Kobayashi-Maskawa Institute for the Origin of Particles and the Universe

Constraints on Non-Universal Gaugino Mass scenario using the "latest" LHC data

Yuji Omura (KMI, Nagoya)

Based on 1601.03484 with J. Kawamura;
1505.03729 with H. Abe, J. Kawamura.

SUSY is a very attractive and elegant BSM to

achieve the gauge coupling unification

suggest dark matter candidates

answer to why EW scale is around 100 GeV

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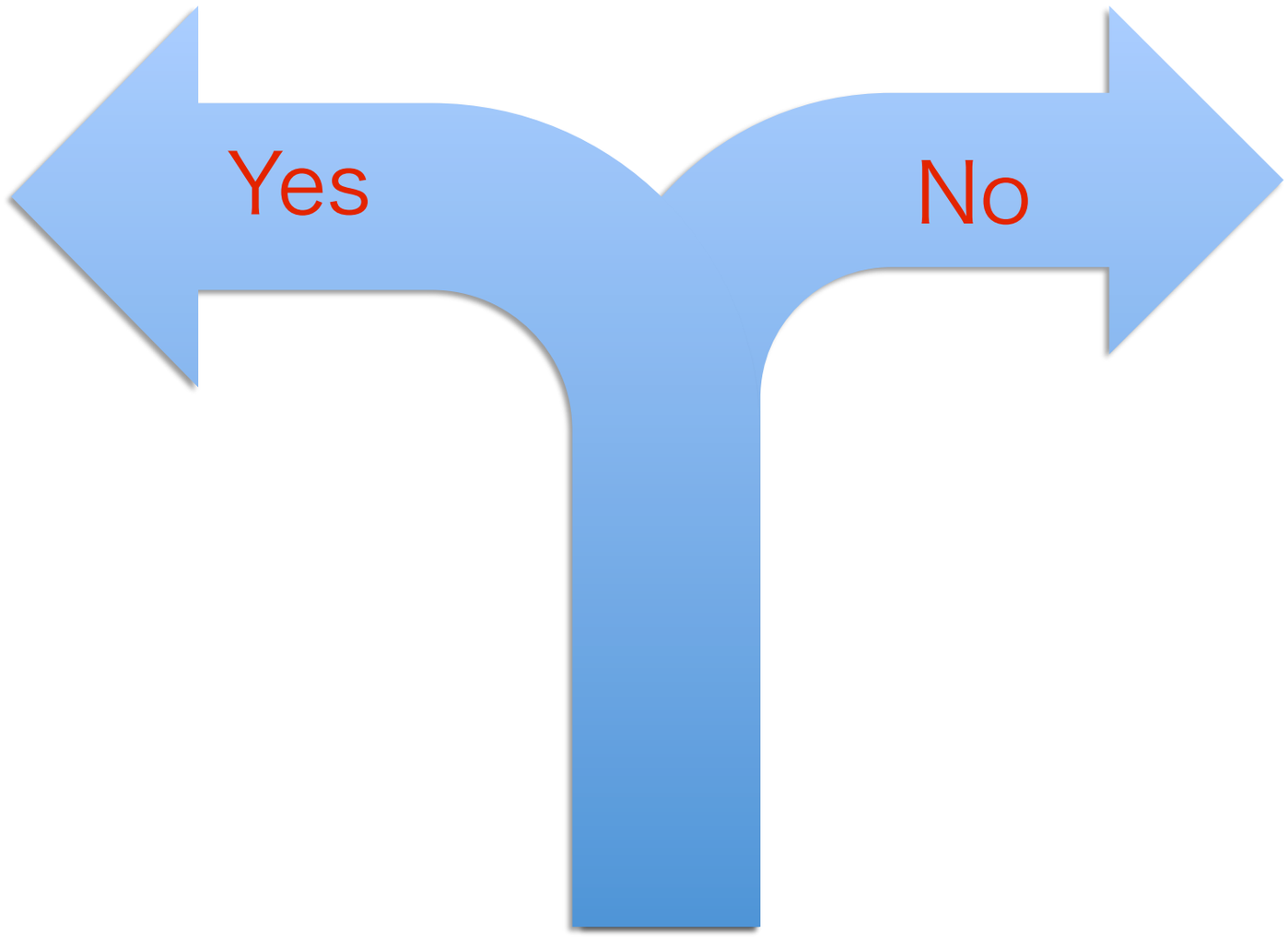
??

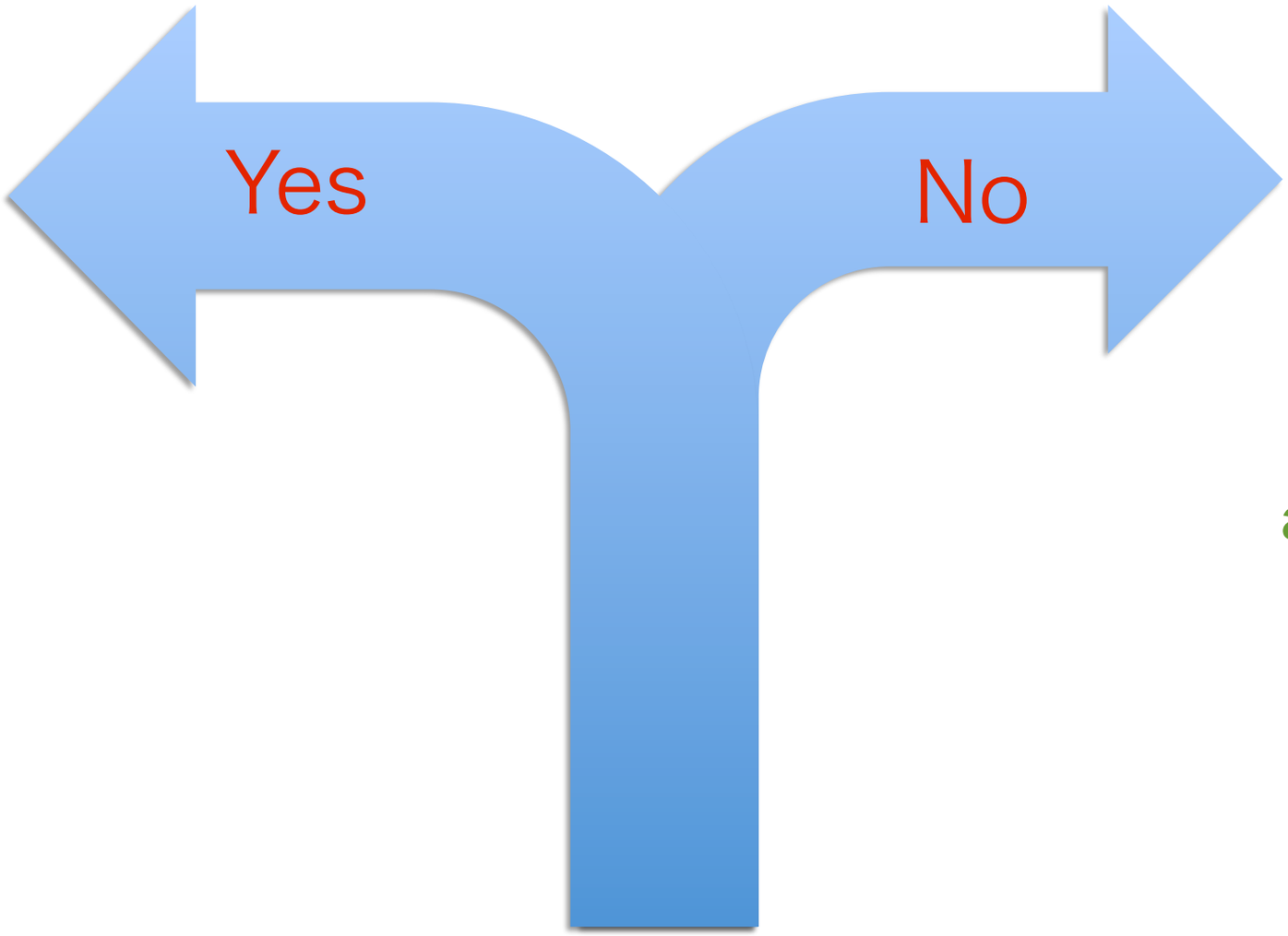
answer to why EW scale is around 100 GeV

Is SUSY really the origin of the EW scale?



Higgs discovery
and
severe constraints

Is SUSY really the origin of the EW scale?



Non SUSY

high-scale SUSY

at least respect…

unification,
DM,
string theory, etc.

Higgs discovery
and
severe constraints

Is SUSY really the origin of the EW scale?

Yes

No

low-scale SUSY

not easy

but possible

effective SUSY

heavy 1,2 generations

light 3 generation

focus-point SUSY

EW scale naturally realized

by specific mass spectrum

extended MSSM

NMSSM

MSSM with U(1)

my talk

Higgs discovery

and

severe constraints

Non SUSY

high-scale SUSY

at least respect…

unification,

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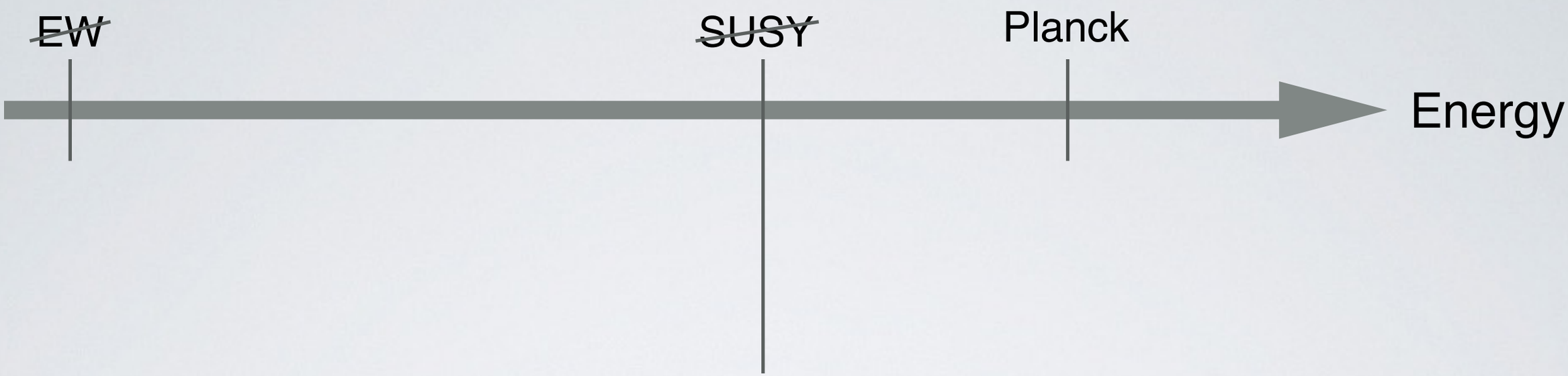
- Short review of little hierarchy problem and solutions
- Current status of Non-Universal Gaugino Mass(NUGM) scenarios at LHC
- Summary

Short review

In supersymmetric model



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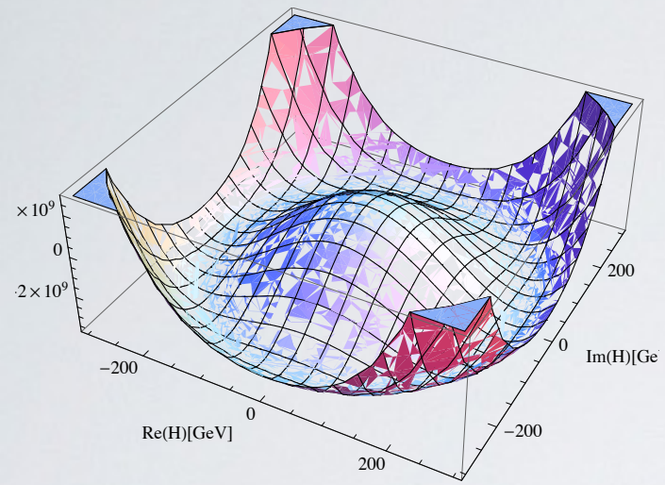

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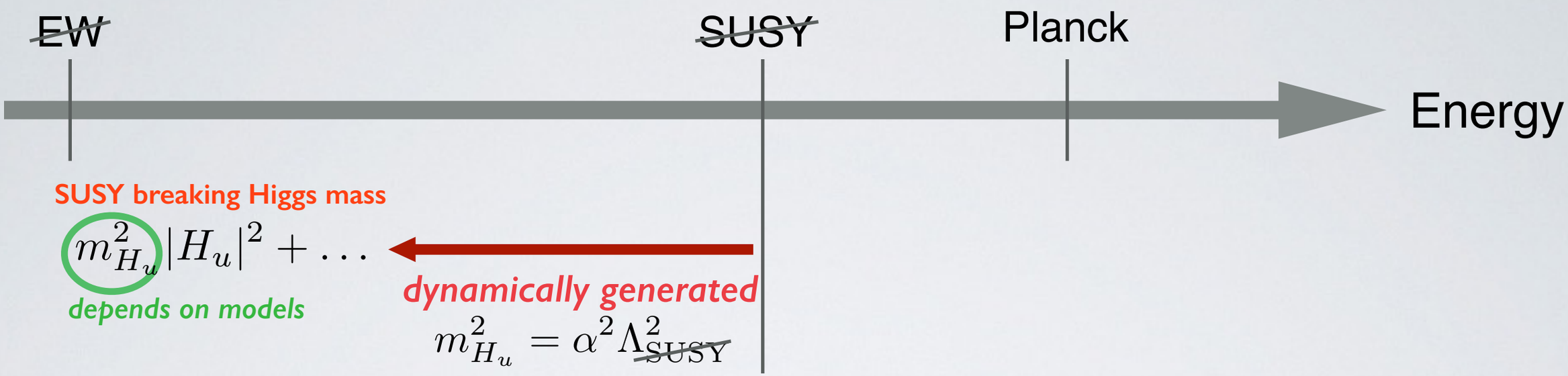


In supersymmetric model

SUSY breaking Higgs mass

$m_{H_u}^2 |H_u|^2 + \dots$

depends on models

dynamically generated

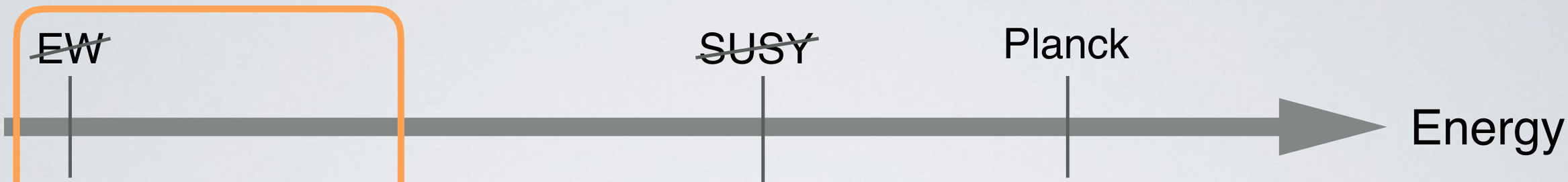
$m_{H_u}^2 = \alpha^2 \Lambda_{\text{SUSY}}^2$

Supersymmetric Higgs mass

$\mu H_u H_d$

maybe effectively generated

In supersymmetric model



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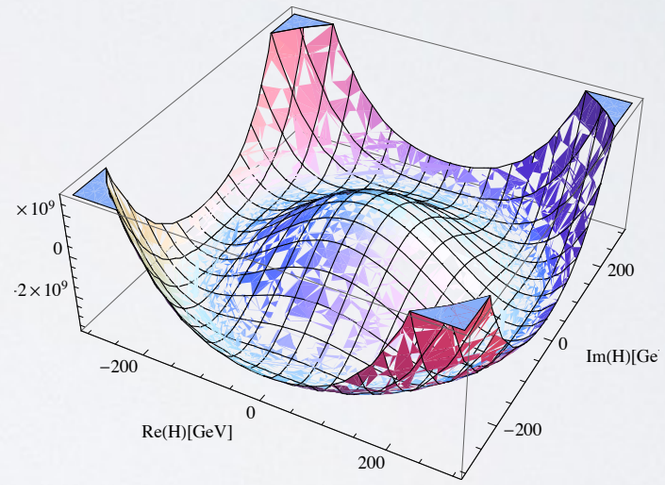


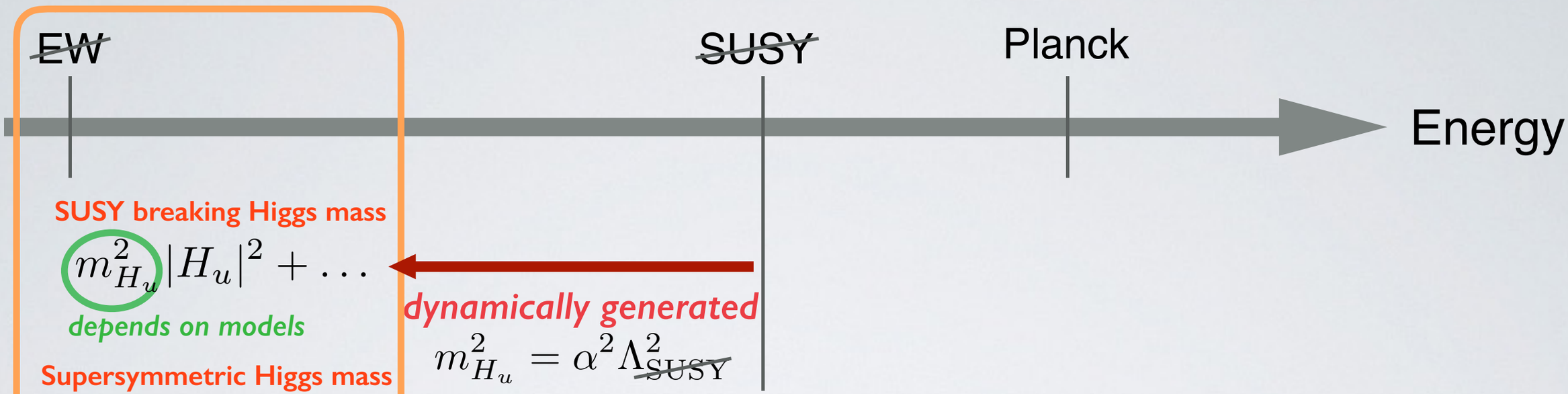
EW scale are predicted by the SUSY scale

$$\frac{1}{2} M_Z^2 \approx -\mu^2 - m_{H_u}^2$$

SUSY — ~~SUSY~~

Short review

In supersymmetric model



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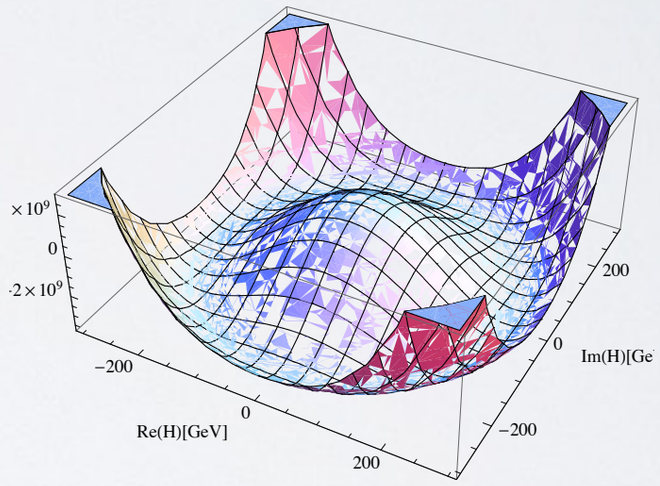

But fine-tuning is required, if SUSY scale is too high.

$\Leftrightarrow$ $(O(100)\mathrm{GeV})^2 = (\mathrm{O}(10)\mathrm{TeV})^2 - (\mathrm{O}(10)\mathrm{TeV})^2$　　***when*** $|m_{H_u}^2| = (O(10)\mathrm{TeV})^2, |\mu|^2 = (O(10)\mathrm{TeV})^2$

should be satisfied!! *(0.01% fine-tuning)*　　***"Little Hierarchy Problem"***

m_{Hu} etc.(SUSY scale) are constrained by

1) direct searches at the LHC

$$M_g \gtrsim 1.5\mathrm{TeV},\ \mathrm{m_{stop}} \gtrsim 600\mathrm{GeV}$$

Mg and m_{stop} relate to m_{Hu}

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naive guess

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2) 126 GeV Higgs mass

h^4 term given by gauge couplings

loop correction should be large

$$m_h^2 \leq M_Z^2 \cos^2 2\beta + \boxed{\Delta m_h^2(m_{stop}^2, A_t - \mu/\tan\beta)}$$

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$$\Delta m_h^2 = \frac{3m_t^4}{4\pi^2 v^2} \ln\left(\frac{m_{stop}^2}{m_t^2}\right) + \cdots @\ A_t - \mu/\tan\beta = 0 \ \Rightarrow\ m_{stop} \gtrsim 10\,\mathrm{TeV}$$ (1205.6497)

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naive guess ⇔ $m_{H_u} \gtrsim \mathcal{O}(10)\,\mathrm{TeV}$

maybe require 0.01% fine-tuning against μ

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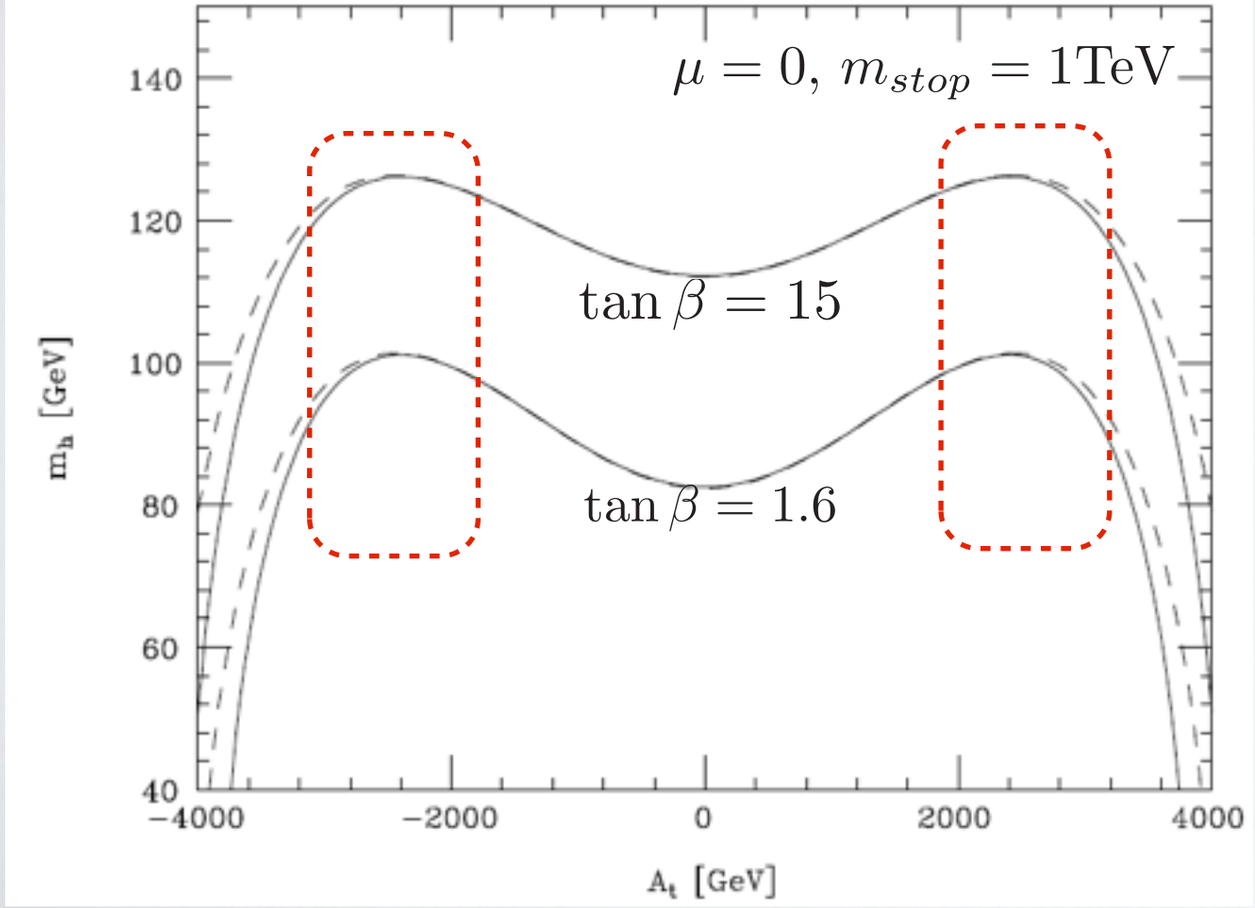
A-term behavior

(Carena, Quiros, Wagner, 95')

one-loop upper bound on Higgs mass

$$m_h^2 \lesssim M_Z^2 \cos^2 2\beta + \frac{3m_t^4}{4\pi^2 v^2}\left\{\ln\frac{m_{stop}^2}{m_t^2} + \frac{X_t^2}{m_{stop}^2}\left(1 - \frac{X_t^2}{12m_{stop}^2}\right)\right\}$$

where $X_t = A_t - \mu/\tan\beta$ and $m_{stop}^2 = \sqrt{m_Q^2 m_U^2}$.



$$\frac{X_t}{m_{stop}} \approx \sqrt{6}$$

shift Higgs mass drastically,

even if stop is light!

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Relation between m_{Hu} and SUSY scale

RG flow from GUT scale to M_Z

$$-2m_{H_u}^2(M_Z) = 5.45M_3^2 + 0.470M_2M_3 - 0.433M_2^2$$
$$+0.0677M_3M_1 - 0.00975M_1^2 + 0.0135M_1M_2$$
$$+A_t(0.773M_3 + 0.168M_2 + 0.0271M_1 + 0.214A_t)$$
$$-1.31m_{H_u}^2 + 0.690m_{Q_3}^2 + 0.690m_{U_3}^2$$

Heavy gluino leads large m_{Hu} naively

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not so simple

cancel each other in some models

$$(\text{small facter}) \times M_3^2$$

when $M_2 \approx 5 \times M_3$

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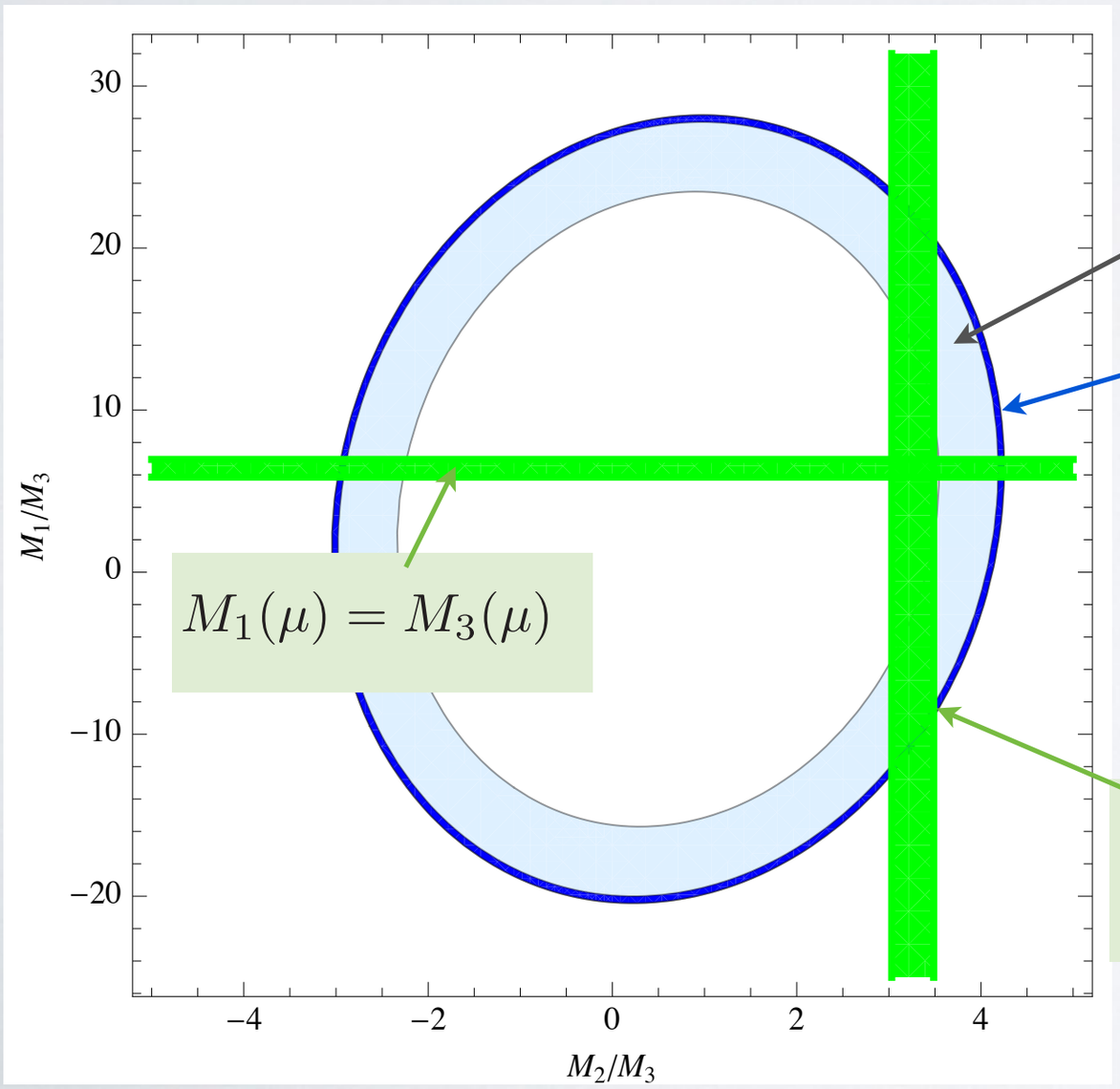
dominant



When gluino is 1 TeV at EW scale,

$$|m_{H_u}^2(M_Z)| \lesssim 0.1 \times (1\mathrm{TeV})^2$$

$$|m_{H_u}^2(M_Z)| \lesssim (100\mathrm{GeV})^2$$

EW scale is naturally realized

green bands predict degenerate gaugino masses below TeV scale.

Samples of the concrete models for the Non-Universal Gaugino Mass scenario

Mirage Mediation

Choi,Jeong,Kobayashi,Okumura, 05', 06'

Kitano,Nomura, 05'

Lebedev,Nilles,Ratz, 05'

Abe,Kawamura, 14'

Gauge mediation 系列

Dermisek,H.D.Kim,I.W.Kim, 05'

Brümmer,Buchmüller, 12'

Brümmer,Ibe,Yanagida, 13'

Yanagida,Yokozaki, 13'

Kobayashi,Omura, 14'

GUT Feng, 13'

etc.

Our approach is bottom-up

We assume that we succeed in constructing a model satisfying

$$M_2/M_3 \simeq 5 \text{ at GUT scale}$$ which very relaxes the fine-tuning

Abe,Kobayashi,Omura, 07’; Abe,Kawamura,Otsuka, 13’

study the current status of Non-Universal Gaugino Mass scenario (NUGM) based on 8-TeV and 13-TeV datas at the LHC.

Abe,Kawamura,Omura, 15’ Kawamura,Omura, 16’

Current status of the NUGM at LHC

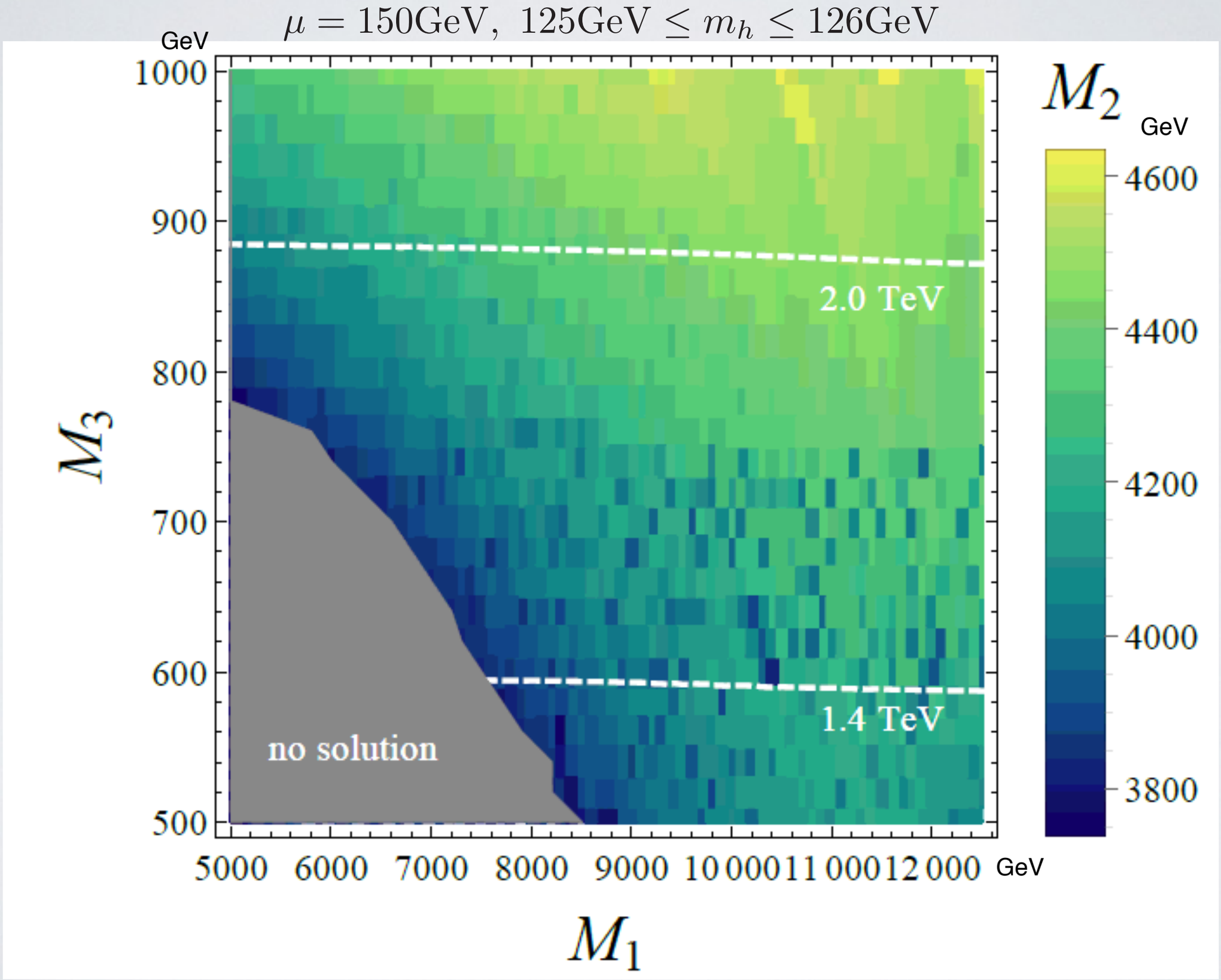
Predictions of the NUGM scenario

1) EW-scale $m_{H_u}^2$ is realized by heavy wino (M_2), and origin of the EW scale is explained.

➡ *4-5 TeV wino > O(1) TeV gluino*

numerical result for 126 GeV Higgs

(Abe,Kawamura,YO)



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2) Wino (and Bino) are heavy and supersymmetric Higgs mass is EW-scale

→ *Light Higgsino predicted*

→ *Lightest chargino and neutralino are Higgsino-like and mass differences are O(1) GeV*

This is because

neutralinos are linear comb. of Bino, Wino, and Higgsinos.

chargino are linear comb. of Wino and Higgsinos.

mass difference are suppressed by heavy Wino and Bino

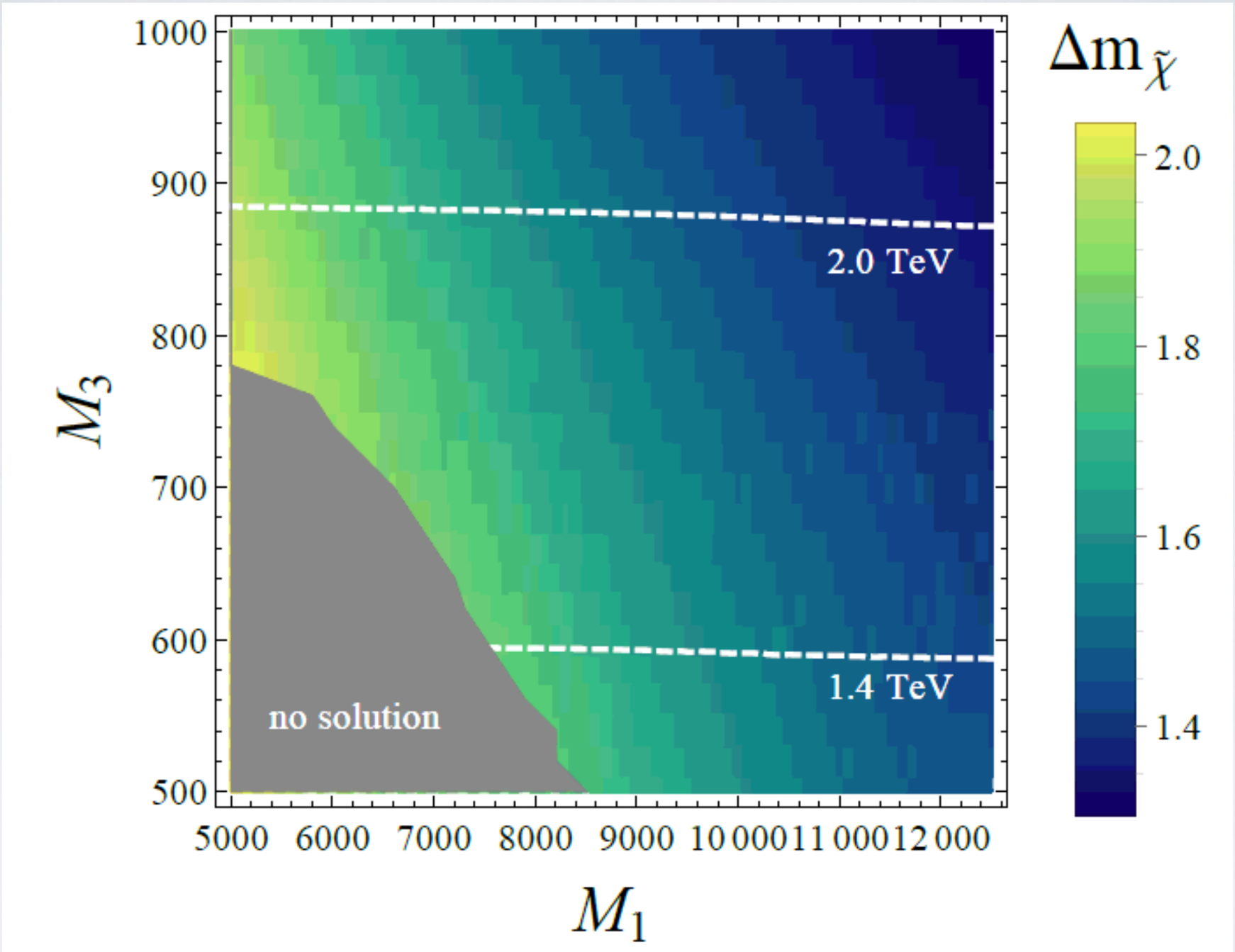
$$m_{\chi_{1,2}} = \mu + \mathcal{O}\left(\frac{M_Z^2}{M_{1,2}}\right)$$

$$m_{\chi_\pm} = \mu + \mathcal{O}\left(\frac{M_W^2}{M_2}\right)$$

Mass difference

(Abe,Kawamura,YO)

$$\mu = 150\mathrm{GeV},\ 125\mathrm{GeV} \leq m_h \leq 126\mathrm{GeV}$$



very small mass difference $\Delta m_\chi \lesssim 2\mathrm{GeV}$

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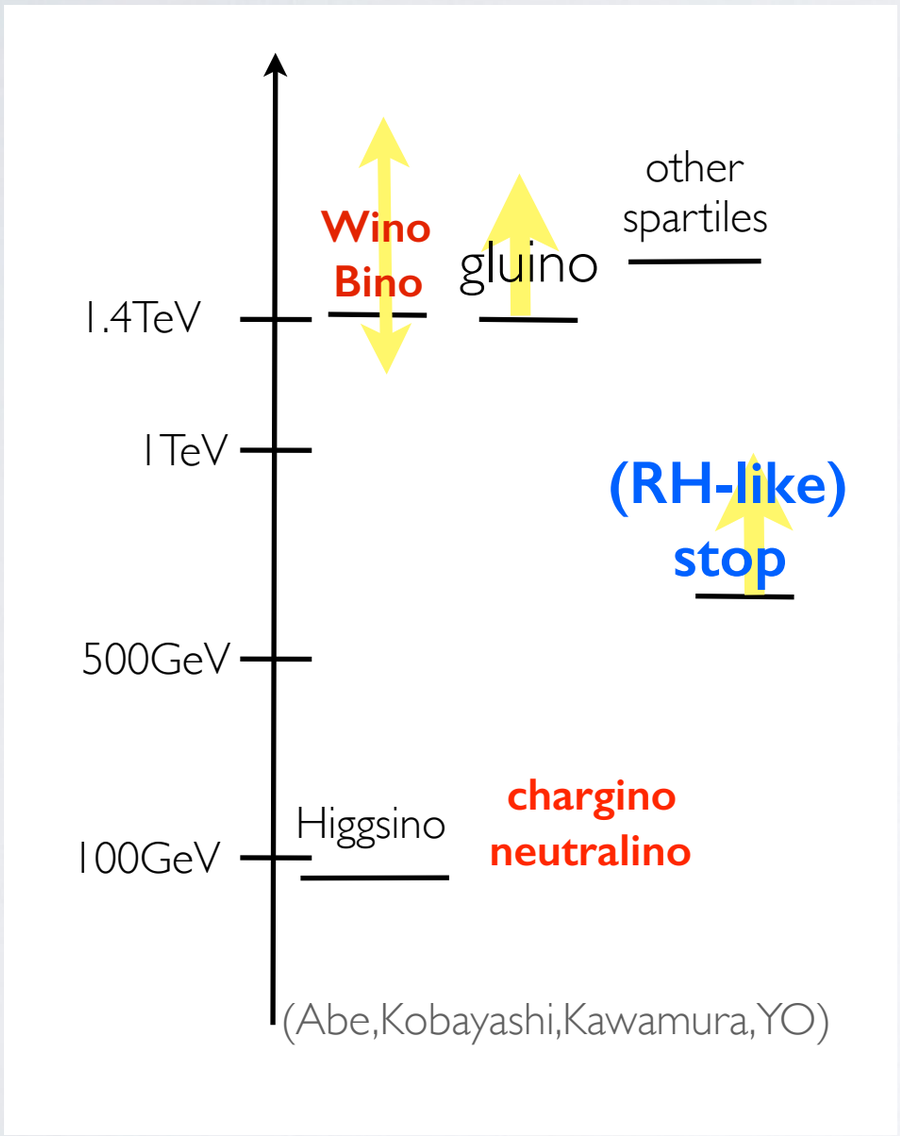
3) Light Right-handed stop are predicted

Light Right-handed stop caused by RG flow

Typical mass spectrum in NUGM scenarios

Non-Universal Gaugino Mass



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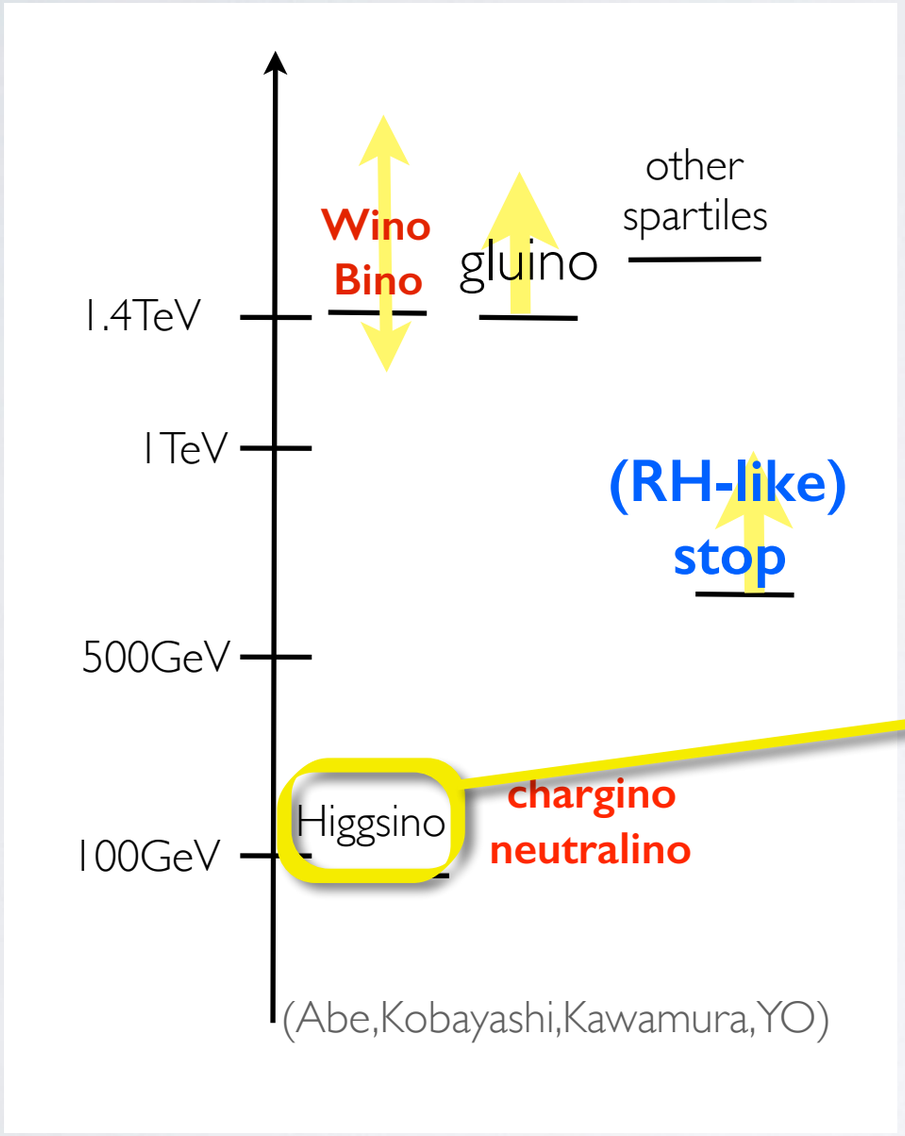

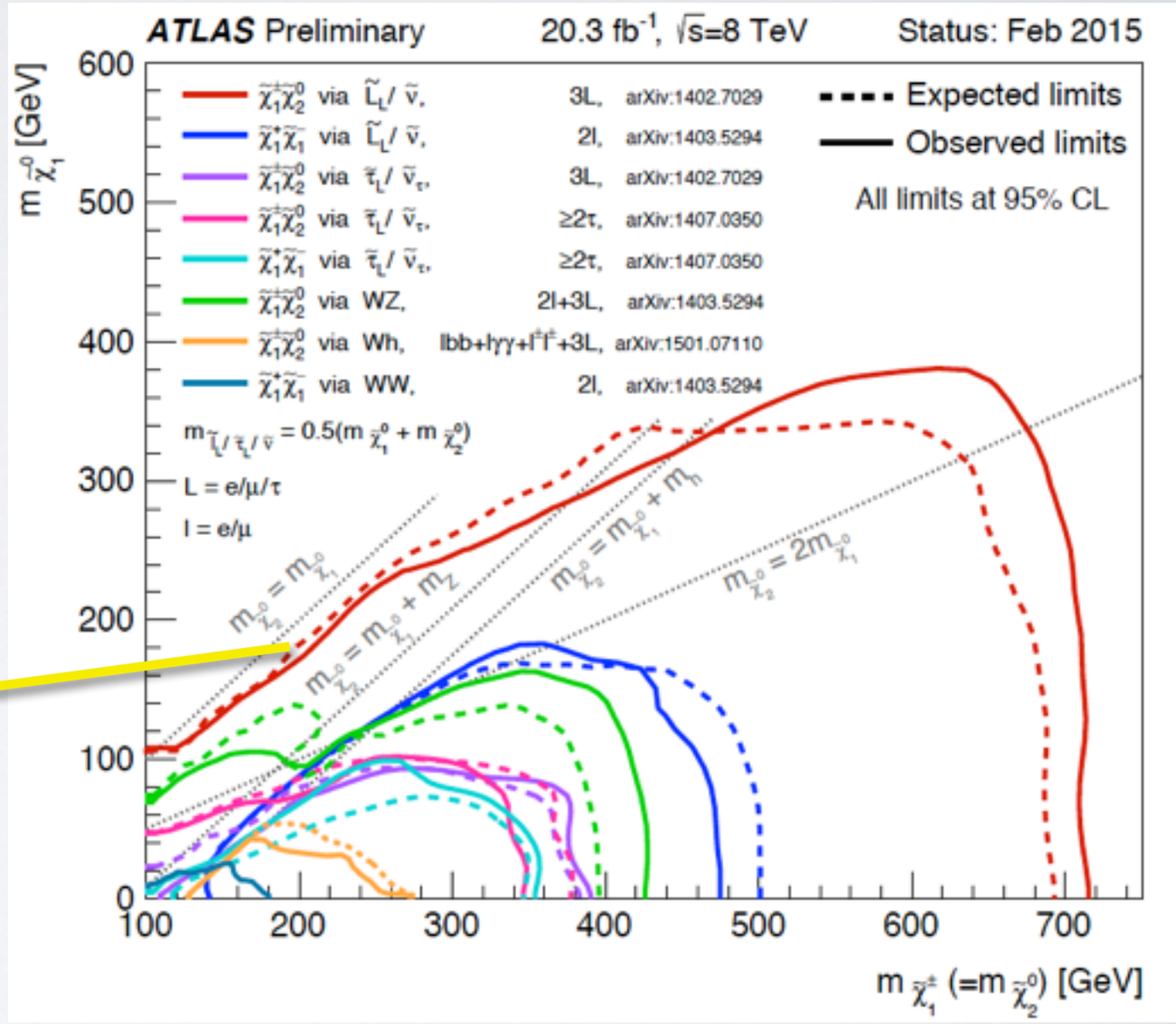

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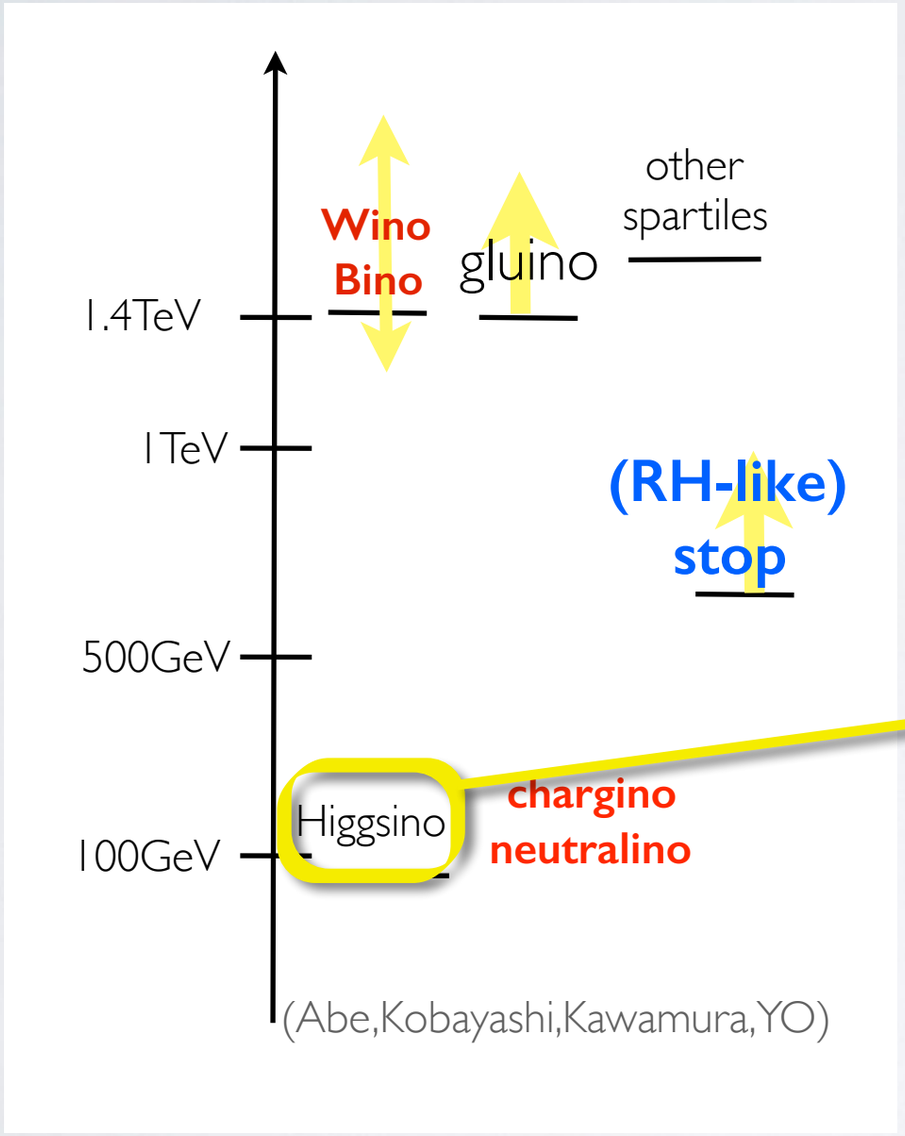

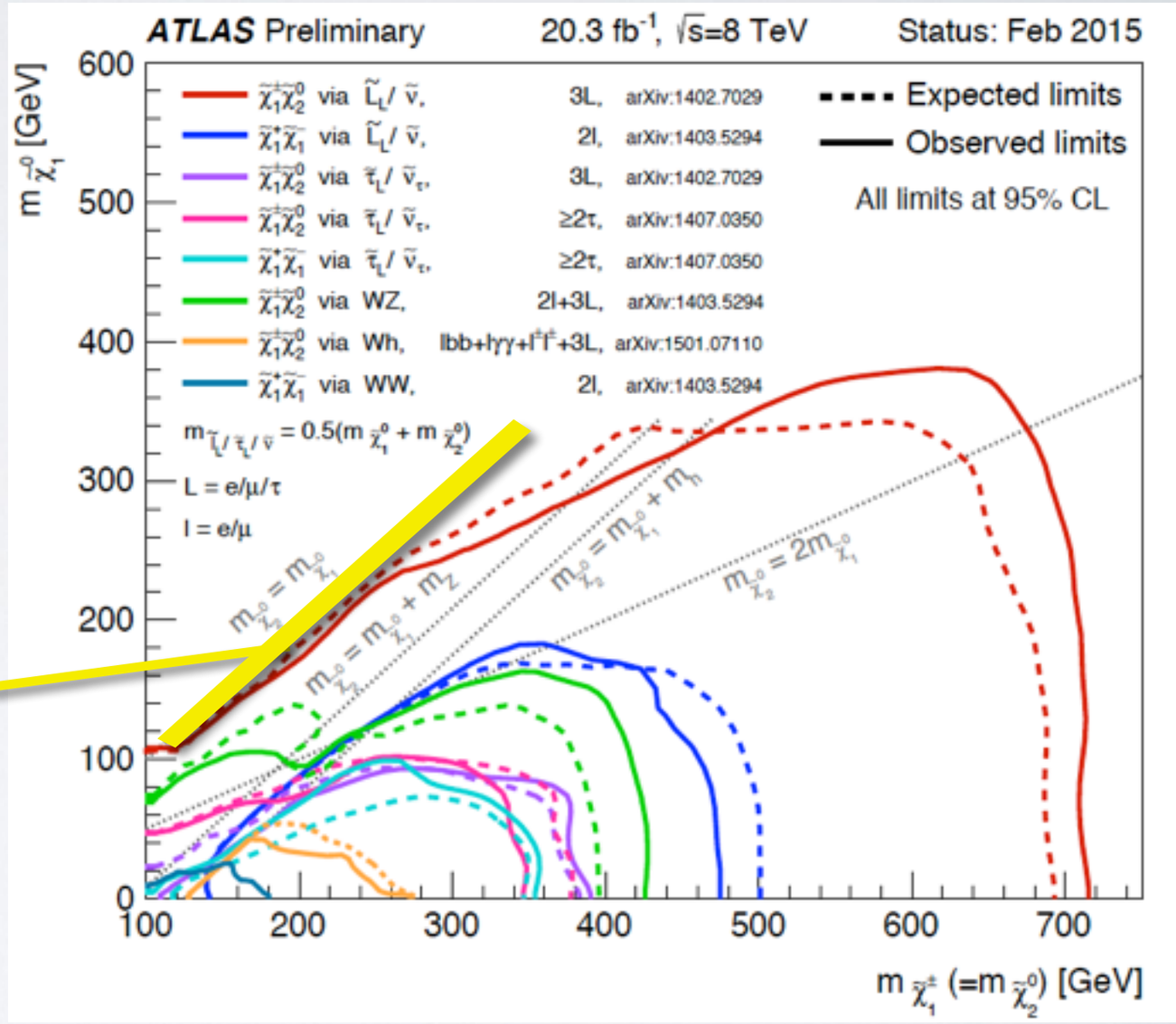

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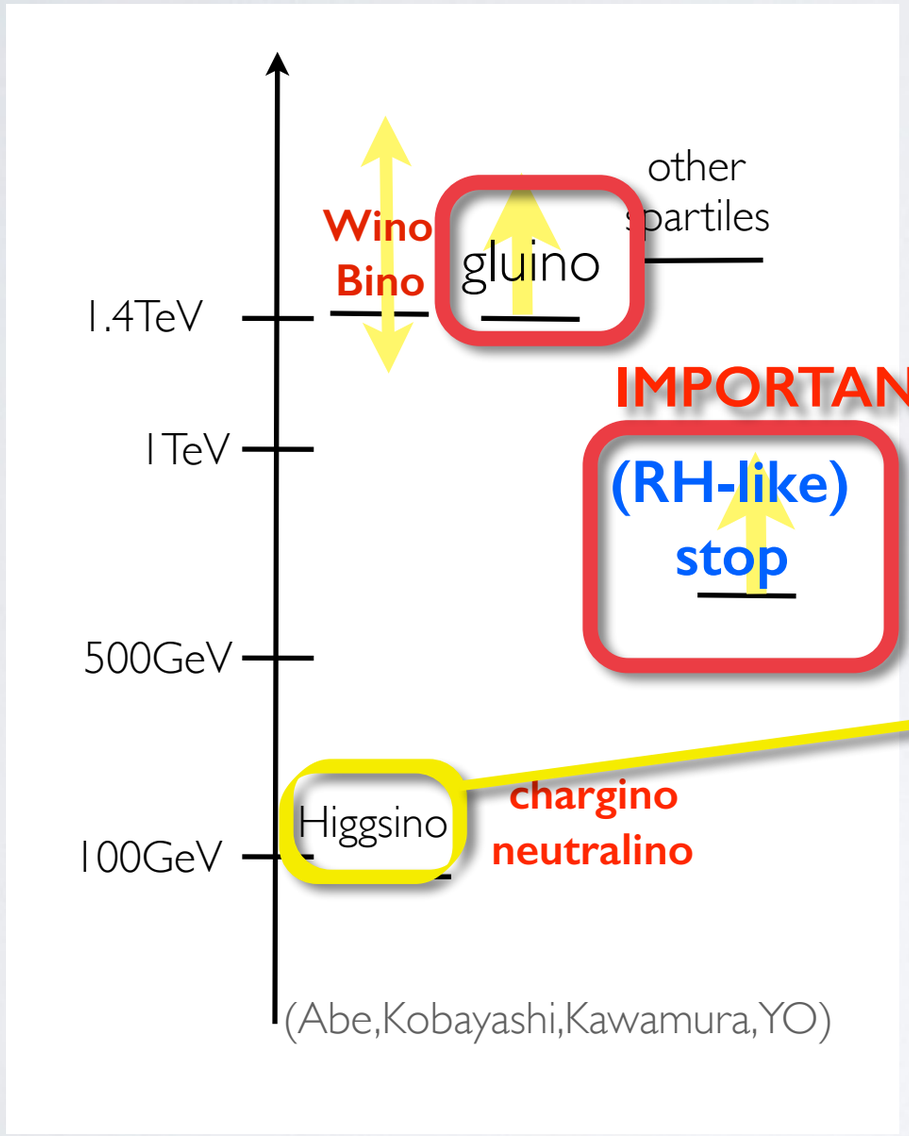
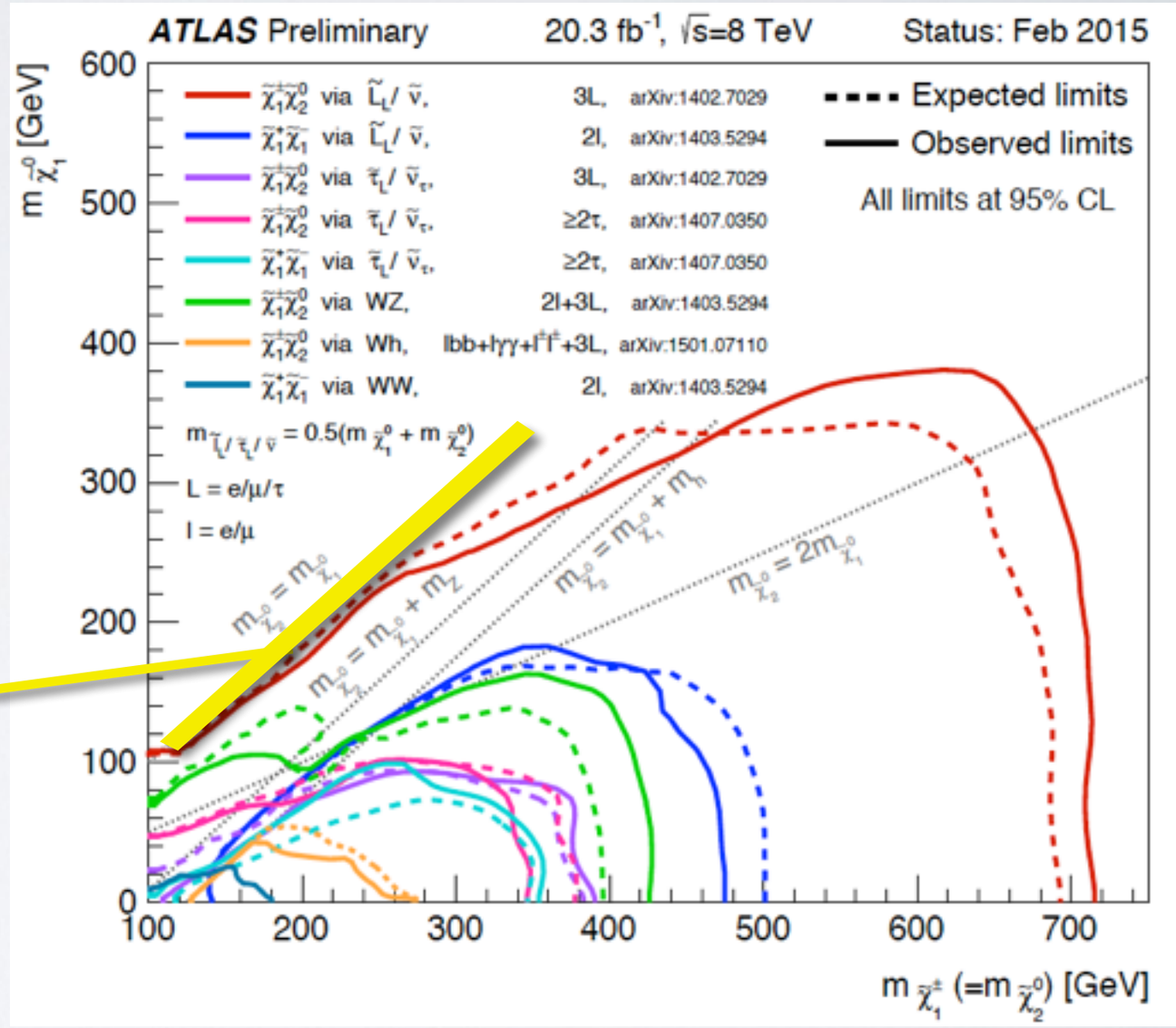
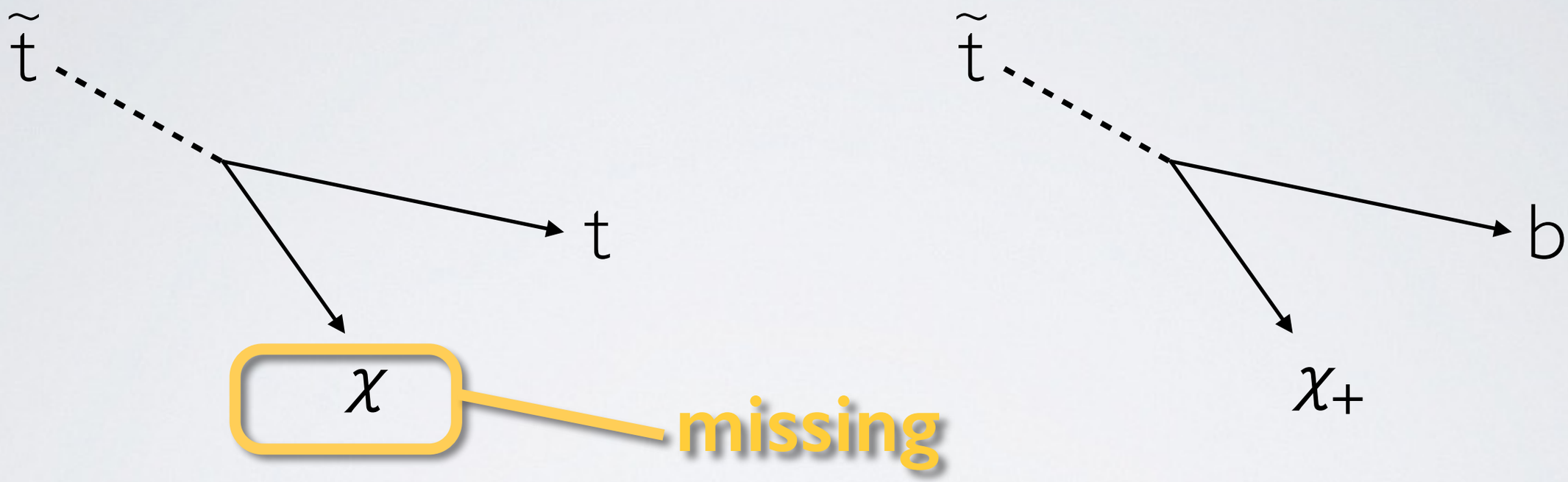




Stop search

(Abe,Kawamura,YO;Kawamura,YO)

Our stop decays to



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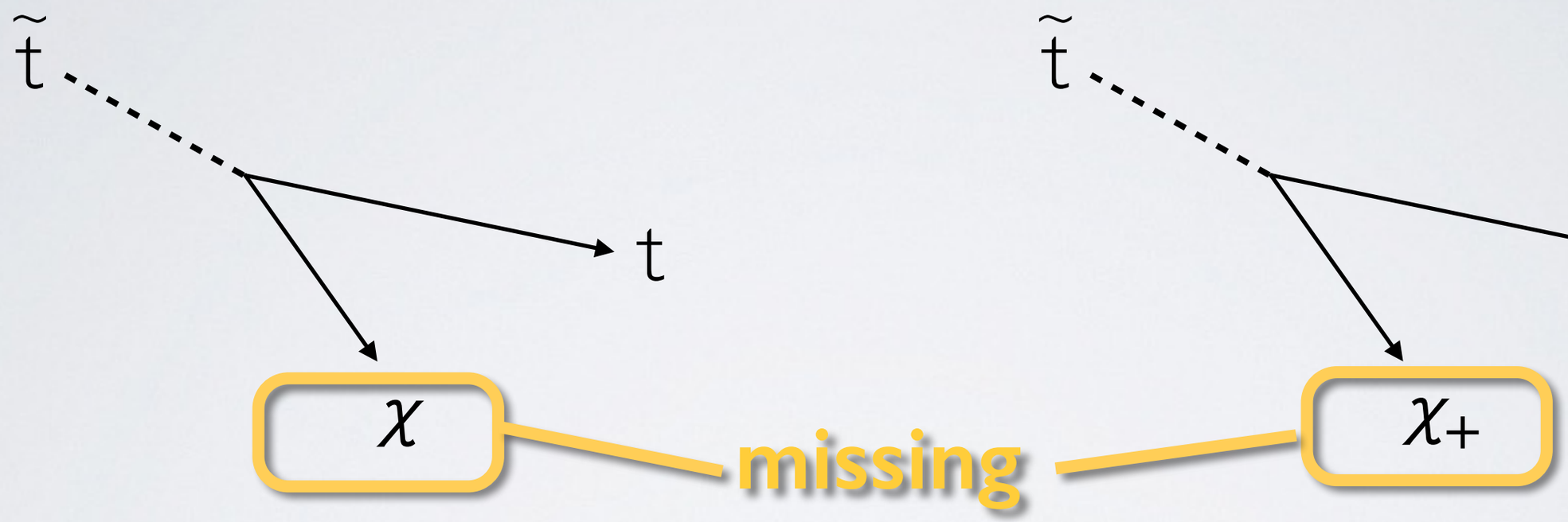

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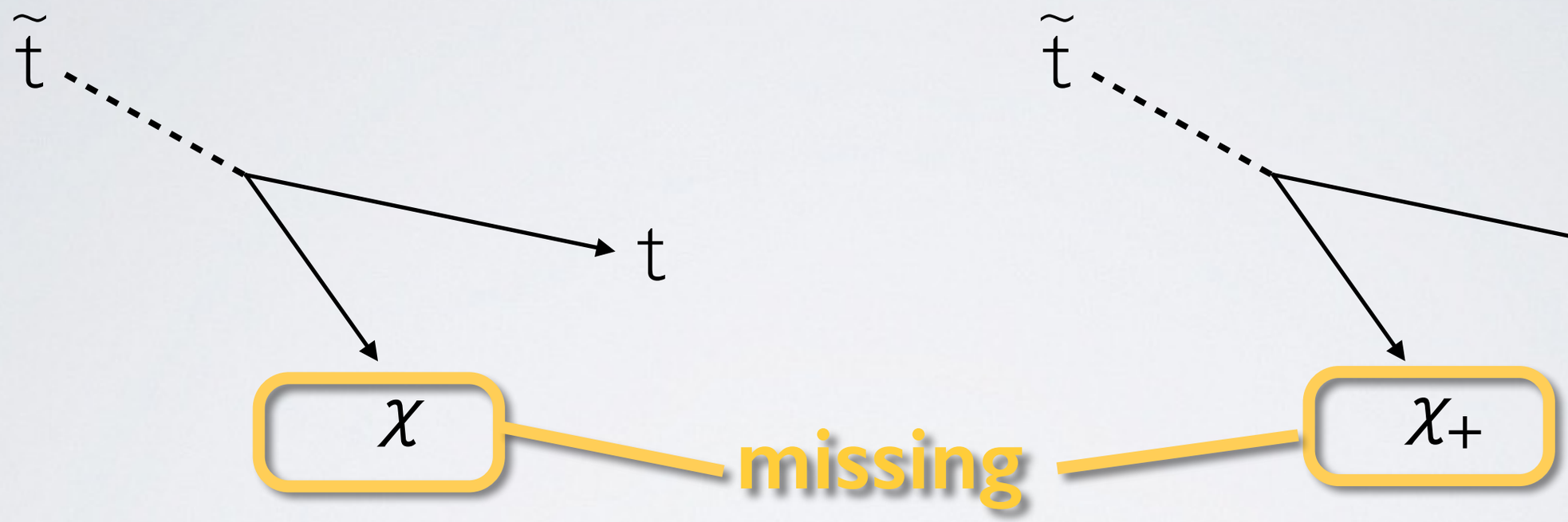

➡ ***Signals***

$$pp \to \tilde{t}\,\tilde{t} \to t\ t\ \text{missing}$$
$$\to b\ b\ \text{missing}$$
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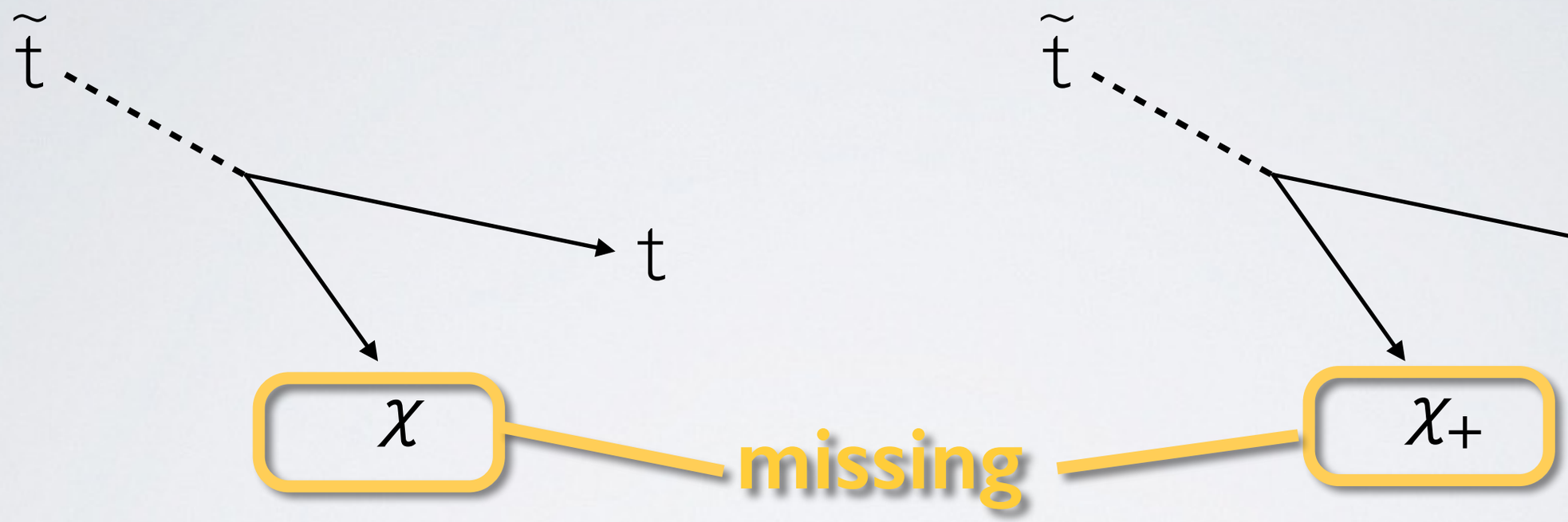

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$$pp \to \tilde{t}\,\tilde{t} \to t\ t\ \text{missing}$$
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Stop search Result

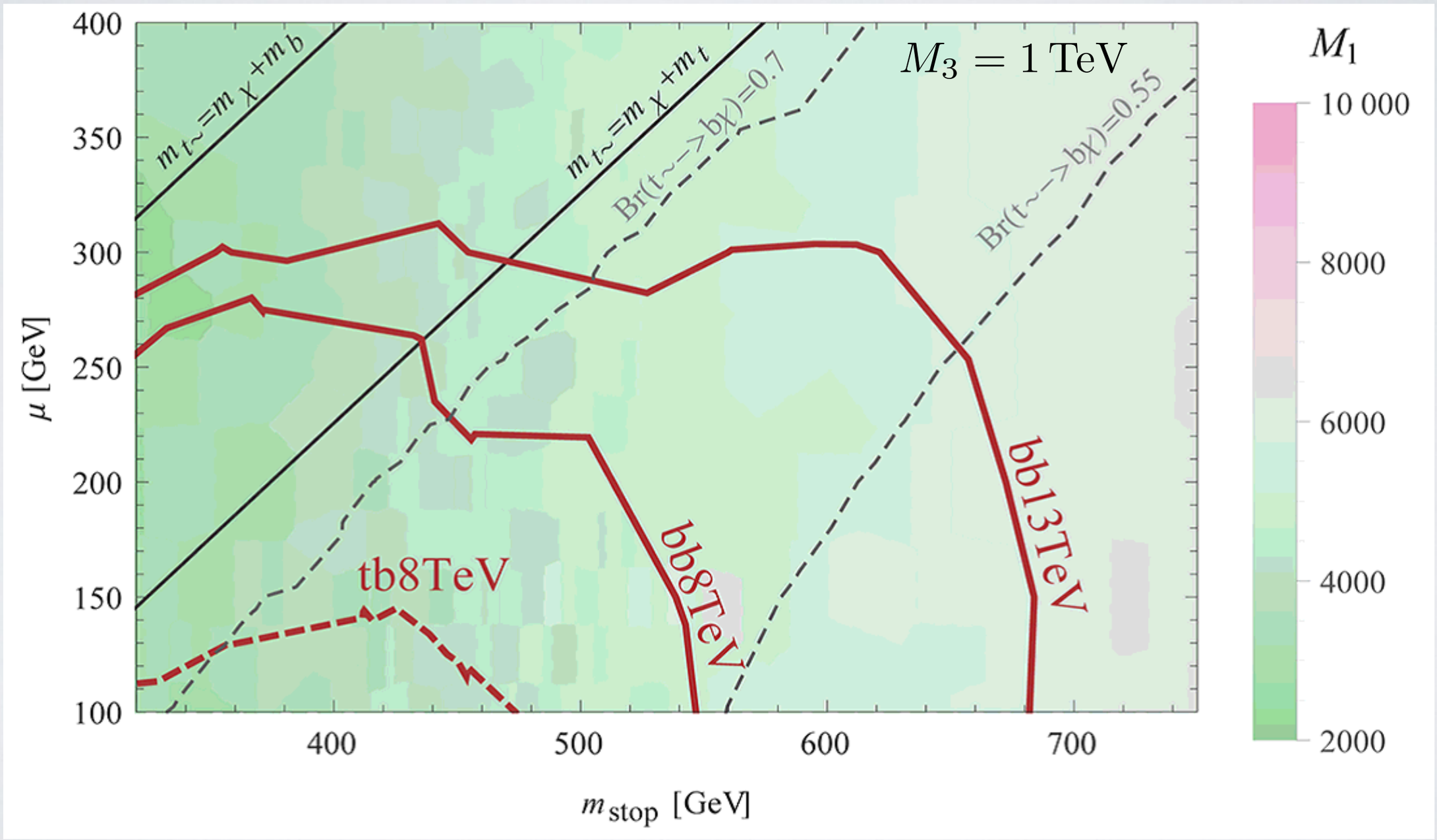
(Abe,Kawamura,YO;Kawamura,YO)

Based on ATLAS-CONF-2015-066,1308.2631,1506.08616

Branching ratio

$$\mathrm{BR}(\widetilde{t} \to b \text{ missing}) \gtrsim 0.5$$

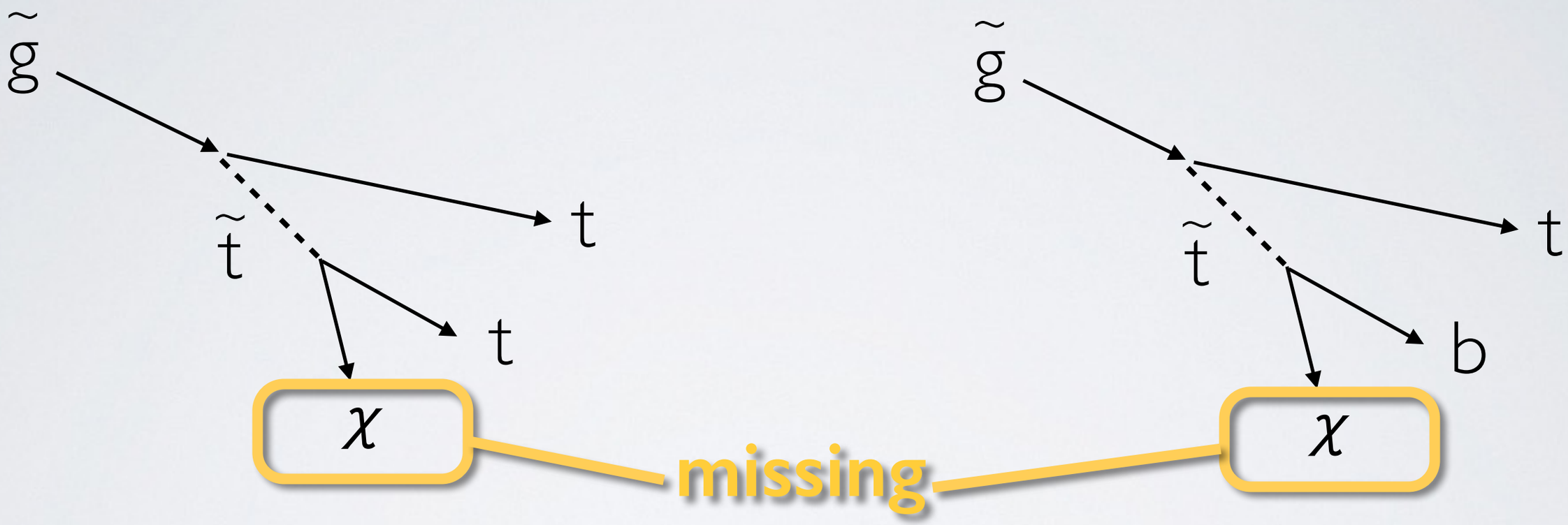
$$125.5\,\mathrm{GeV} \leq m_h \leq 126\,\mathrm{GeV}$$
$$\tan\beta = 15$$
$$m_0 = 1\,\mathrm{TeV}$$



Gluino search

(Kawamura, YO)

Our gluino decays to



➡ ***Signals***

$pp \to \tilde{g}\,\tilde{g} \to$ tt tt missing

$\to$ tt bb missing

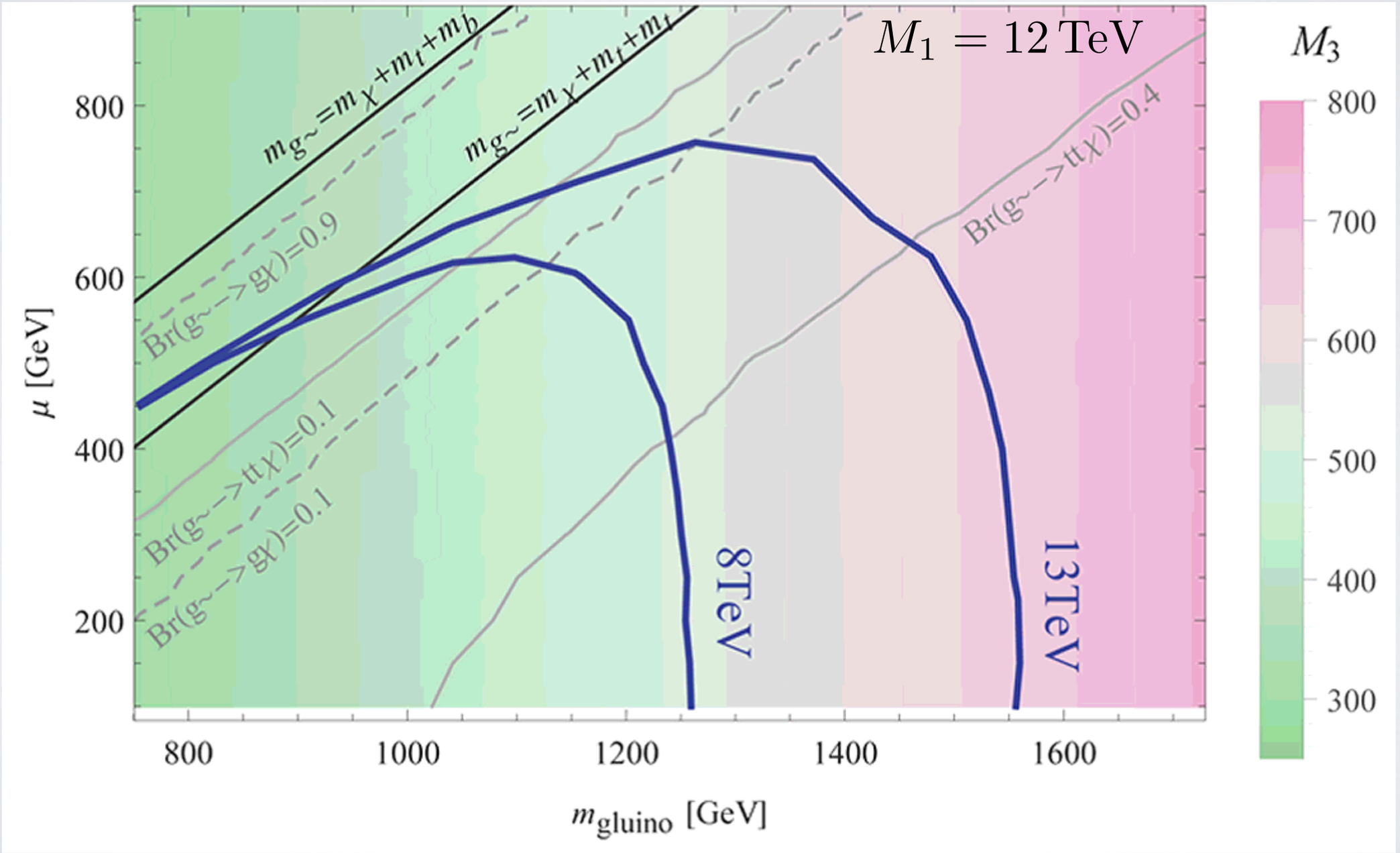
Gluino search Result

Based on ATLAS-CONF-2015-067, 1407.0600

(Kawamura, YO)

$$125.5\,\mathrm{GeV} \leq m_h \leq 126\,\mathrm{GeV}$$
$$\tan\beta = 15$$
$$m_0 = 1\,\mathrm{TeV}$$

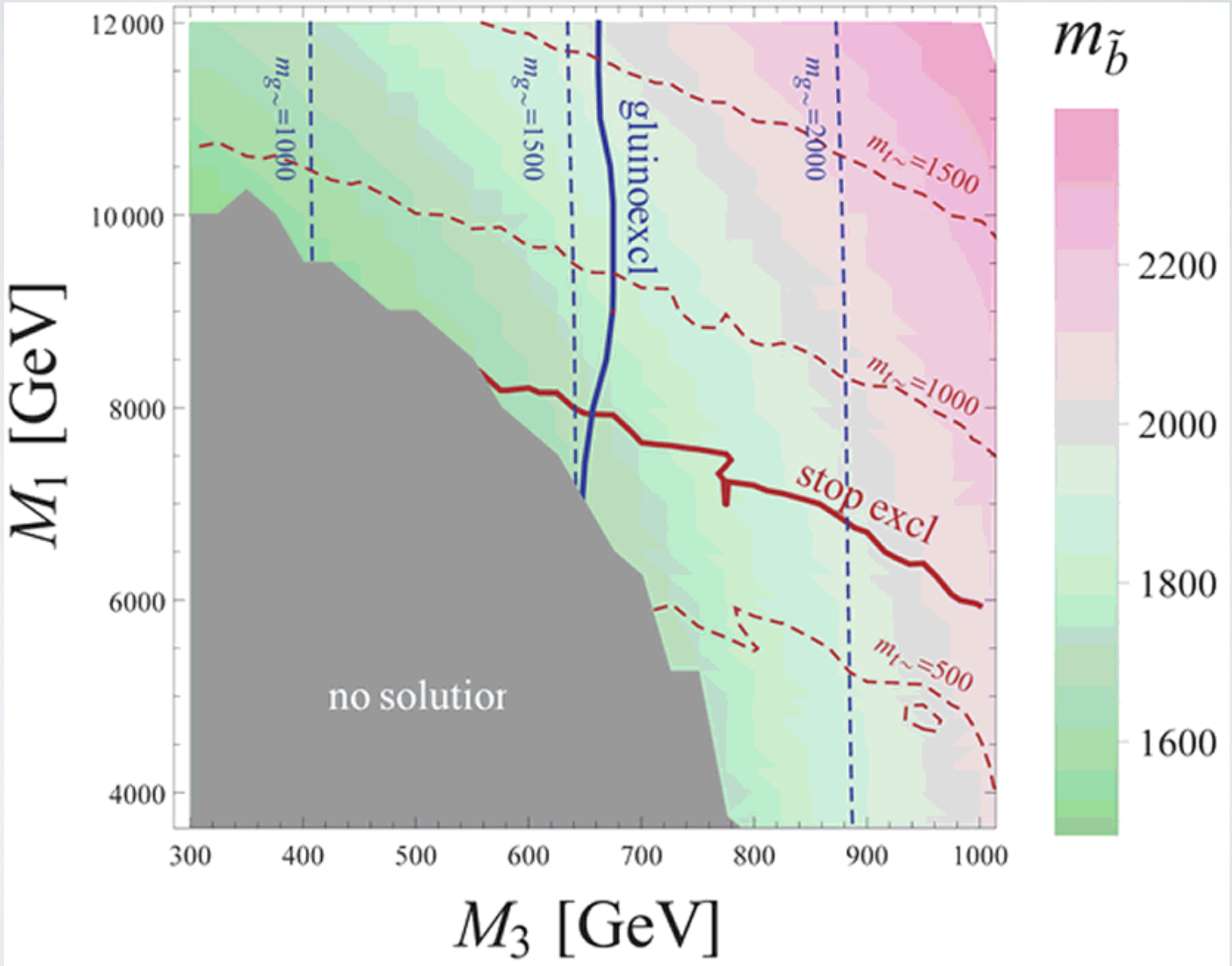
13-TeV already exceeds the 8-TeV result!



$$125.5\,\mathrm{GeV} \leq m_h \leq 126.1\,\mathrm{GeV}$$
$$\tan\beta = 15$$
$$m_0 = 1\,\mathrm{TeV}$$

Combined Result with $\mu = 150\,\mathrm{GeV}$

(Kawamura,YO)



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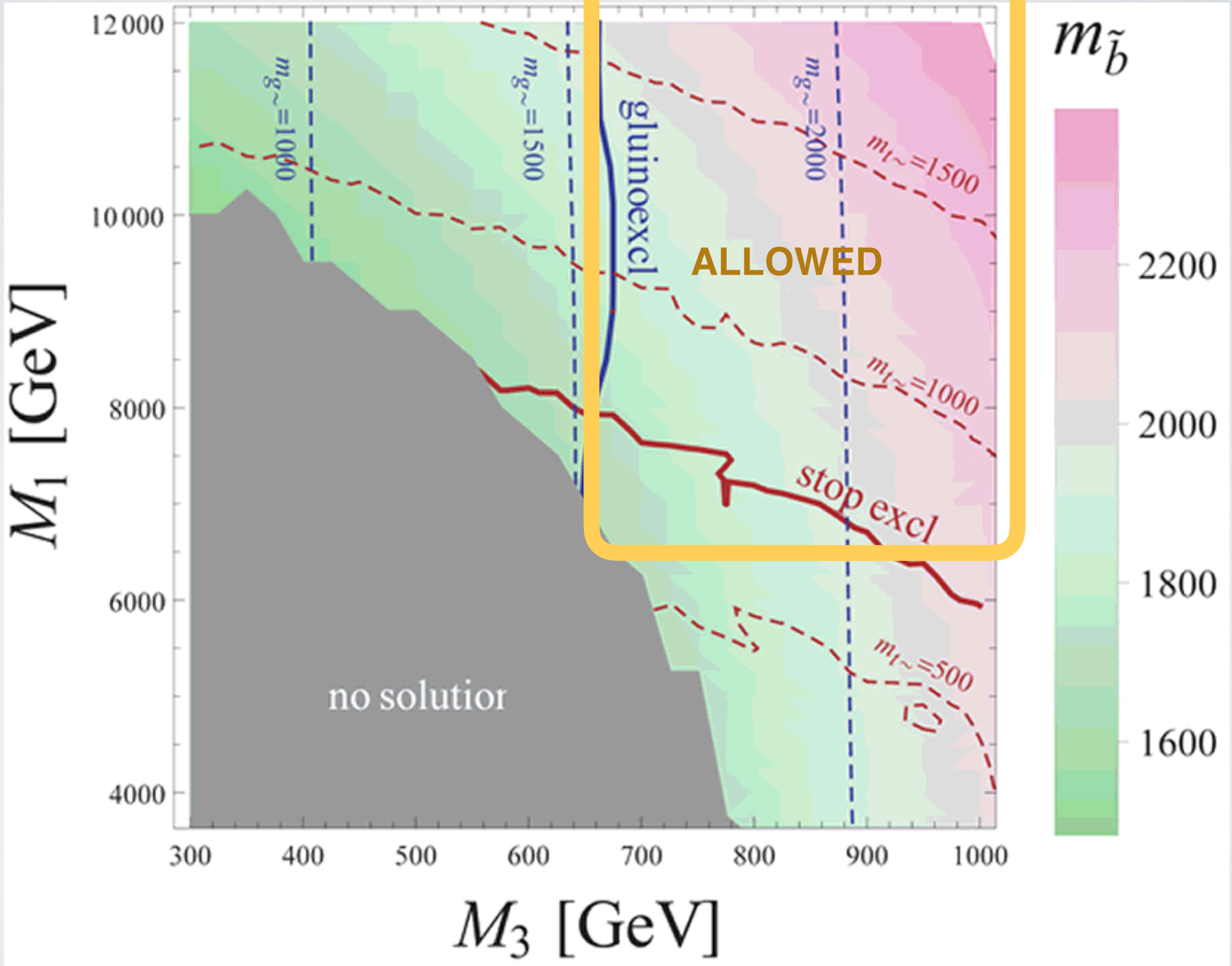
(Kawamura,YO)



SUMMARY

SUSY なかなか見つからない・・・

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だが、ヒントはいくつかでている

Higgs mass ~125 GeV

Direct search at LHC

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だが、ヒントはいくつかでている

Higgs mass ~125 GeV

Direct search at LHC

SUSY scenario がかなり絞られてきており、

Non-trivial な SUSY spectrum が有力

SUMMARY

Non-Universal Gaugino Mass scenario

$$M_2/M_3 \simeq 5 \text{ at GUT scale}$$

(large A-term can be realized by large M2)

重要な予言

light Right-handed stop

degenerate neutralinos and chargino

stop search: $\tilde{t} \to t\chi_{1,2},\ b\chi^+$
gluino search: $\tilde{g} \to t\bar{t}\chi$

$\Rightarrow$ $m_{\tilde{t}} \gtrsim 700$ GeV, $m_{\tilde{g}} \gtrsim 1.6$ TeV $\Rightarrow$ $(m_{\tilde{b}} \gtrsim 1.8$ TeV$)$

Let's discuss what the underlying theory is!

END

A term for Higgs mass

(Abe,Kawamura,YO)