The lightest Higgs mass in MSSM + extra matter

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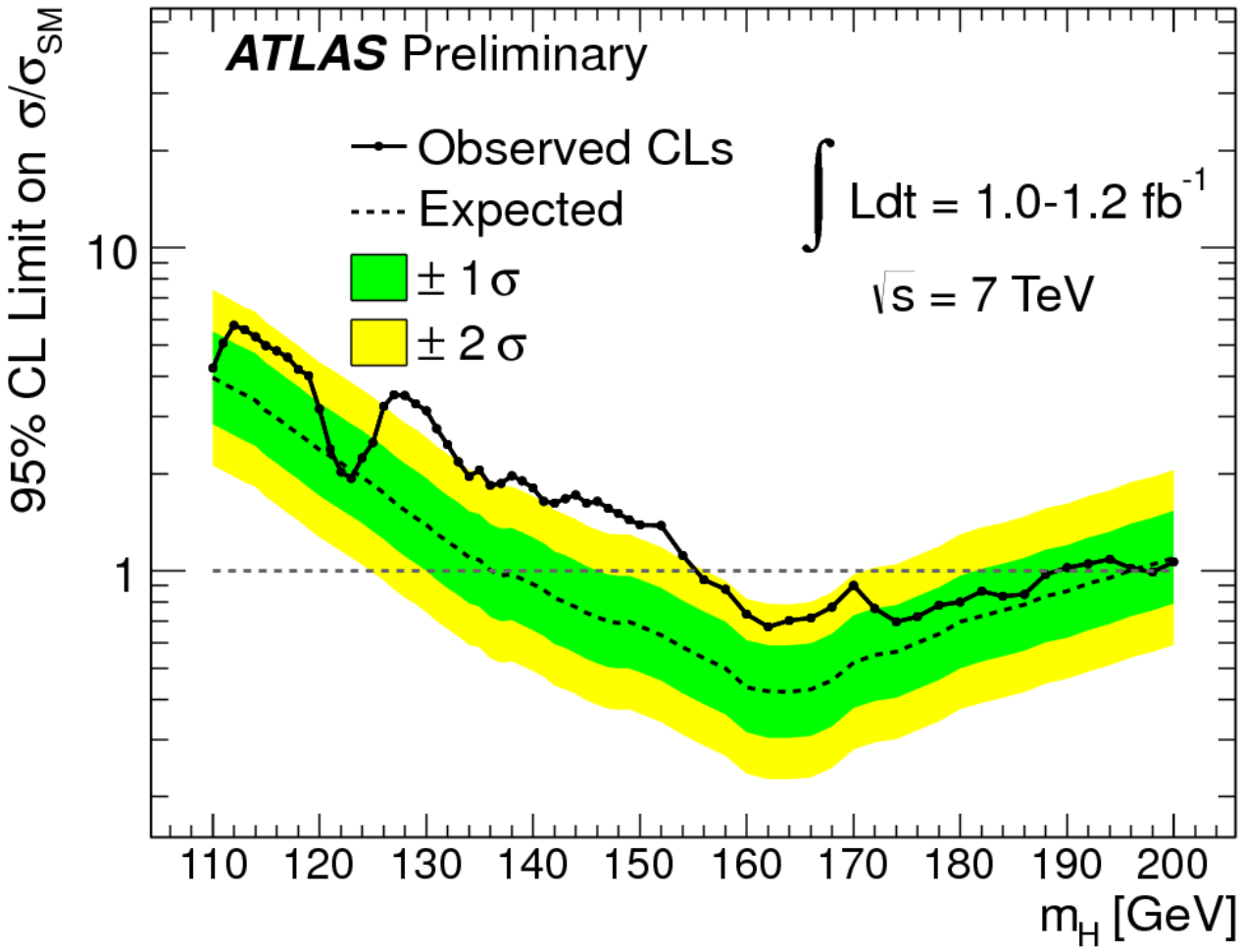
“**Non-anomalous Discrete R-symmetry, Extra Matters, and Enhancement of the Lightest SUSY Higgs Mass**”,
M. Asano, T. Moroi, RS and T. T. Yanagida [arXiv:1108.2402]

Higgsがもうすぐ見つかる？ (すでに見え始めている？)



[The ATLAS Collaboration, ATLAS-CONF-2011-112]

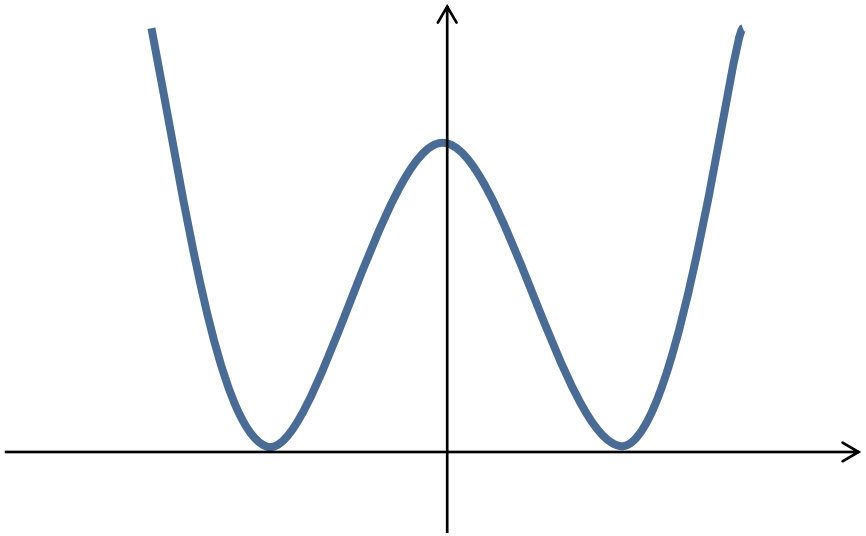
Supersymmetry (MSSM)のHiggs sector

2 Higgs doublet $\begin{pmatrix} H_u^+ \\ H_u^0 \end{pmatrix} \begin{pmatrix} H_d^0 \\ H_d^- \end{pmatrix}$

CP-even Higgs	2	h_0, H_0
CP-odd Higgs	1	A_0
Charged Higgs	2	$H^\pm$
NG-boson (eaten by W, Z)	3	$(W_L^\pm, Z_L)$

CP-even Higgsの軽い方が、
Standard Model-like Higgsとなる。

MSSMは軽いHiggsを予言する。



$$V = \frac{\lambda}{2}|H|^4 - m^2|H|^2$$

$$\longrightarrow \quad m_h^2 = \lambda v^2$$

MSSMでは、4点結合がgauge couplingだけで決まる。

$$V_{MSSM} = \frac{g^2 + g'^2}{8}\left(|H_u^0|^2 - |H_d^0|^2\right)^2 + \cdots$$

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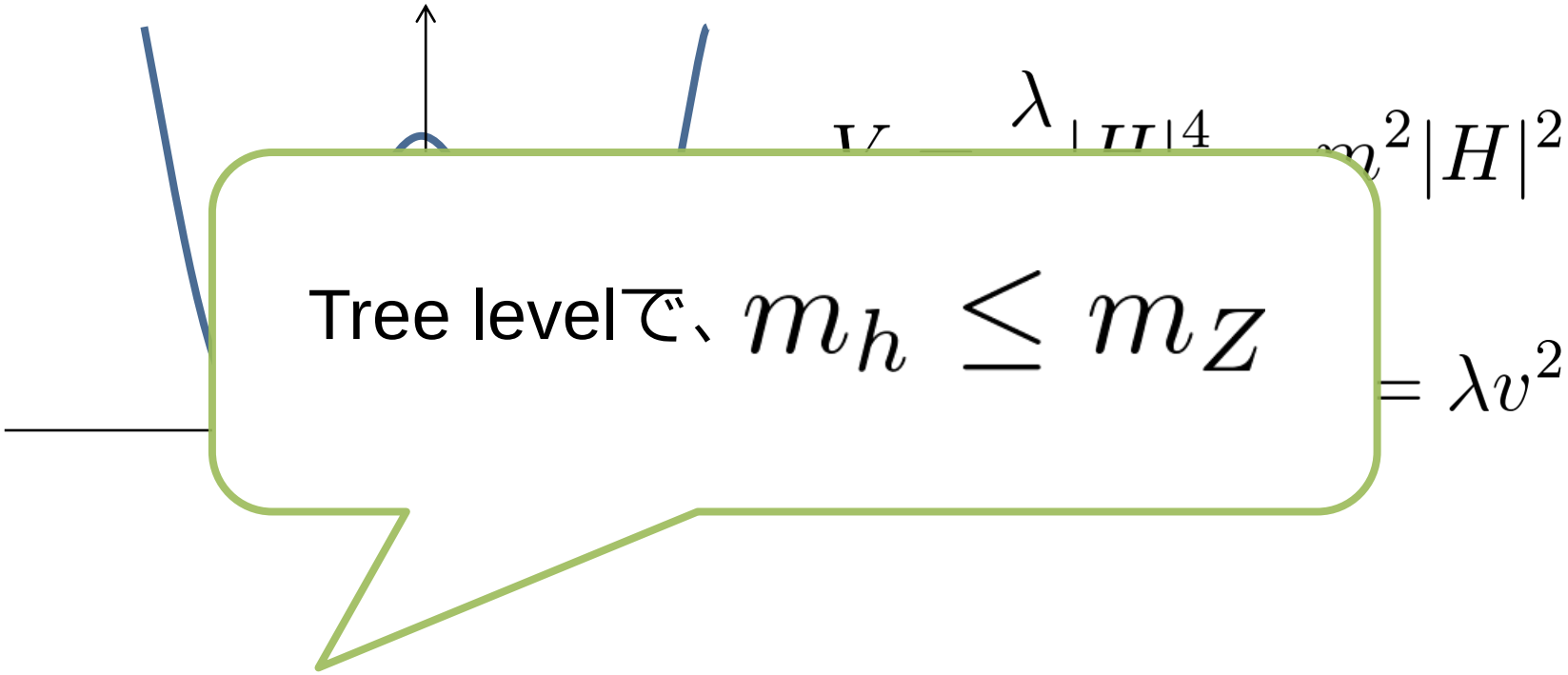

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Loop correctionで、Higgsの質量は上がる。

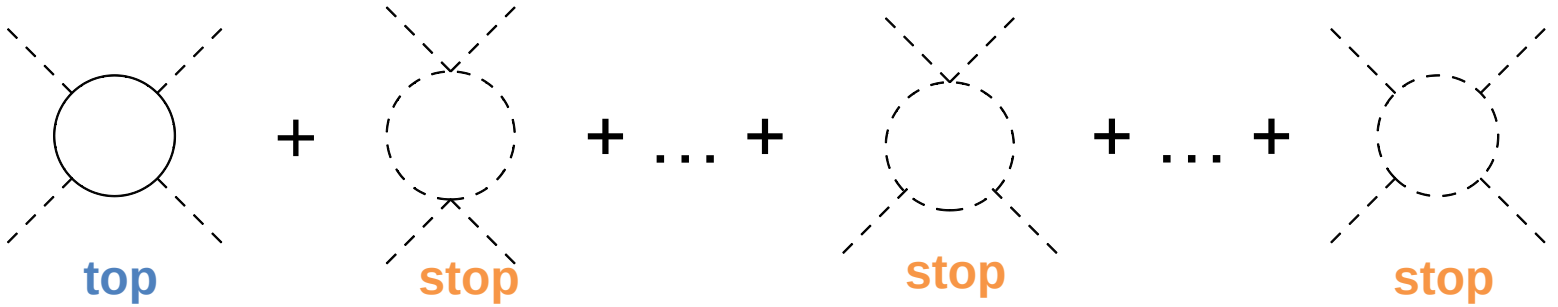
[Okada, Yamaguchi, Yanagida (‘91)]

top，stop の寄与が重要！

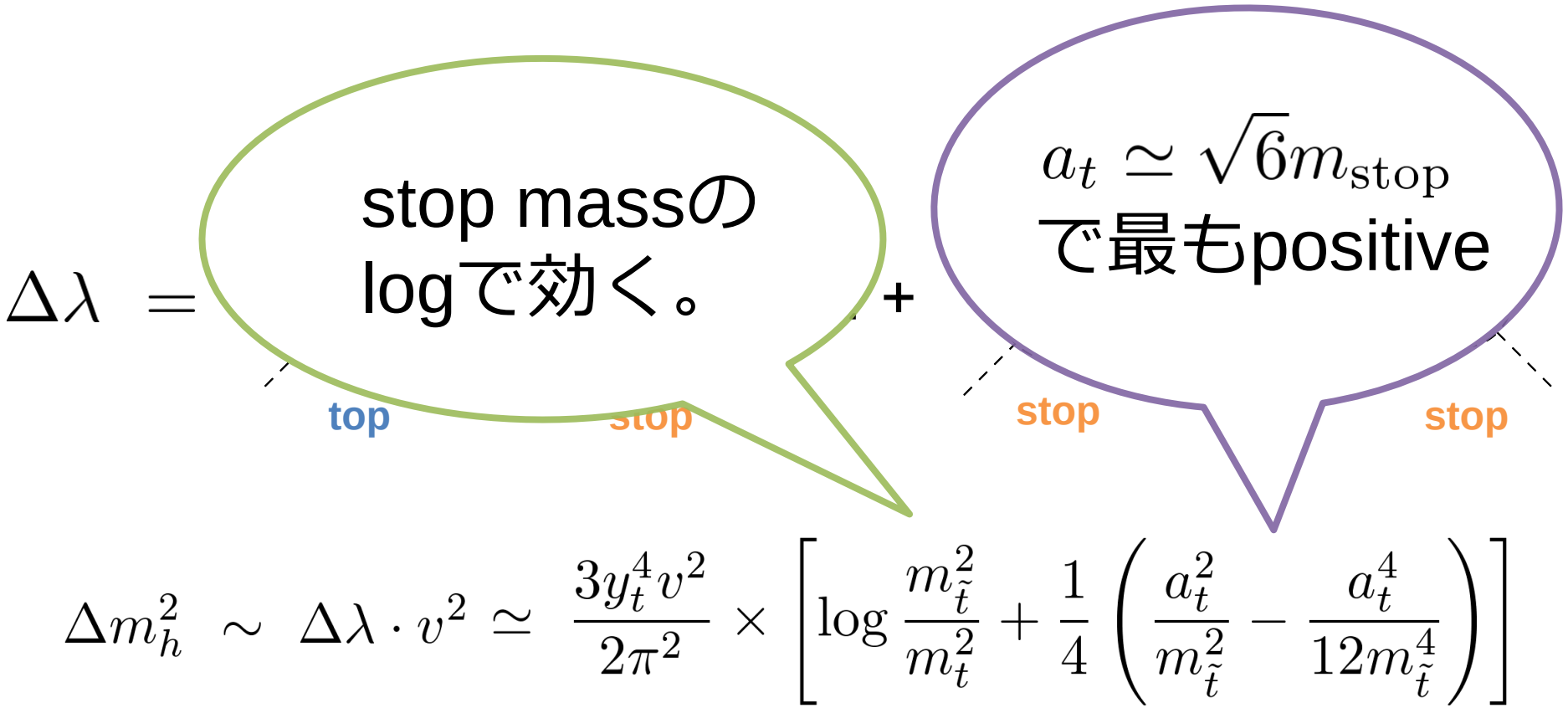
$$\mathcal{L}_{int.} \ni \begin{cases} y_t \ H_u^0 t_L t_R^c + h.c. \\ y_t^2 \ |H_u^0|^2 |\tilde{t}_L|^2 + y_t^2 \ |H_u^0|^2 |\tilde{t}_R^c|^2 \\ y_t a_t \ H_u^0 \tilde{t}_L \tilde{t}_R^c + h.c. \end{cases}$$

Higgs massの補正 ⟷ スカラー4点の補正

$$\Delta m_h^2 \ \sim \ \Delta\lambda \cdot v^2$$

$\Delta\lambda \;=$ 

$$\Delta m_h^2 \;\sim\; \Delta\lambda \cdot v^2 \simeq \frac{3y_t^4 v^2}{2\pi^2} \times \left[\log \frac{m_{\tilde{t}}^2}{m_t^2} + \frac{1}{4}\left(\frac{a_t^2}{m_{\tilde{t}}^2} - \frac{a_t^4}{12 m_{\tilde{t}}^4} \right) \right]$$



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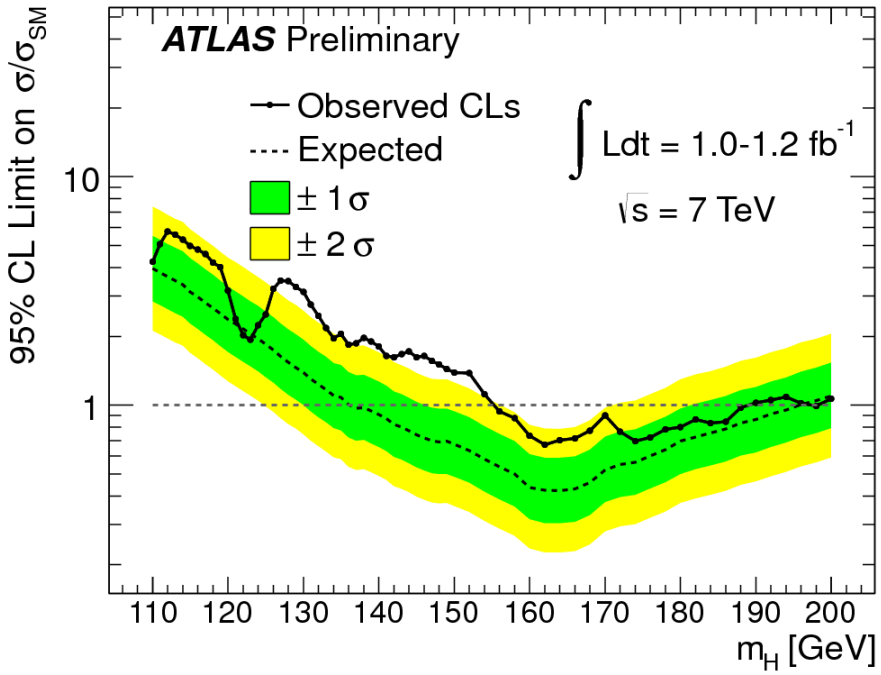
補正にはやっぱり限度がある。

$m_{\rm stop}$ が1TeVなら、せいぜい125GeV

[Carena, Haber (‘02)]



130-150 GeVにHiggsいるかも？

vs

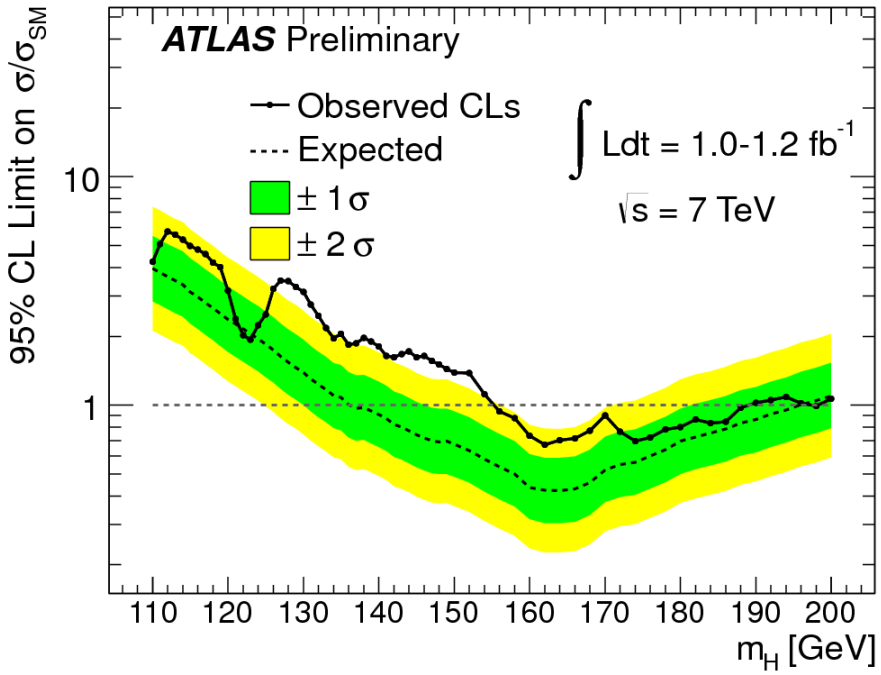
SUSY(MSSM)だとHiggs軽い！

4点結合を大きくできれば、Higgsは重くできる！

- tree level (Next-to-MSSM)

$$W \ni \lambda S H_u H_d \quad \longrightarrow \quad \Delta V = |\lambda H_u H_d|^2 + \cdots$$

- loop level (Extra Matter)



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Extra matterのmotivation

discrete R symmetry Z_{NR} の anomaly cancelation

[Kurosawa, Maru, Yanagida (‘01)]

Extra matterのmotivation

discrete R symmetry Z_{NR} の anomaly cancelation

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Proton decayを強くsuppressする。

(普通のR-parityより強力)

$$W = \frac{1}{\Lambda} QQQL + \frac{1}{\Lambda} \bar{U}\bar{U}\bar{D}\bar{E}$$

Giudice Masiero mechanismと組み合わせられる。

Z_{NR} の破れ
SUSYの破れ

$$\longrightarrow \int d^2\theta \ \mu H_u H_d$$

具体的なセットアップ

Vector-likeなmatter
massは、Giudice-Masiero Mechanismを想定。

$$\longrightarrow \quad m_{\rm extra} \sim \mathcal{O}(1)\ {\rm TeV}$$

- Perturbative GUT
- Anomaly Cancelation of Z_{NR}

$$\longrightarrow \quad 5+\bar{5}, \quad 3\times(5+\bar{5}), \quad 10+\bar{10}$$

具体的なセットアップ

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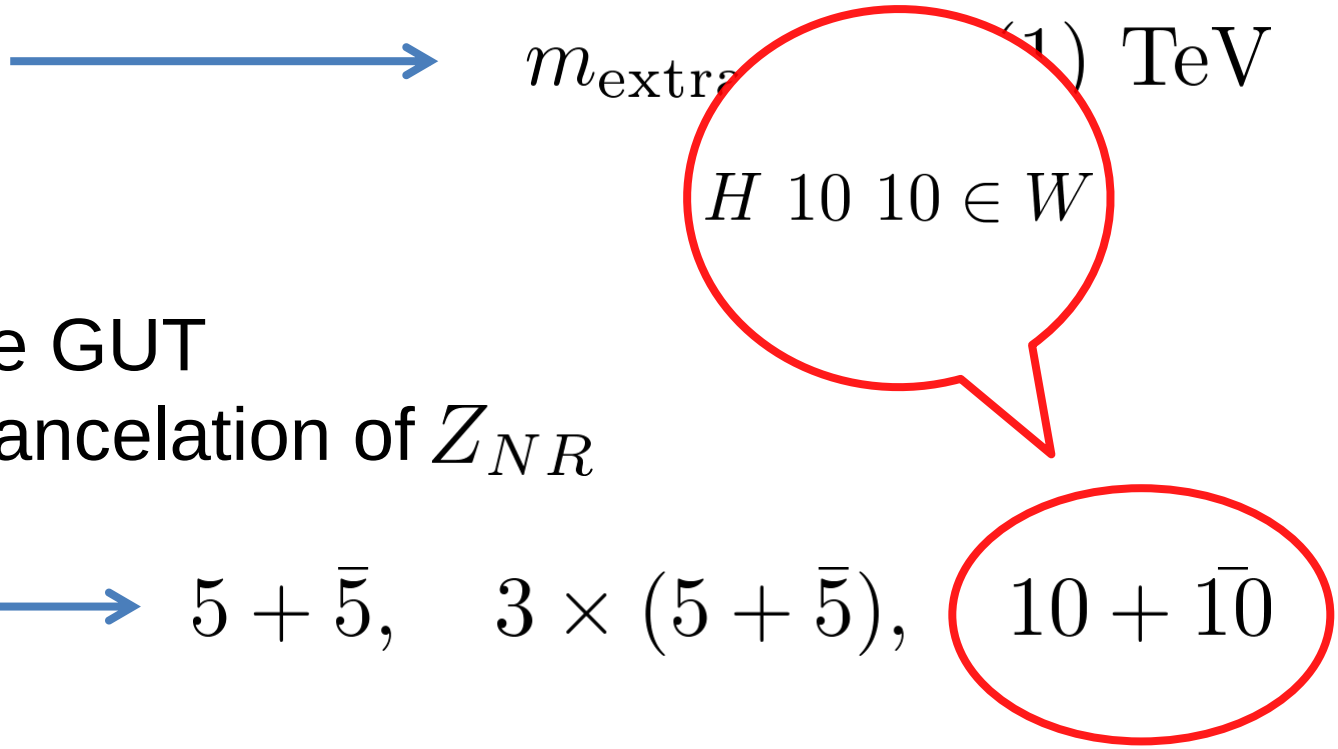

- Perturbative GUT
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具体的なセットアップ

MSSM + $10 + \bar{10}$

$$10 = (Q, U, E), \quad \bar{10} = (\bar{Q}, \bar{U}, \bar{E})$$

$$W_{\rm ex} = M_Q Q\bar{Q} + M_U U\bar{U} + M_E E\bar{E} + y_U H_u QU$$

$$\mathcal{L}_{\rm soft,ex} = a_U y_U H_u QU + h.c.$$

Giudice-Masiero Mechanism → $M_Q, M_U, M_E \sim \mathcal{O}(1)\mathrm{TeV}$

Extra matterの Higgs 4点に対する寄与

(基本的には、top&stopと一緒。)

log的な寄与

A-termなどの寄与

$$\Delta\lambda \simeq \frac{3y^4}{8\pi^2}\left[\ln\left(\frac{M^2+m^2}{M^2}\right) - \frac{1}{4}\frac{A^4-(8M^2+12m^2)A^2+8M^2m^2+10m^4}{(M^2+m^2)^2}\right]$$

$M = M_Q = M_U = M_E$ (SUSY-invariant mass)

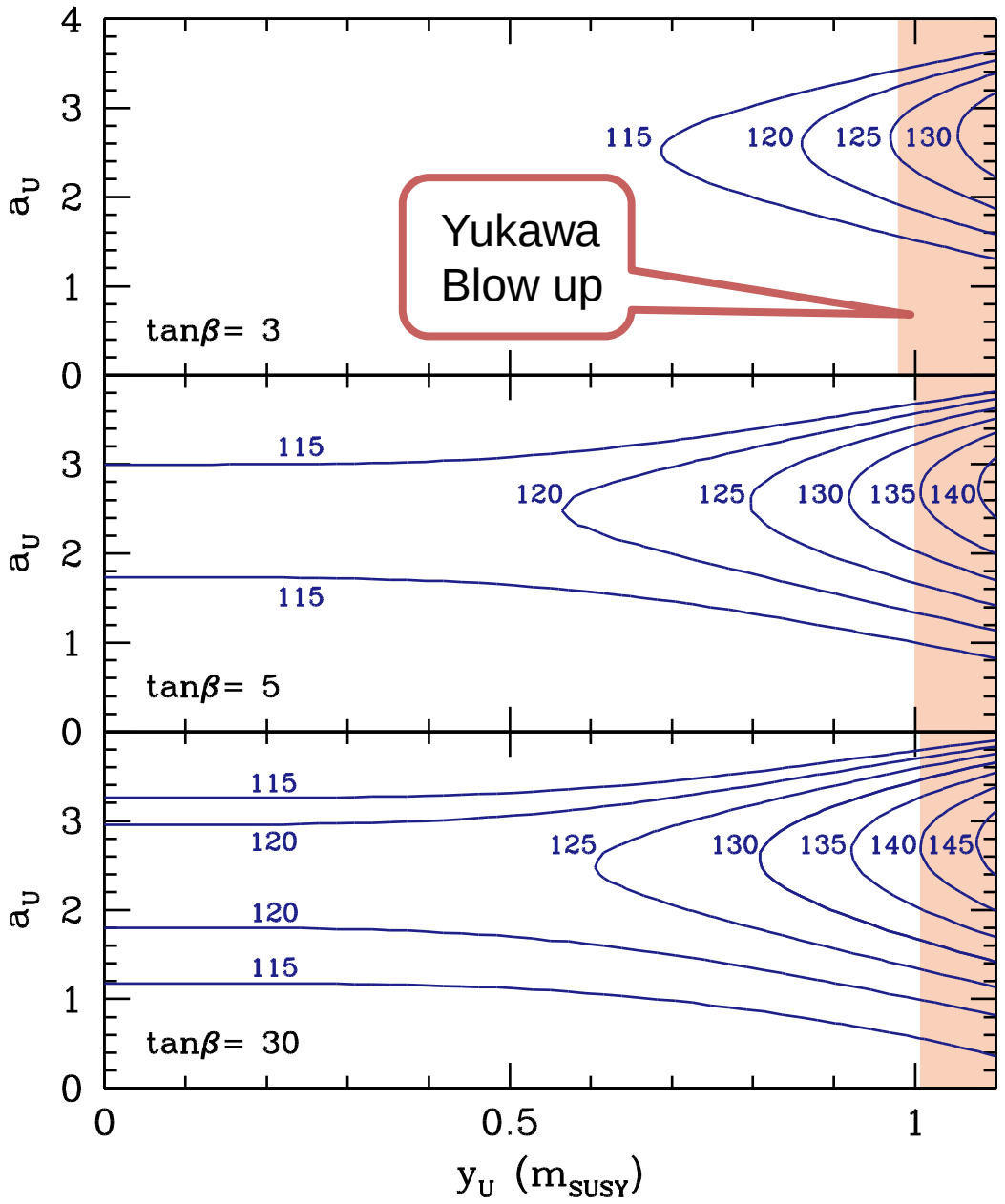
$m^2 = m_Q^2 = m_U^2 = m_E^2$ (soft mass)

$$M_Q = M_U = M_E = m_{\mathrm{SUSY}} = 1\ \mathrm{TeV}$$

$$a_t = a_U$$

* Effectiveに|Hu|^4が出るので、large tanbetaが有利。

* YukawaとA-termの両方効く。



[Asano, Moroi, RS and Yanagida [arXiv:1108.2402]]

$$M_Q = M_U = M_E = m_{\rm SUSY} = 1\ {\rm TeV}$$

$$a_t = \sqrt{6}\ {\rm TeV}$$

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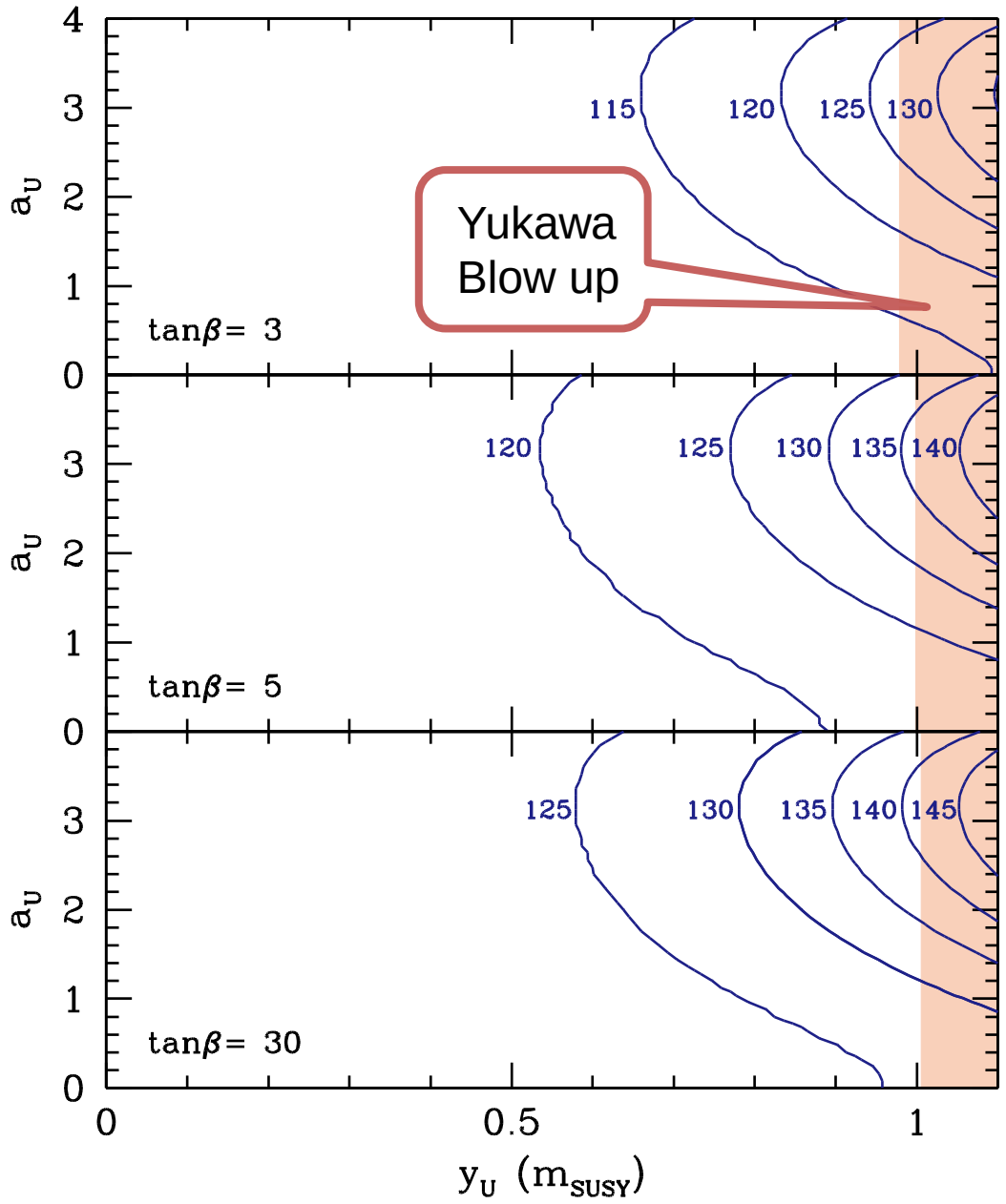


[Asano, Moroi, RS and Yanagida [arXiv:1108.2402]]

Conclusion

$$m_{\mathrm{SUSY}} \lesssim 1\ \mathrm{TeV} \longrightarrow m_h \lesssim 125\ \mathrm{GeV}$$

@ MSSM

Extra Matter (10+10*)

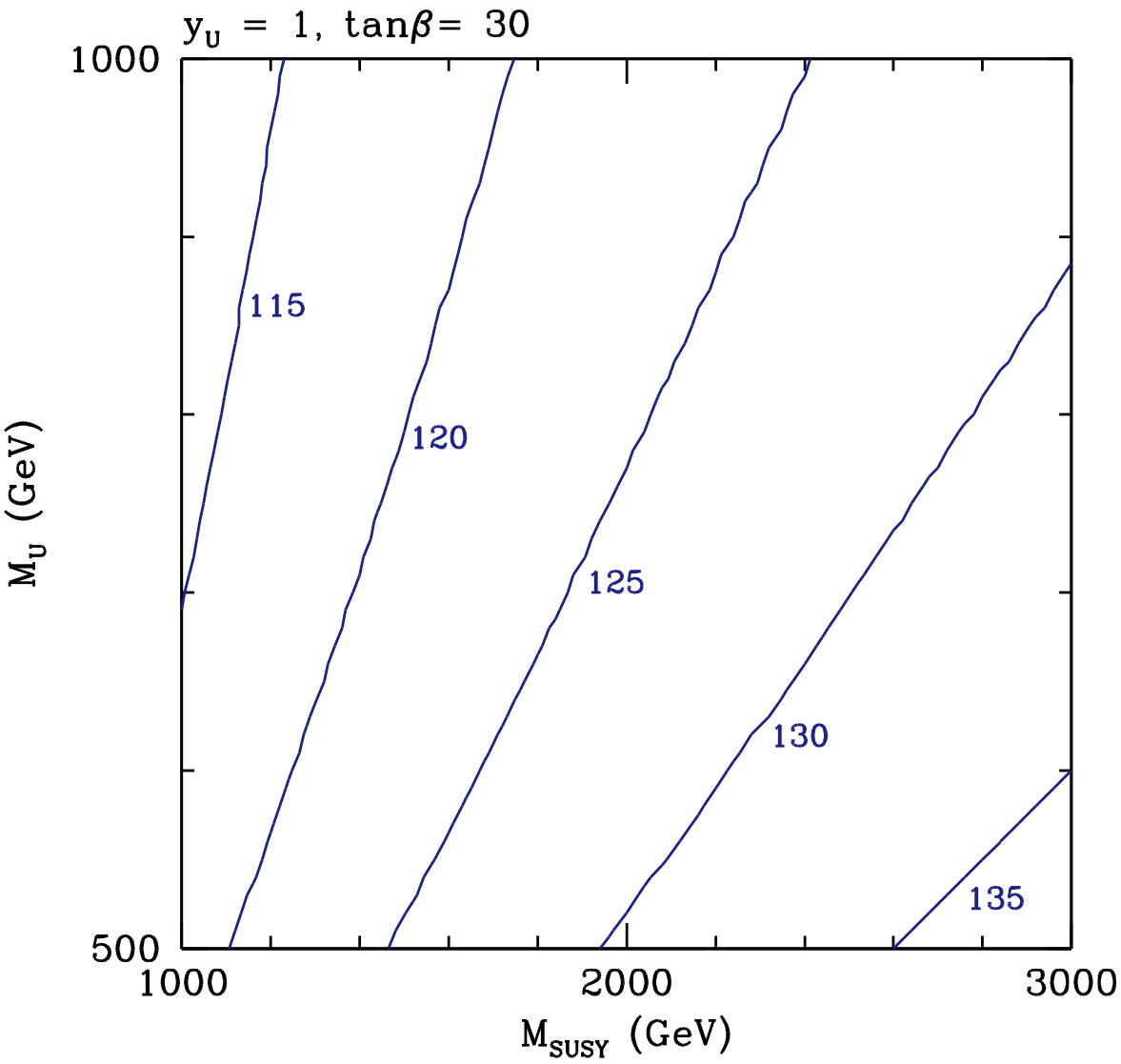
Enhancement of m_h ⟶ ~ 140 GeV

Anomaly Cancelation of Z_{NR}

- proton stability
- Giudice-Masiero mechanism

Backup

A-termを0にした場合。



Giudice Masiero Mechanism

[Giudice, Masiero (‘88)]

$$\int d^2\theta \ \mu H_u H_d$$

Mu Problem!

Higher dimensional Operator

$$\int d^4\theta \frac{Z^\dagger}{M_{\rm Pl}} H_u H_d \longrightarrow \mu \sim m_{3/2}$$

Gravity Mediationと組み合わせれば、
Muの大きさが良い塩梅になれる。

Z_{NR} の一例

(SUSY breaking)

$$Z_{4R} \xrightarrow{\langle W \rangle \neq 0} Z_{2R}$$

usual R-parity
with parity-odd extra matter

	$\bar{5}_{\rm SM}$	$10_{\rm SM}$	N	5_H	$\bar{5}_H$	$10_{\rm ex}$	$\bar{10}_{\rm ex}$	θ
Z_{4R}	1	1	1	0	0	1	-1	1