Focus Point Assisted by Right-handed Neutrinos

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"Focus Point Assited by Right-Handed Neutrinos"
hep-ph/1111.3506, PLB 708 (2012) 107
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@ 2012.2.21 Toyama

Naturalness

- **Standard Model**

$$\delta m^2 \sim \Lambda^2$$

$$V = \frac{\lambda}{2}|H|^4 - m^2|H|^2 \longrightarrow m_Z^2 = \frac{g^2 + g'^2}{2\lambda} m^2$$

Cancellation between m_0^2 and δm^2 $\longrightarrow$ $\mathcal{O}\left(\frac{m_Z^2}{\Lambda^2}\right)$ tuning

- **Supersymmetry (MSSM)**

$$\frac{m_Z^2}{2} = -m_{H_u}^2 - \mu^2 + \mathcal{O}\left(\frac{m_H^2}{\tan^2\beta}\right)$$

Cancellation between $m_{H_u}^2$ and μ^2 $\longrightarrow$ $\mathcal{O}\left(\frac{m_Z^2}{\mu^2}\right)$ tuning

Finetuning Measure

The parameters in UV theory determines EW scale (mZ).

e.g) mSUGRA case ⟶ $m_Z^2 = m_Z^2(m_0, m_{1/2}, A_0, \mu_0, B_0)$

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Finetuning measure :

$$\Delta = \max[\Delta(a)] \qquad \Delta(a) = \left| \frac{a}{m_Z^2} \frac{\partial m_Z^2}{\partial a} \right| = \left| \frac{\partial \log m_Z^2}{\partial \log a} \right|$$

[Ellis, Enqvist, Nanopoulos and Zwirner (1986)]

$$a \longrightarrow (1+\epsilon)a$$

$$\Downarrow$$

$$m_Z^2 \longrightarrow (1+\Delta\times\epsilon)m_Z^2$$

$\Delta = 10$ $\longrightarrow$ 10 % tuning required

$\Delta = 30$ $\longrightarrow$ 3.3 % tuning required

$\Delta = 100$ $\longrightarrow$ 1 % tuning required

Finetuning Measure in SUSY

Naïve estimation of

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μ_0 —RGE running→ $\mu \sim \mu_0$

Mediation scale — EW scale

$$\Delta(\mu_0) = \left| \frac{\mu_0}{m_Z^2} \frac{\partial m_Z^2}{\partial \mu_0} \right| \sim \frac{4\mu_0^2}{m_Z^2}$$

Heavy Higgsino -> finetuning…

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$m_{H_u,0}^2,\ m_{Q,0}^2,\ \cdots$ —RGE running→ $m_{H_u}^2,\ m_Q^2,\ \cdots$

Mediation scale — EW scale

If $|m_{H_u}^2| \sim \mathcal{O}(1) \times m_Q^2 \longrightarrow \Delta(m_{Q,0}) \sim \frac{m_{Q,0}^2}{m_Z^2}$

Heavy squark -> finetuning ???

Focus Point [Feng, Matchev and Moroi (1999)]

Heavy Squark is not so bad!

When $m_0 \gg M_{1/2},\ A_0$

$$\frac{d}{d\log\mu}\begin{pmatrix} m_{Q_3}^2 \\ m_{U_3}^2 \\ m_{H_u}^2 \end{pmatrix} \simeq \frac{y_t^2}{16\pi^2}\begin{pmatrix} 2 & 2 & 2 \\ 4 & 4 & 4 \\ 6 & 6 & 6 \end{pmatrix}\begin{pmatrix} m_{Q_3}^2 \\ m_{U_3}^2 \\ m_{H_u}^2 \end{pmatrix}$$

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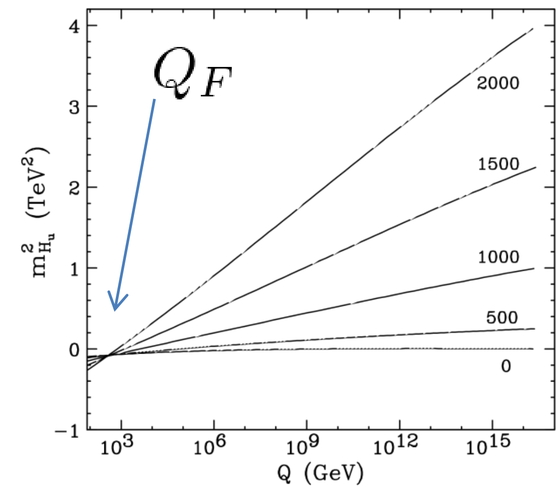

[Feng, Mathcev and Moroi; PRL84 (2000) 2322]

Solution of RGEs is **proportional to m0**

The scale Q_F with $m_{H_u}^2(Q_F) = 0$ is almost independent on m0.

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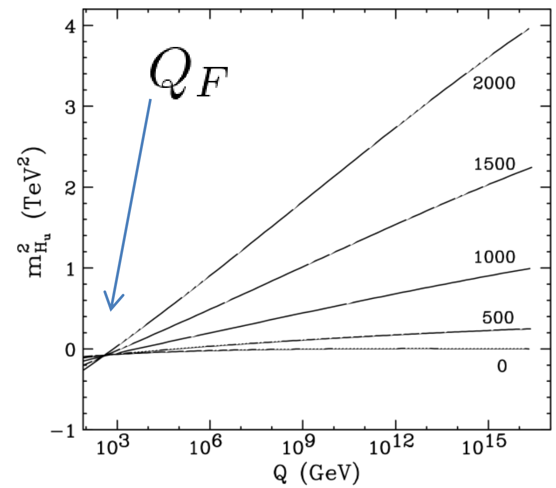

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Solution of RGEs is **proportional to m0**

The scale Q_F with $m_{H_u}^2(Q_F) = 0$ is almost independent on m0.

Q_F is determined by
- gauge coupling
- Yukawa coupling
- Universal scalar mass at GUT scale

→ $Q_F \sim \mathcal{O}(100)\ \mathrm{GeV}$

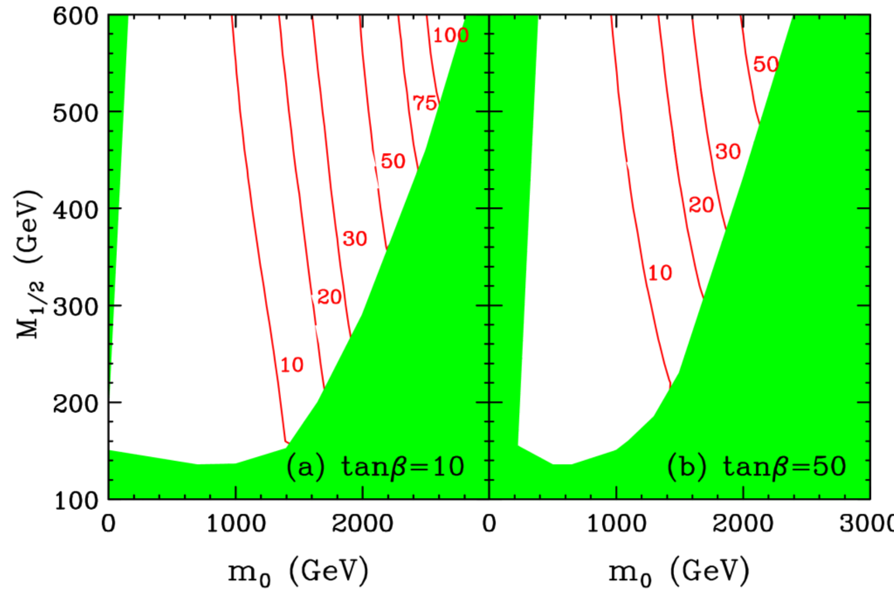
mSUGRA

Focus Point

Focus point behavior
helps NATURALNESS.

$$\frac{\partial m_{H_u}^2}{\partial m_0^2} \ll 1$$

$$\Delta(m_0) = \left| \frac{m_0}{m_Z^2} \frac{\partial m_Z^2}{\partial m_0} \right| \ll \frac{m_0^2}{m_Z^2}$$



[Feng, Mathcev and Moroi; PRD61 (2000) 075005]

Stop loop correction is HARMFUL to naturalness !!

$$\frac{m_Z^2}{2} \simeq -\mu^2 - m_{H_u}^2(Q) - \delta m_{H_u}^2(Q)$$
$$\sim -\mu^2 - m_{H_u}^2(Q = m_{\tilde{t}})$$

Focus Point

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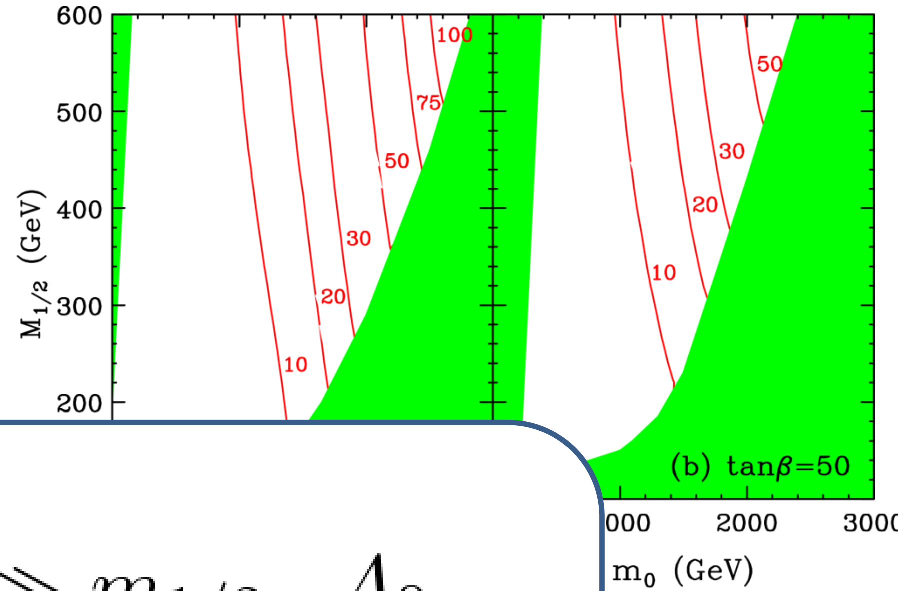


1 (2000) 075005]

Δ

In mSUGRA with $m_0 \gg m_{1/2},\ A_0$

Finetuning can be "mild", but….

Not completely FREE !!

Stop loop correction is HARMFUL to naturalness !!

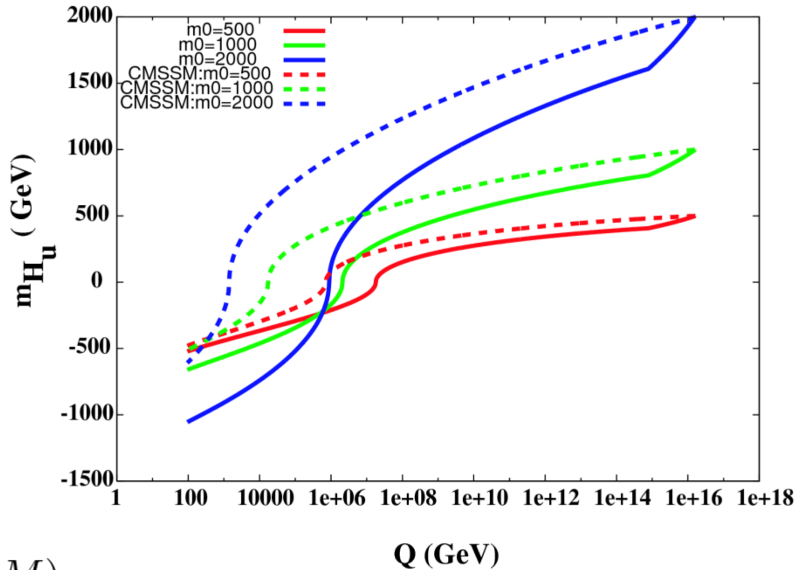
$$\begin{aligned}\frac{m_Z^2}{2} &\simeq -\mu^2 - m_{H_u}^2(Q) - \delta m_{H_u}^2(Q) \\ &\sim -\mu^2 - m_{H_u}^2(Q = m_{\tilde{t}})\end{aligned}$$

Focus Point with νR [Kadota and Olive (2009)]

Large Yukawa coupling modifies
Running of soft mass. $y_\nu \sim \mathcal{O}(1)$

$$W = y_\nu N_i L_i H_u + \frac{M}{2} N_i^2$$

$$\frac{dm_{H_u}^2}{d\log\mu} = \frac{dm_{H_u}^2}{d\log\mu}\bigg|_{\mathrm{MSSM}} + \frac{y_\nu^2}{16\pi^2}(m_{N_3}^2 + m_{L_3}^2 + m_{H_u}^2)\theta(\mu - M)$$

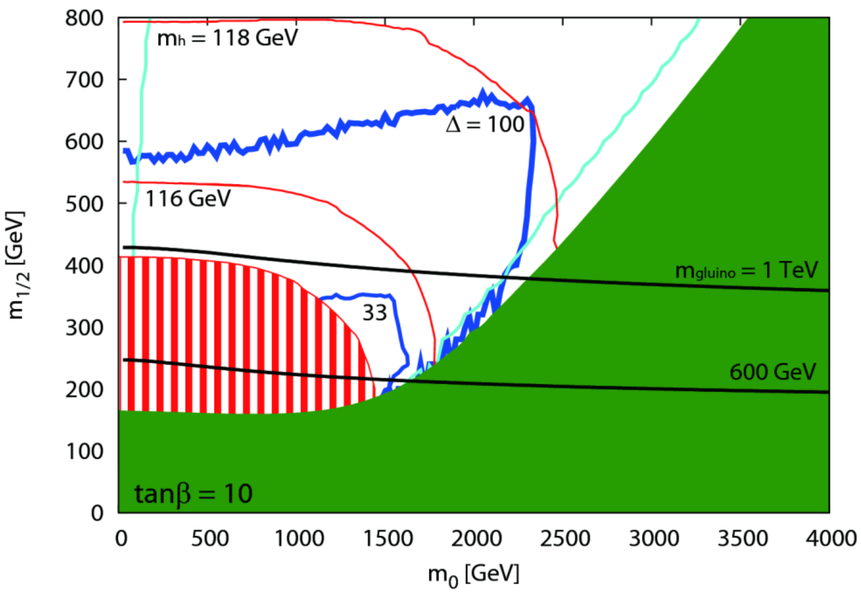


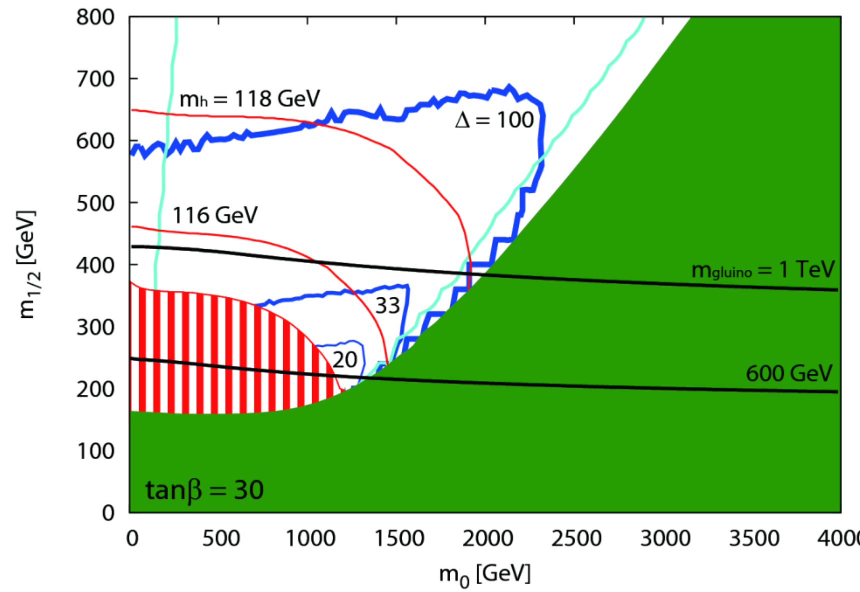
[Kadota and Olive; PRD80 (2009) 095015]

We calculate finetune measure in mSUGRA framework with νR

Result

mSUGRA





Green : μ < 104 GeV

Red Stripe : m_higgs < 114.4 GeV

Turquoise : $\Omega_{\rm DM} h^2 = 0.112$

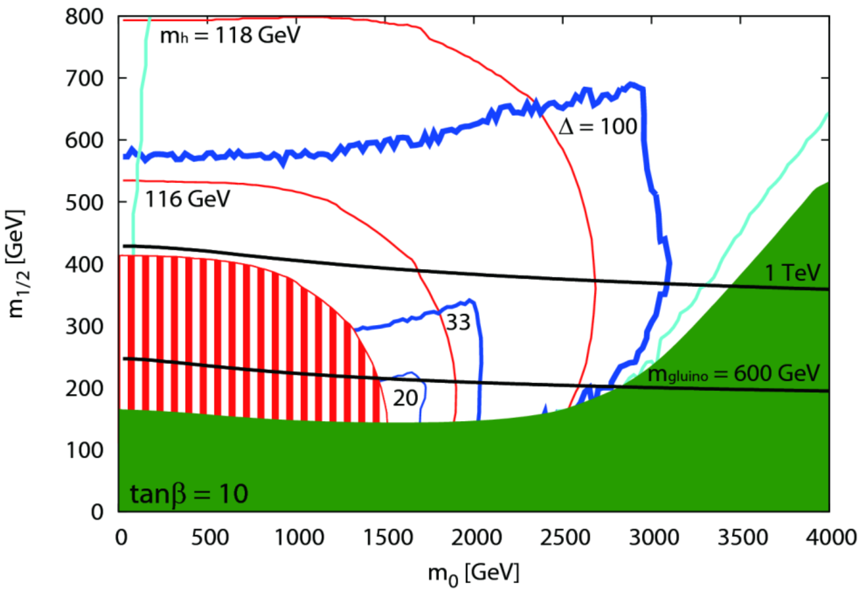
$$\Delta = \max_{a \in m_0, m_{1/2}, A_0, \mu, B_0} [\Delta(a)]$$

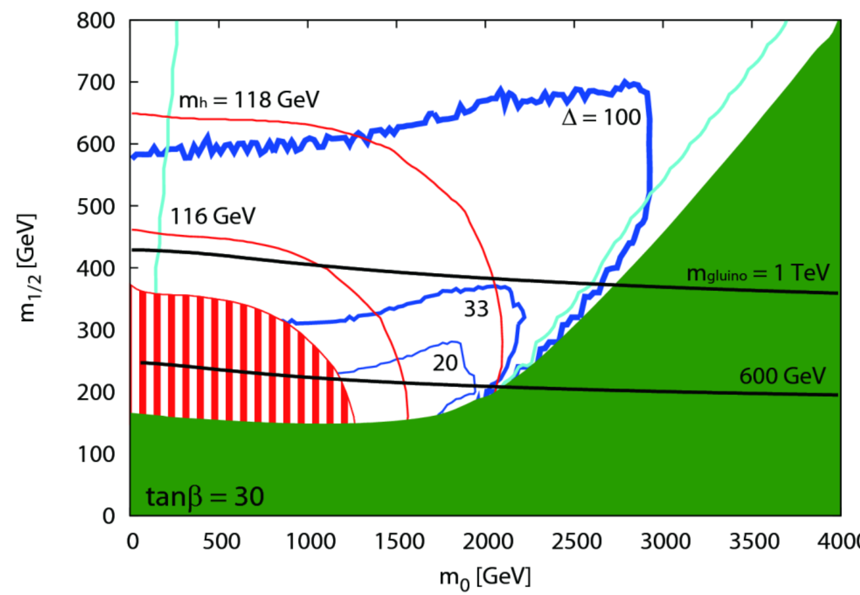
[Asano, Moroi, RS and Yanagida; PLB708 (2012) 107]

Result

mSUGRA with νR

$$M_N = 2 \times 10^{14}\ \mathrm{GeV}$$





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Conclusion

Large Y_ν softens fine tuning
In multi TeV squark region.

In focus point region,
Higgs mass is relatively small.