g_B = g$,

$$\Delta V = \frac{9g^2\Lambda^2}{64\pi^2}(H_A^\dagger H_A + H_B^\dagger H_B) = \frac{9g^2\Lambda^2}{64\pi^2} H^\dagger H$$

which is invarinat under U(4), so does not contribute to the mass of Goldstone boson.

⇨Goldstone boson mass is completely insensitive to the quadratic divergence

⇨But there exist logarithmic terms which trigger the EWSB

- Coleman-Weinberg Potential,

$$V_{CW} = \pm \frac{1}{64\pi^2} \sum_i M_i^4 \left(\log \frac{\Lambda^2}{M_i^2} + \frac{3}{2} \right)$$

and with Higgs doublets,

$$\begin{aligned} H_A^\dagger H_A &= h^\dagger h - \frac{(h^\dagger h)^2}{3f^2} + \ldots \\ H_B^\dagger H_B &= f^2 - h^\dagger h + \frac{(h^\dagger h)^2}{3f^2} - \ldots \end{aligned}$$

Left Right Twin Higgs Model

- Global $U(4)_1 X U(4)_2$, $SU(2)_L X SU(2)_R X U(1)_{B-L}$ gauged.

- SSB,

$$H = \begin{pmatrix} H_L \\ H_R \end{pmatrix}, \qquad \hat{H} = \begin{pmatrix} \hat{H}_L \\ \hat{H}_R \end{pmatrix}$$

$$\langle H \rangle = \begin{pmatrix} 0 \\ 0 \\ 0 \\ f \end{pmatrix}, \qquad \langle \hat{H} \rangle = \begin{pmatrix} 0 \\ 0 \\ 0 \\ \hat{f} \end{pmatrix}$$

$$\Rightarrow \quad H = f e^{\pi/f} \begin{pmatrix} 0 \\ 0 \\ 0 \\ 1 \end{pmatrix}, \qquad \pi = \begin{pmatrix} -\frac{N}{2\sqrt{3}} & 0 & 0 & h_1 \\ 0 & -\frac{N}{2\sqrt{3}} & 0 & h_2 \\ 0 & 0 & -\frac{N}{2\sqrt{3}} & C \\ h_1^* & h_2^* & C^* & \frac{\sqrt{3}N}{2} \end{pmatrix}$$

- After EWSB,

$$\langle H \rangle = \begin{pmatrix} 0 \\ if \sin x \\ 0 \\ f \cos x \end{pmatrix}, \qquad \langle \hat{H} \rangle = \begin{pmatrix} 0 \\ 0 \\ 0 \\ \hat{f} \end{pmatrix}$$

,where $x = v/(\sqrt{2} f)$

⇒ Gauge sector :

Heavy Z & W bosons in addition to SM gauge bosons.

- Fermion Sector

To cancel the top quark contributions, new vector-like partner is introduced

$$\mathcal{L}_{Yuk} = y_L \bar{Q}_{L3} \tau_2 H_L^* Q_R + y_R \bar{Q}_{R3} \tau_2 H_R^* Q_L - M \bar{Q}_L Q_R + h.c.,$$

where $Q_{L,R3}=-i(u_{L,R3},d_{L,R3})$.

⇒ There exits extra heavy top quark which gives large logarithmic term to the SM Higgs masses.

- Higgs Sector

14-6 = 8 Nambu-Goldstone bosons get masses through quantum effects and soft symmetry breaking terms.

$$V_\mu = -\mu_r^2 (H_R^\dagger \hat{H}_R + c.c.) + \hat{\mu}^2 \hat{H}_L^\dagger \hat{H}_L$$

In addition to the SM Higgs, there are

$\phi^\pm, \phi^0, \hat{h}_1^\pm$ nd $\hat{h}_2^0$

ρ – parameter

- Tree level

$$\rho \equiv \frac{M_W^2}{M_Z^2 c_\theta^2}$$

- loop level

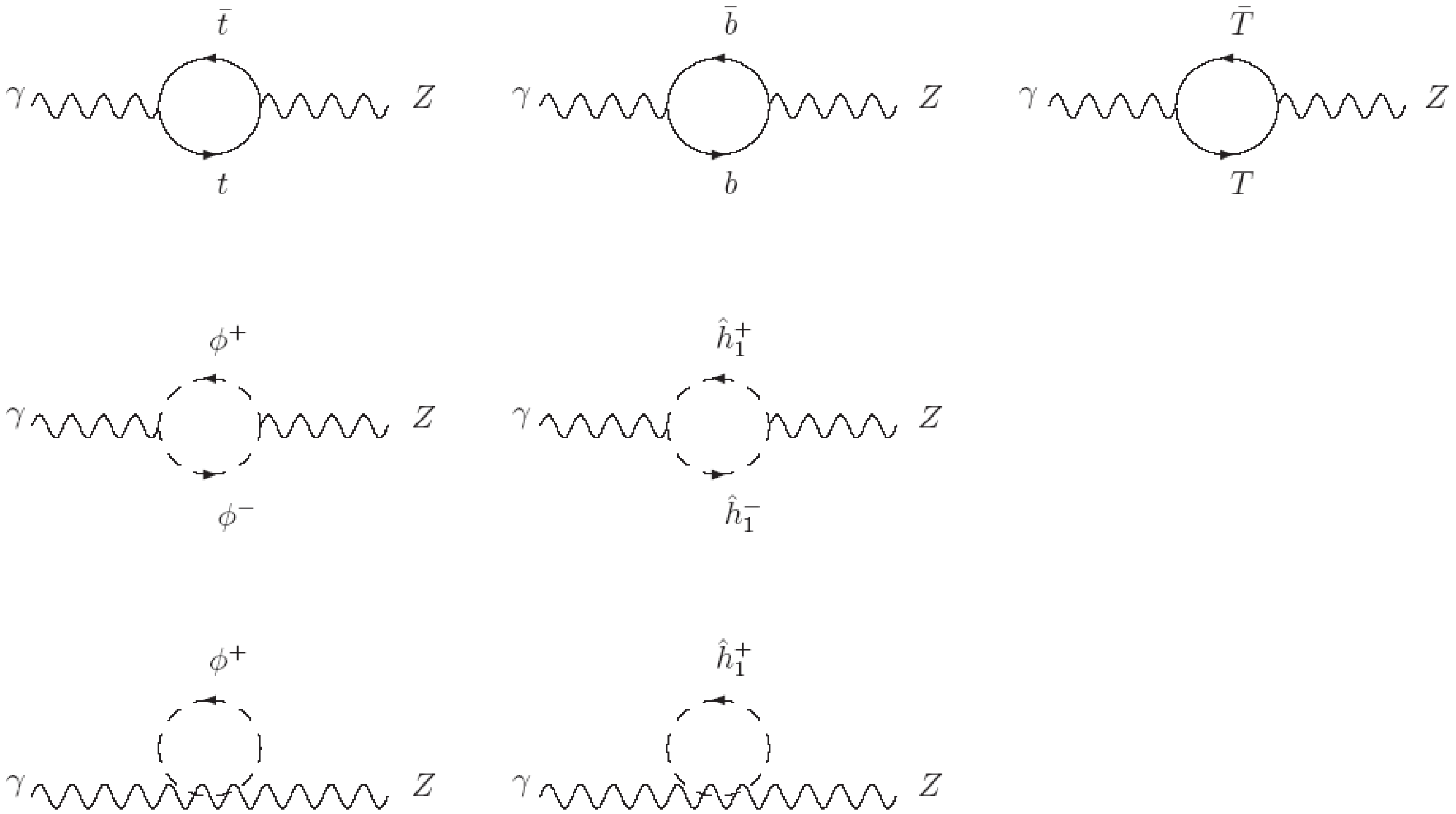
With Mw predicted from the model,

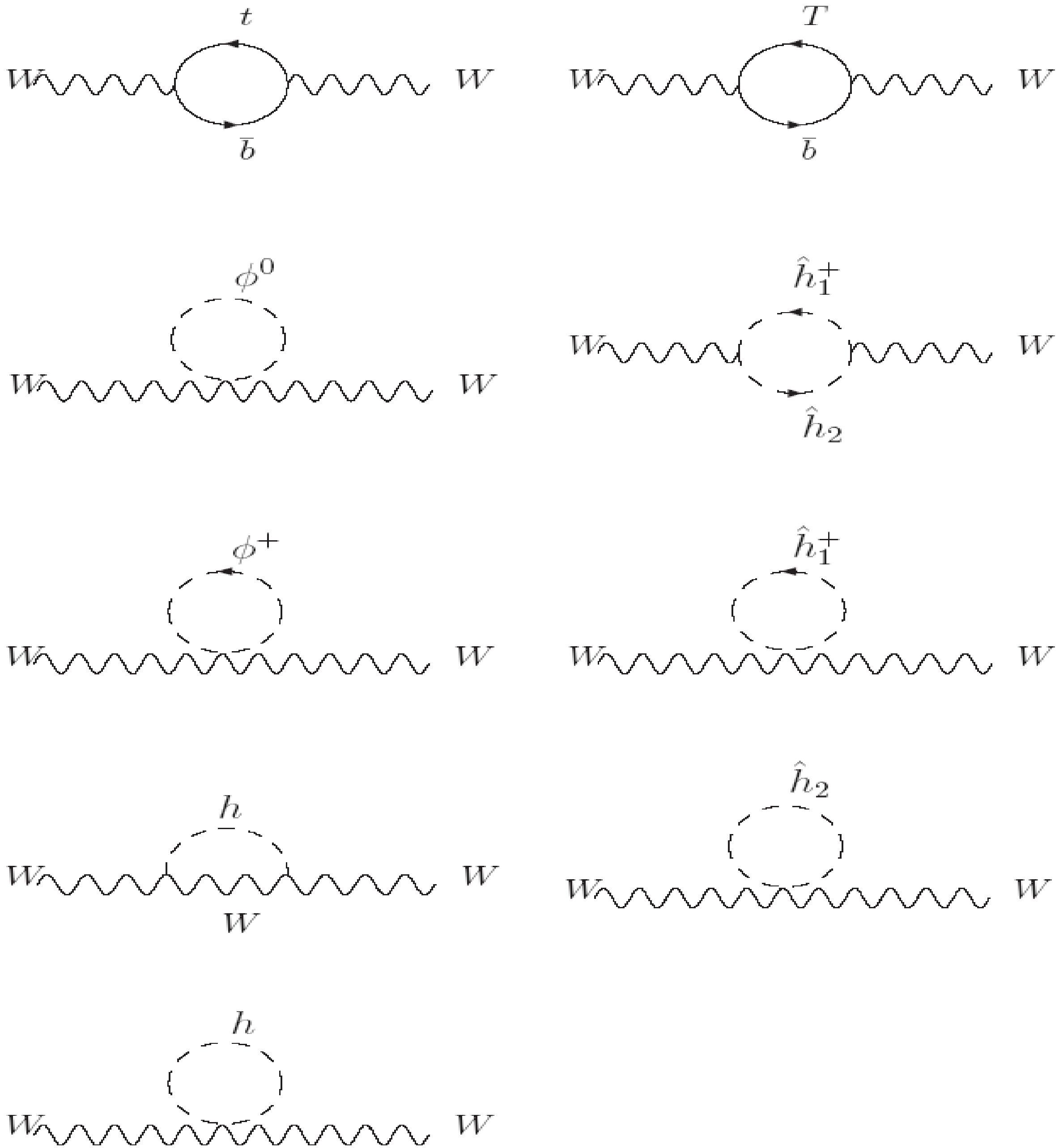
$$M_W^2 = \frac{1}{2}\left[a(1+\Delta\hat{r}) + \sqrt{a^2(1+\Delta\hat{r})^2 + 4a\Pi^{WW}(0)}\right],$$

$$\Delta\hat{r} = -\frac{\Delta s_\theta^2}{s_\theta^2} - \frac{Re(\Pi^{ZZ}(M_Z^2))}{M_Z^2} + \Pi^{\gamma\gamma\prime}(0) + 2(\frac{g_V^e - g_A^e}{Q_e})\frac{\Pi^{\gamma Z}(0)}{M_Z^2} - \frac{c_\theta^2 - s_\theta^2}{c_\theta s_\theta}\frac{Re(\Pi^{\gamma Z}(M_Z^2))}{M_Z^2}$$

$$a \equiv \frac{\pi\alpha(M_Z)}{\sqrt{2}G_F s_\theta^2}$$

- Relevant diagrams





t
W
W
b̄
T
W
W
b̄
φ⁰
W
W
ĥ₁⁺
W
W
ĥ₂
φ⁺
W
W
ĥ₁⁺
W
W
h
W
W
W
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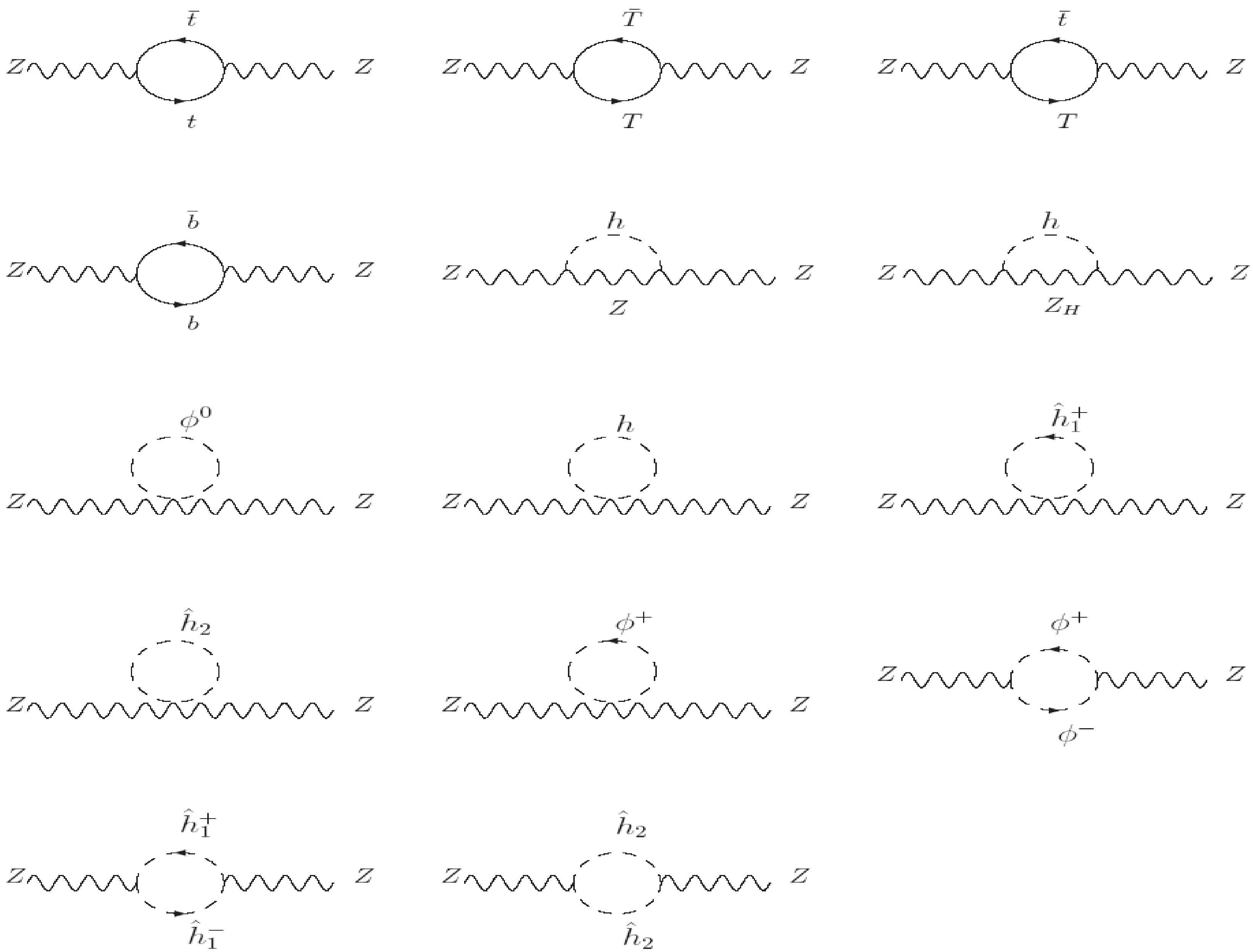
W
W
h
W
W



$\bar{t}$ Z Z t
$\bar{T}$ Z Z T
$\bar{t}$ Z Z T
$\bar{b}$ Z Z b
h Z Z Z
h Z Z Z_H
ϕ^0 Z Z
h Z Z
$\hat{h}_1^+$ Z Z
$\hat{h}_2$ Z Z
ϕ^+ Z Z
ϕ^+ Z Z ϕ^-
$\hat{h}_1^+$ Z Z $\hat{h}_1^-$
$\hat{h}_2$ Z Z $\hat{h}_2$

Numerical Results

- Inp

$$\begin{aligned} G_F &= 1.16637(1) \times 10^{-5}\ \mathrm{GeV}^{-2}, \\ M_Z &= 91.1876(21)\ \mathrm{GeV}, \\ \alpha(M_Z)^{-1} &= 127.918(18), \\ s_\theta^2 &= 0.23153(16). \end{aligned}$$

- Experimental bound (PDG)

$$1.00989 \leq \rho^{exp} \leq 1.01026.$$

- Free Parameters of LRTH

$$f,\ M,\ \mu_r,\ \hat{\mu}$$

⇨ Mass of the heavy top is soley determined by f and M.

⇨ Masses of the scalar particles largely depend on all of them.

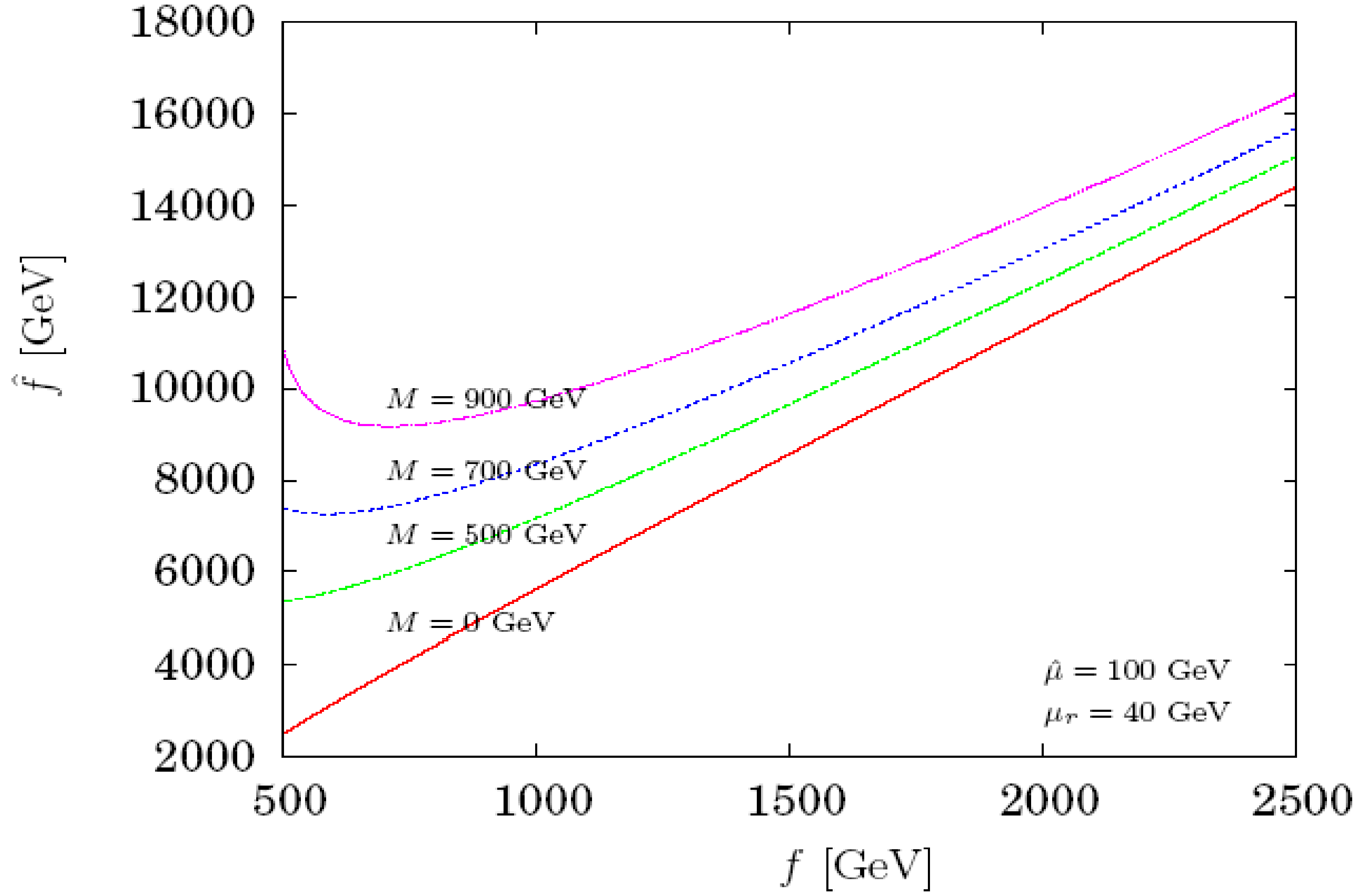
⇨ $\hat{f}$ determined from the EWSB conditions.

negative mass squared, v = 246 GeV

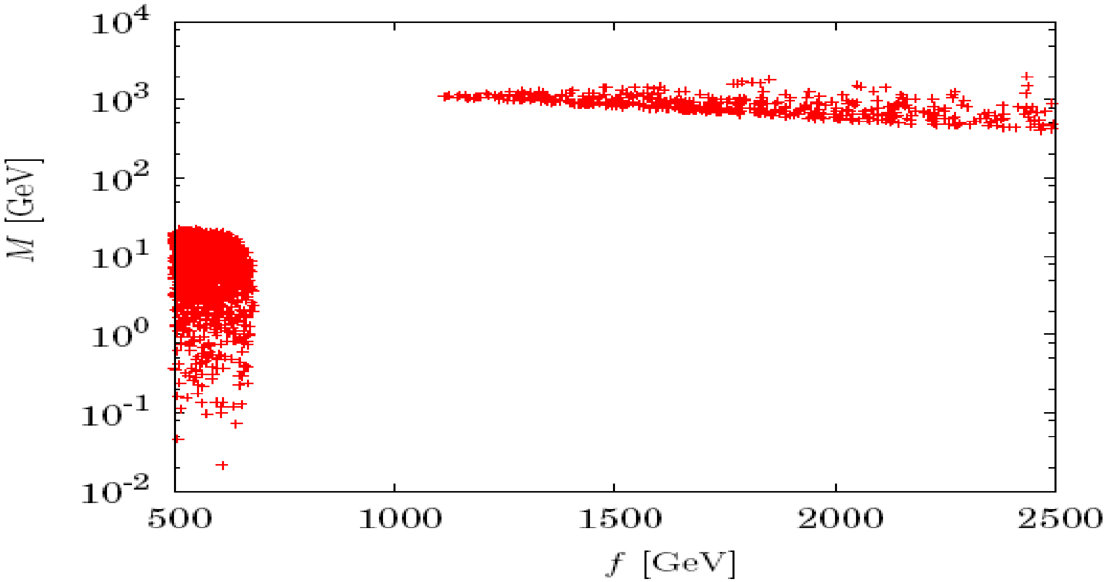
- Numerical range

$$500\ \text{GeV} \leq f \leq 2500\ \text{GeV}, \qquad 0 \leq M, \mu_r, \hat{\mu} \leq f.$$

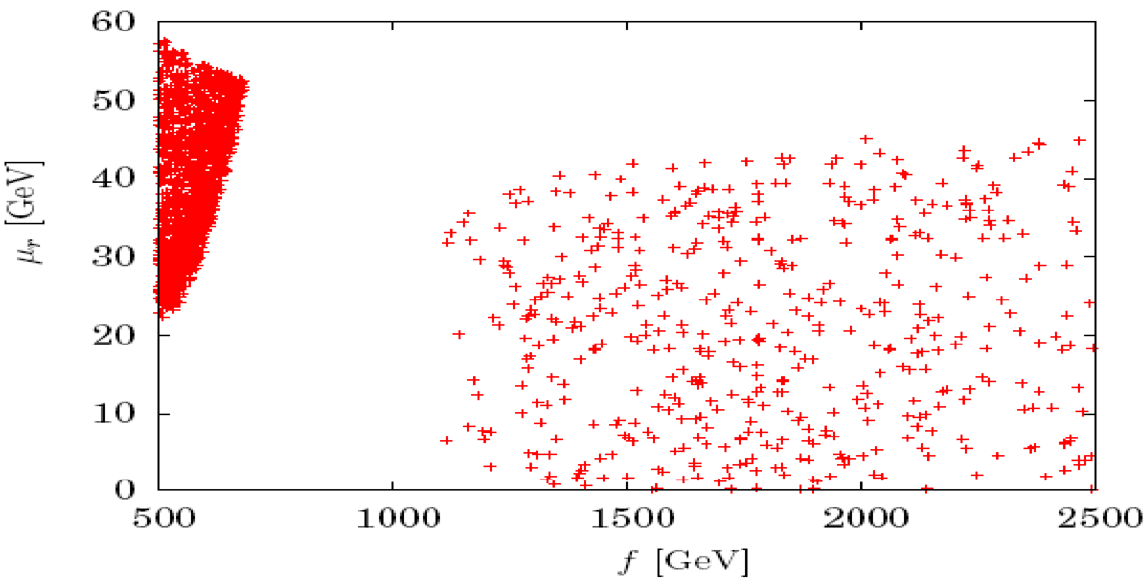
- Division of the allowed parameter space to two regions, less than **670 GeV** or larger than **1.1 TeV**.
- Constraint for f from heavy W and Z boson masses
- If we accept the lower bound for heavy W is roughly **1.6 TeV** from LR model with K_L-K_S mixing, then small f region will be excluded.



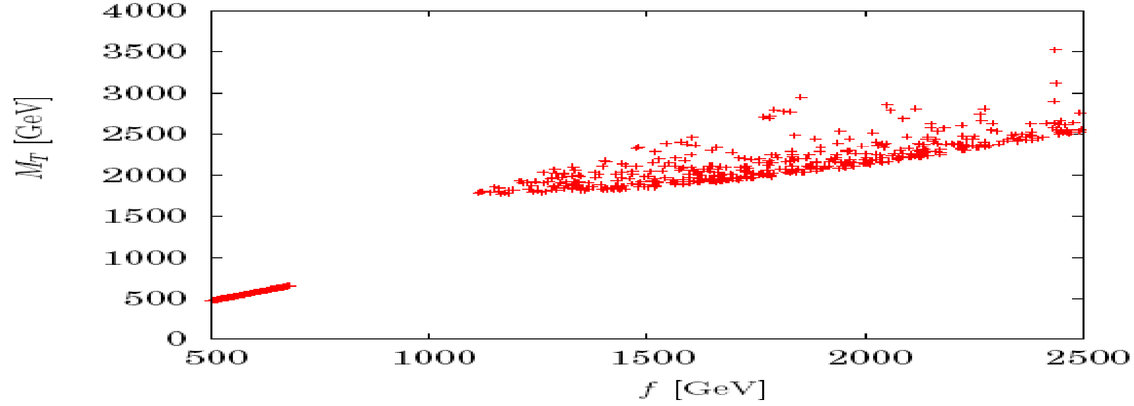
18000
16000
14000
12000
10000
8000
6000
4000
2000
$\hat{f}$ [GeV]
500
1000
1500
2000
2500
f [GeV]
M = 900 GeV
M = 700 GeV
M = 500 GeV
M = 0 GeV
$\hat{\mu}$ = 100 GeV
μ_r = 40 GeV



(a)

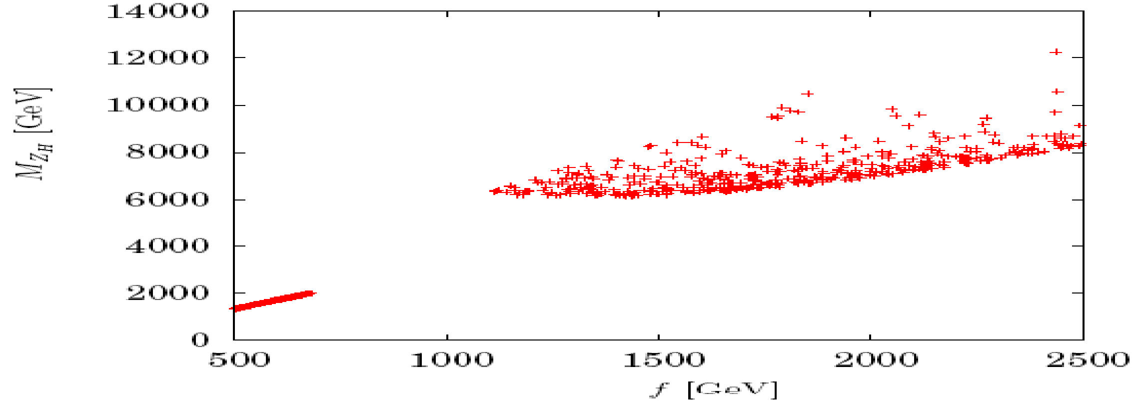


(b)



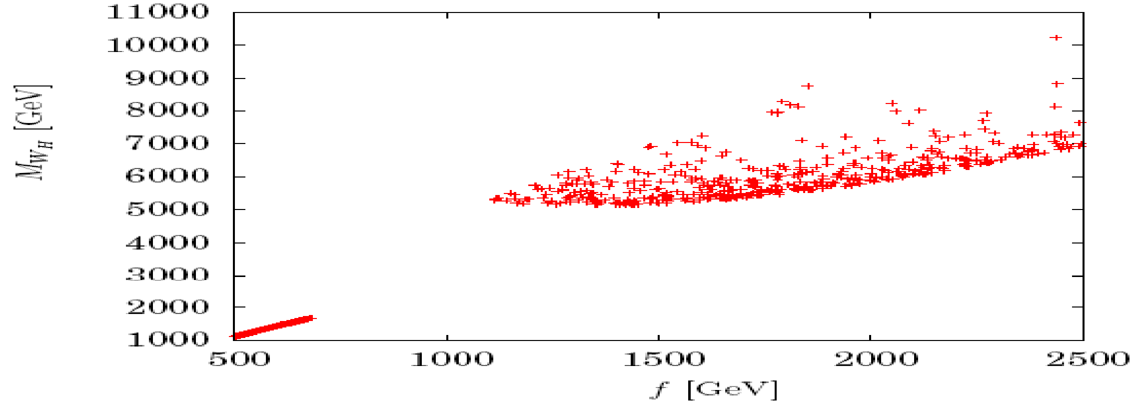
M_T [GeV]
4000
3500
3000
2500
2000
1500
1000
500
0
500
1000
1500
2000
2500
f [GeV]

(a)



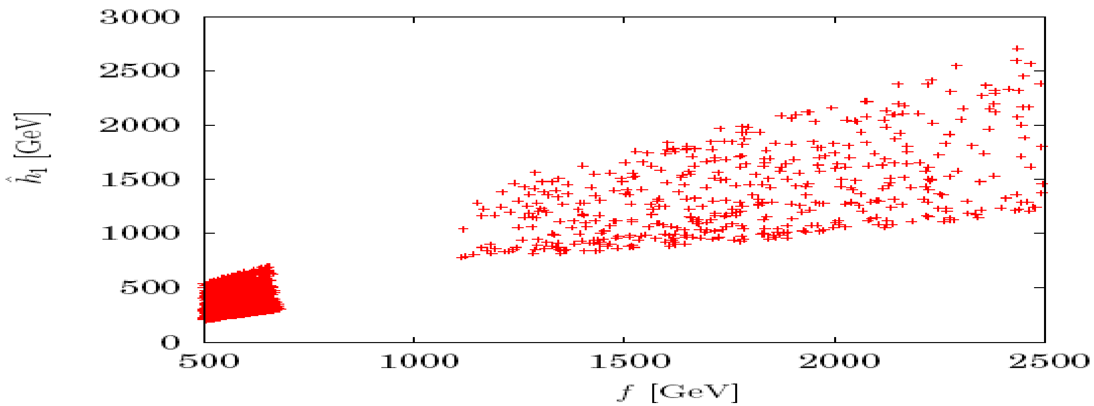
M_{Z_H} [GeV]
14000
12000
10000
8000
6000
4000
2000
0
500
1000
1500
2000
2500
f [GeV]

(b)



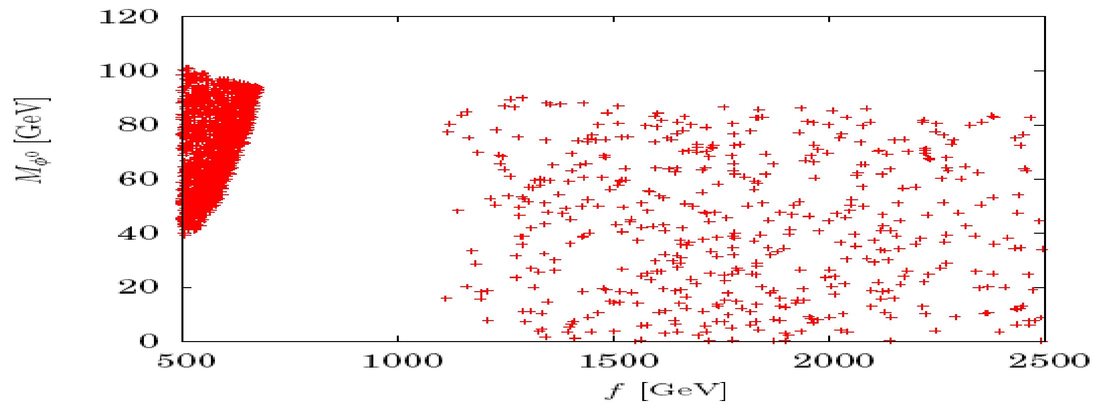
M_{W_H} [GeV]
11000
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
500
1000
1500
2000
2500
f [GeV]

(c)



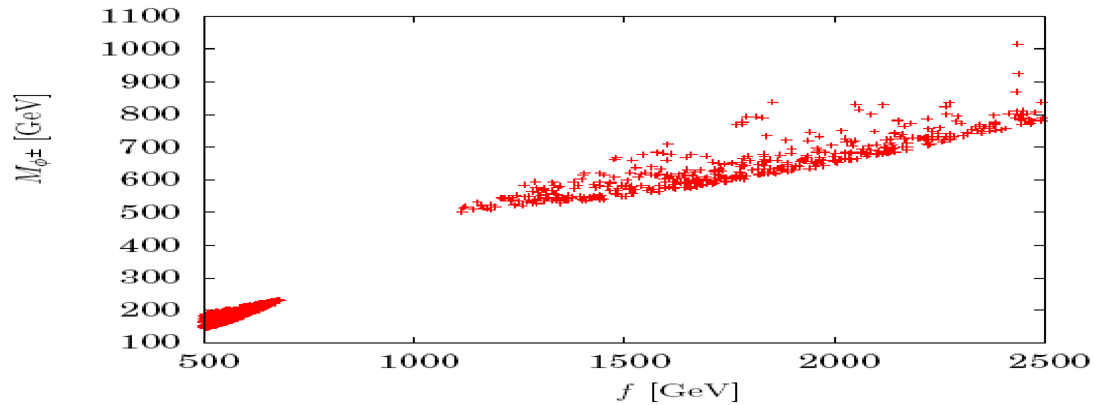
3000
2500
2000
1500
1000
500
0
$\hat{h}_1$ [GeV]
500
1000
1500
2000
2500
f [GeV]

(a)



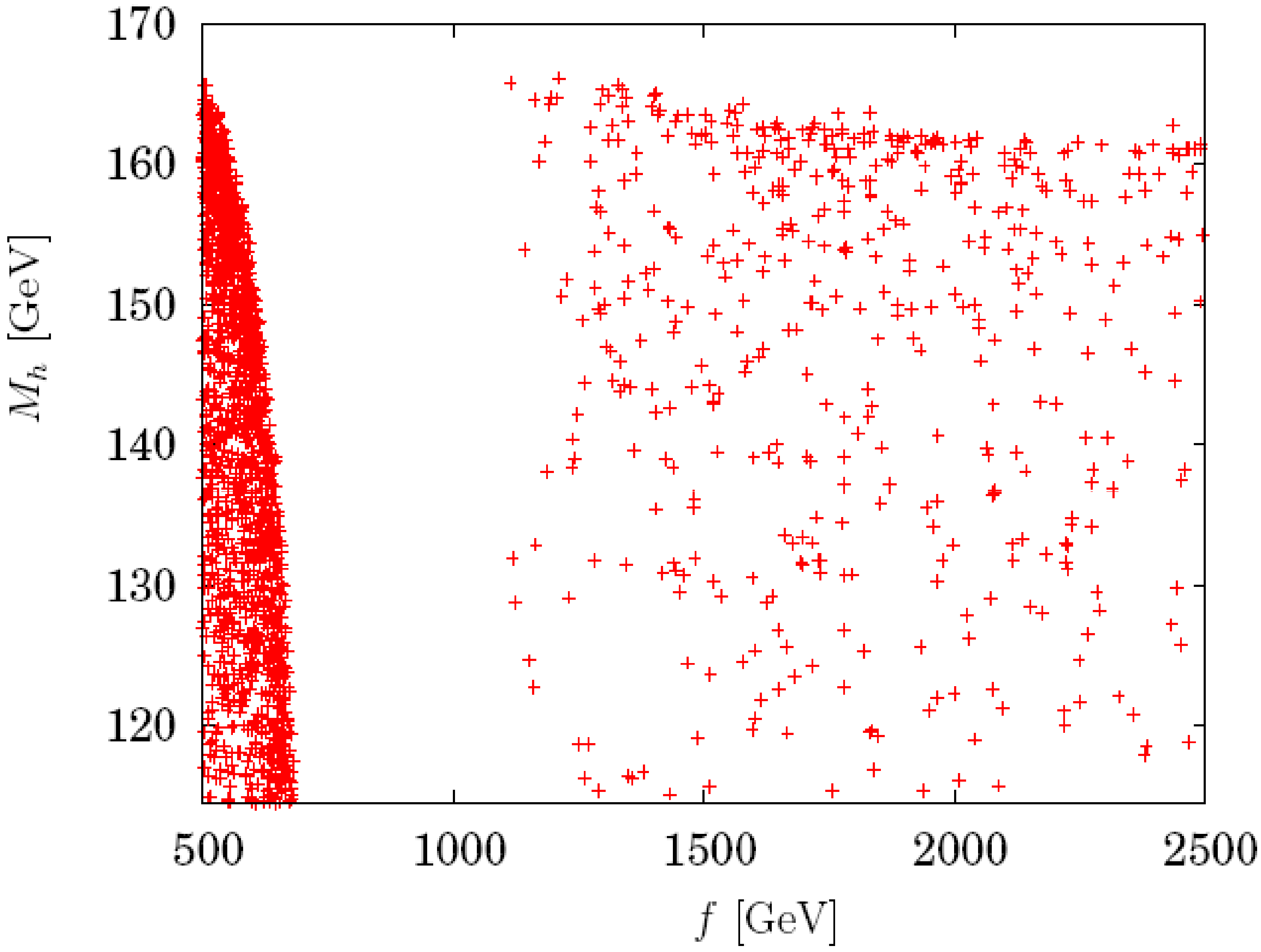
120
100
80
60
40
20
0
M_{ϕ^0} [GeV]
500
1000
1500
2000
2500
f [GeV]

(b)



1100
1000
900
800
700
600
500
400
300
200
100
$M_{\phi^\pm}$ [GeV]
500
1000
1500
2000
2500
f [GeV]

(c)



170
160
150
140
130
120
500
1000
1500
2000
2500
M_h [GeV]
f [GeV]

Summary and Conclusion

- We have calculated 1-loop corrected ρ parameter in the LRTH model.
- With the constraints for heavy particles we can give a serious bound on the *f* and masses of the non-SM particles.
- We also gives a typical mass range for Higgs boson.(maybe upper bound.)

- Our numerical results significantly reduce the parameter space which are favorably accessible to the LHC
- More study on the precision variables, Peskin-Takeuchi STU analysis.
- Flavor and CP structure of the LRTH model wait for you attentions.