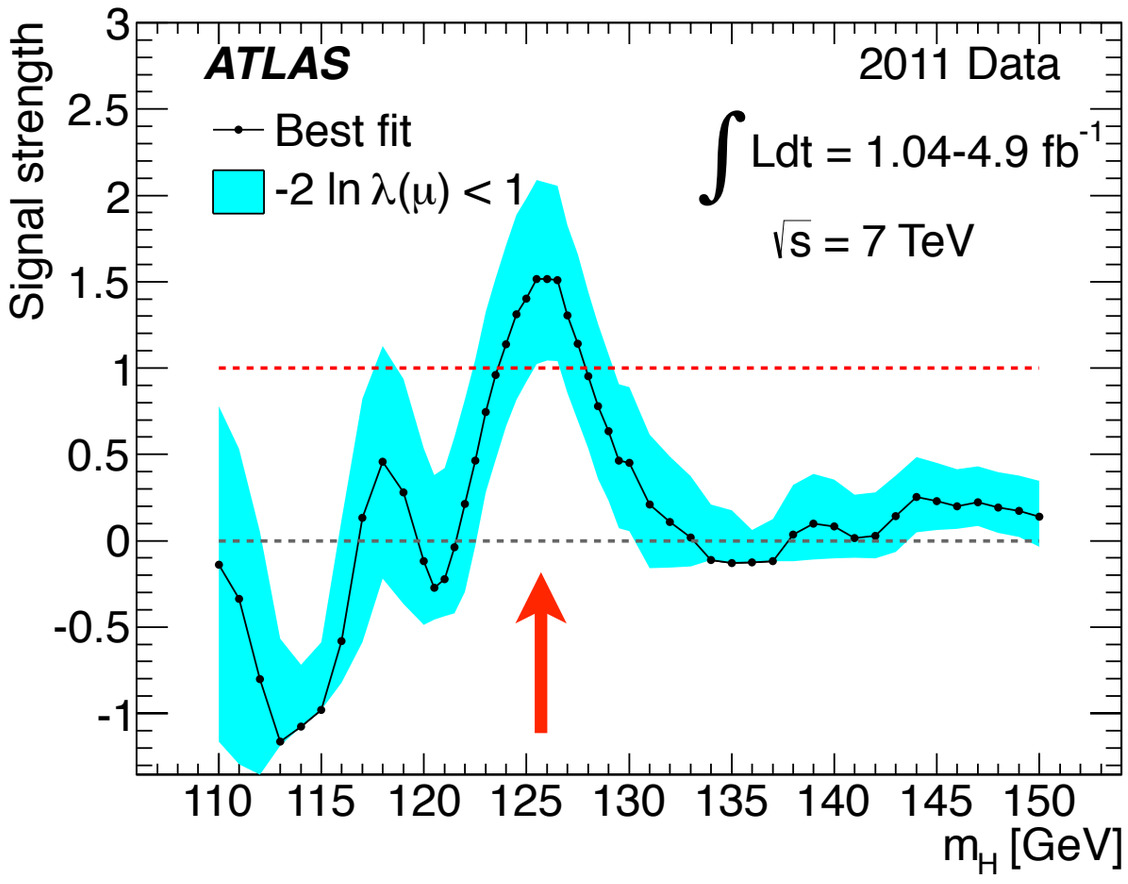
GMSB extensions in light of recent Higgs searches

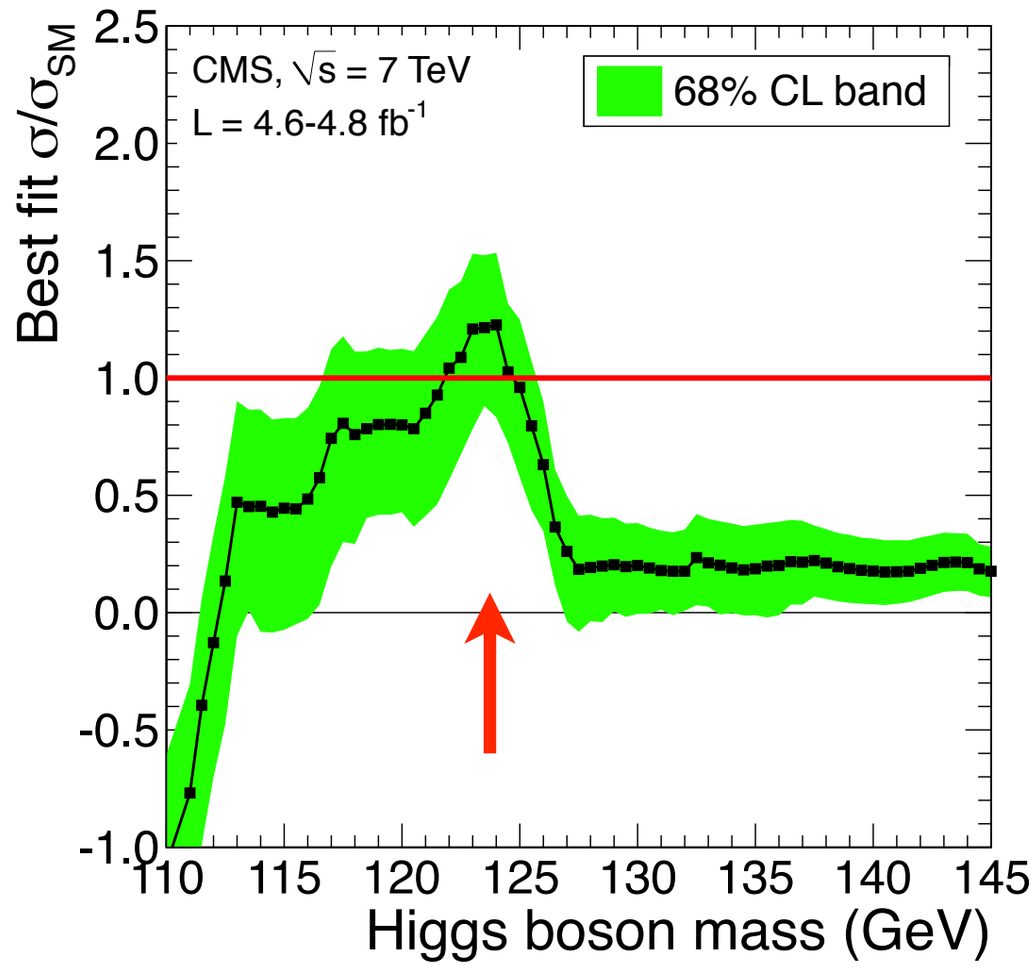
Motoi ENDO (Tokyo)

in collaboration with K.Hamaguchi, S.Iwamoto, K.Nakayama and N.Yokozaki

Toyama workshop, 2012.2.21

Higgs around 125GeV(?)





Event excesses may indicate Higgs mass around 125GeV

What is implied for physics beyond SM?

Today's Talk

- Why extended GMSB?
  - low energy phenomena and cosmology
  - Higgs mass & muon g-2
- GMSB + large A_t term
- GMSB + vector-like matters (talk by Iwamoto)
- GMSB + extra U(1) gauge symmetry
- Summary

Physics beyond SM

- Hints of New Physics
  - neutrino oscillation (right-handed neutrino)
  - early universe (e.g. dark matter)

  } proof

  - hierarchy problem (weak scale ≪ Planck)
  - GUT ($g_1 \simeq g_2 \simeq g_3$ @ ~10^{16}GeV)
  - muon g-2

  } imply

>3σ deviation between SM and experiment

c.f. talk by Nomura

Muon g-2

c.f. talk by Nomura

g-factor: deviation from 2 due to radiative corrections

$$\mathcal{L} = e\bar{\psi}\gamma^{\mu}\psi A_{\mu}$$

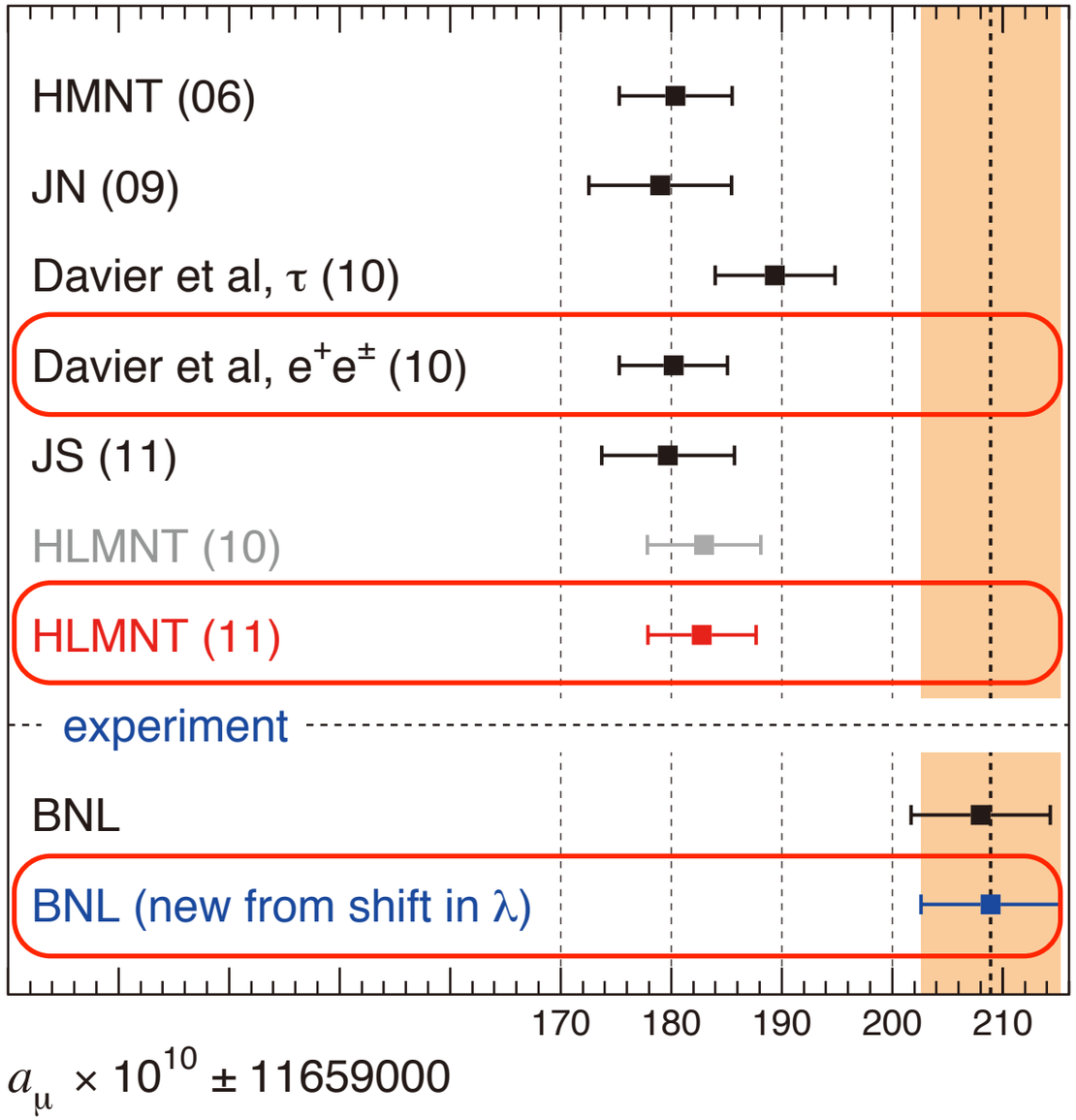
$$\rightarrow \frac{e}{4m}\bar{\psi}\sigma^{\mu\nu}\psi F_{\mu\nu} \times F_2$$

$$F_2^{\text{rad.}} = \frac{g-2}{2} \equiv a_{\mu}$$

$$a_{\mu}^{\text{exp}} - a_{\mu}^{\text{SM}} = (26.1 \pm 8.0) \cdot 10^{-10}$$

> 3σ deviation

cf. $a_{\mu}(\text{EW}) = 1.5 \times 10^{-9}$



Muon g-2 in NP

challenge to explain the deviation:

$$a_\mu(\mathrm{NP}) \sim \frac{\alpha_{\mathrm{NP}}}{4\pi}\frac{m_\mu^2}{m_{\mathrm{NP}}^2} \quad \longleftrightarrow \quad a_\mu(\mathrm{EW}) \sim \frac{\alpha_2}{4\pi}\frac{m_\mu^2}{m_W^2}$$

note: muon mass due to chirality flip

- current discrepancy is as large as a_μ(EW)
- light new particle or large coupling cf. talk by Tsumura
- enhancement required for NP in TeV scale

SUSY is natural

- Hints of New Physics

SUSY

- ~~neutrino oscillation~~
- early universe (e.g. DM) → LSP (χ_1^0 or $\psi_{3/2}$)
- hierarchy problem → solved
- GUT → unification
- muon g-2 → natural

$$\Delta a_\mu(\chi^\pm) \simeq \frac{\alpha_2 m_\mu^2}{8\pi m_{\rm soft}^2} {\rm sgn}(M_2\mu) \underline{\tan\beta}$$

What is unnatural?

- Flavor/CP violations

$$\delta_{ij} = \frac{(\tilde{m}^2)_{ij}}{\tilde{m}^2} \lesssim O(10^{-(2-4)}),\ \ \delta_{\rm CP} \lesssim O(10^{-(2-3)})$$

- gravitino problems ($m_{3/2}$ ~ 1TeV)

$$T_R \lesssim O(10^{(5-6)}){\rm GeV},\ \ E_{\rm inf} \lesssim O(10^{11}){\rm GeV}$$

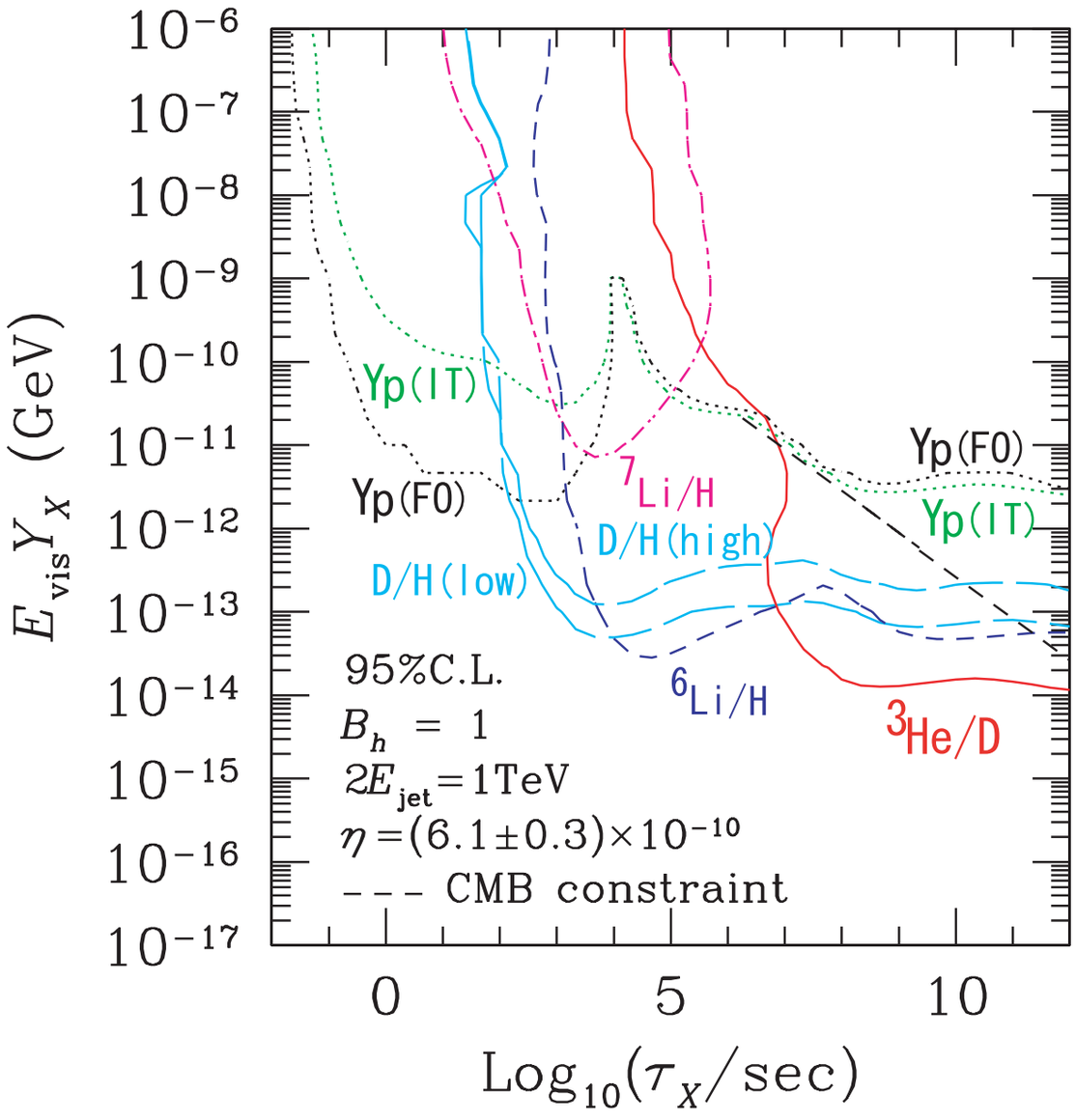
- tension bet. Higgs mass ~125GeV & muon g-2

Limit on Gravitino Abundance

- massive and long-lived

$$\tau_{3/2} \sim 10^{(4-5)}\mathrm{sec}\left(\frac{m_{3/2}}{1\mathrm{TeV}}\right)^{-3}$$

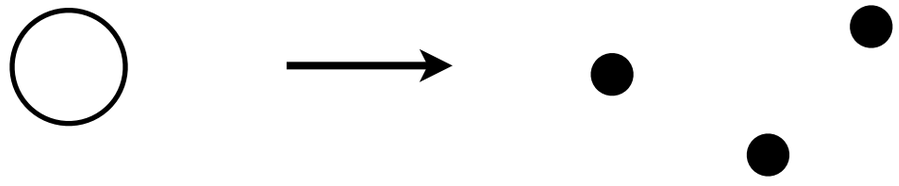
- generate energetic showers at decay
  - change abundance of light nuclei
- gravitino abundance is tightly limited



[Kawasaki,Kohri,Moroi]

Gravitino Productions

radiation: T_R



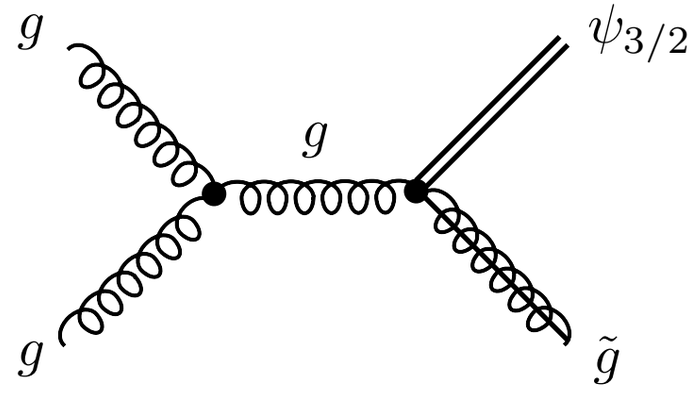
inflaton

thermal production

$$Y_{3/2}^{(th)} \sim 10^{-12} \left(\frac{T_R}{10^{10}\mathrm{GeV}} \right)$$

up to corrections

e.g. $g + g \to \tilde{g} + \psi_{3/2}$



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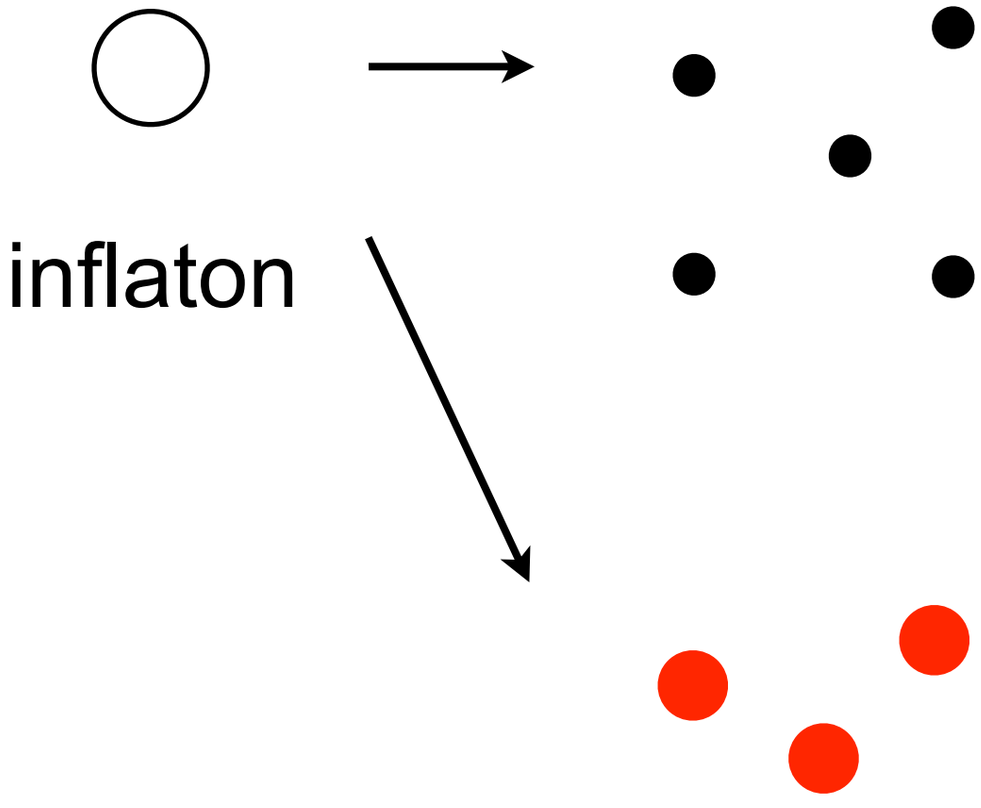

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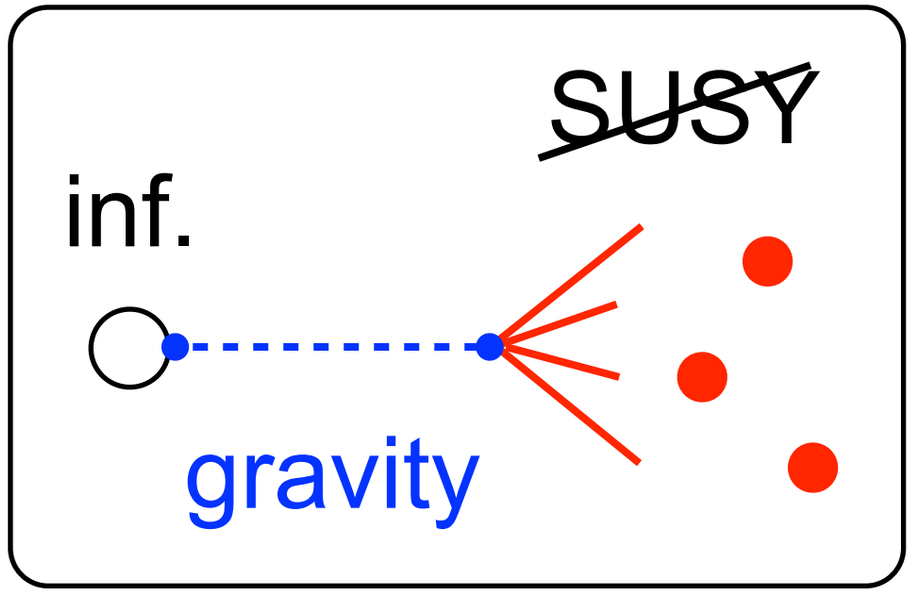

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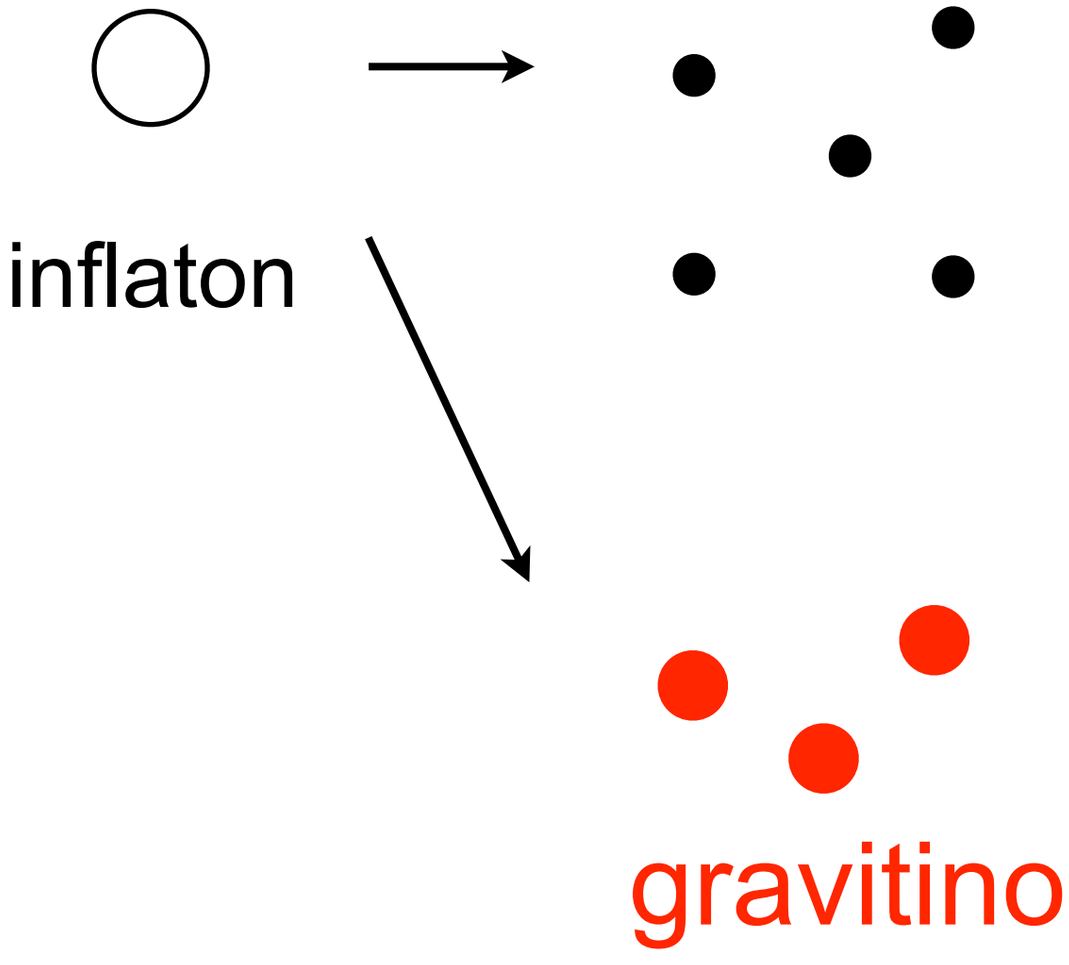

thermal production

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up to corrections

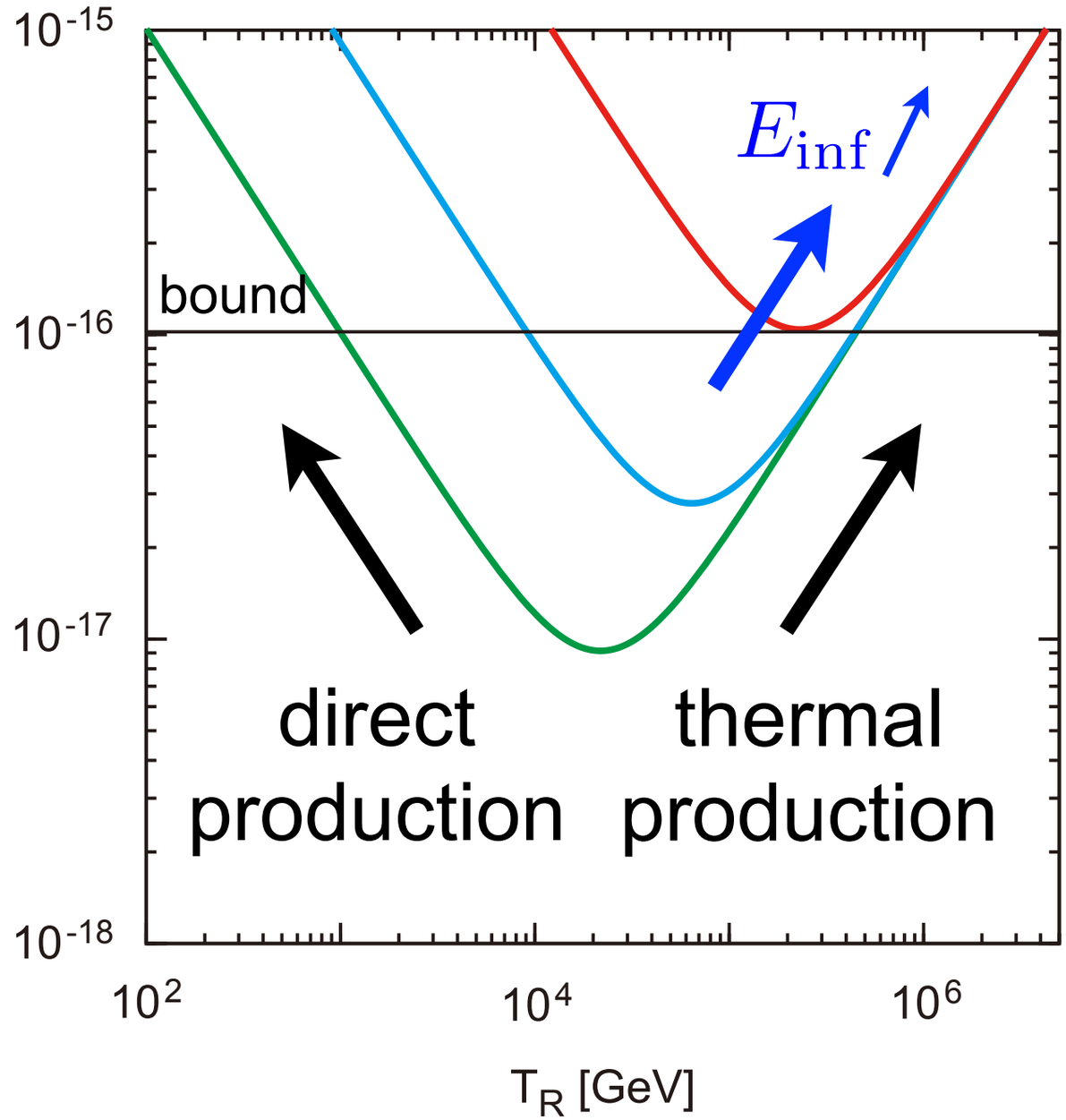
non-thermal production

$$Y_{3/2}^{(nt)} \propto T_R^{-1} \left(\frac{E_{\mathrm{inf}}}{M_P} \right)^4$$

E_{inf}: inflation scale

Bound on T_R and E_{inf}

- abundance is given by T_R and E_{inf}
- exclude high T_R or low T_R for given E_{inf}
- exclude too high E_{inf}



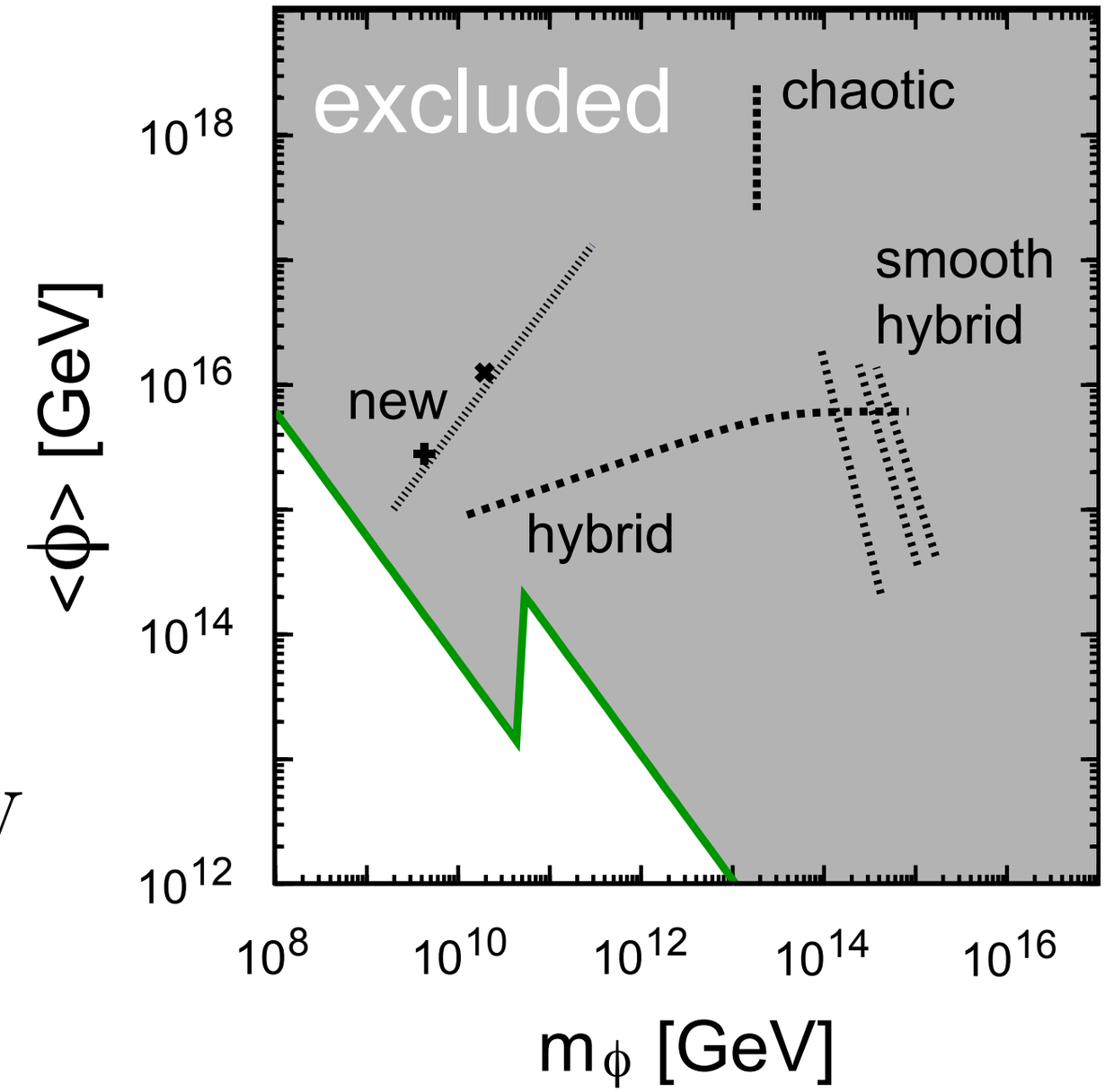
Bound on Inflation

tight constraint on inflation models from thermal and direct gravitino productions

figure:

Bino LSP $M_{1/2} = 300\mathrm{GeV}$

$m_{3/2} = 1\mathrm{TeV}$



[ME, Takahashi, Yanagida]

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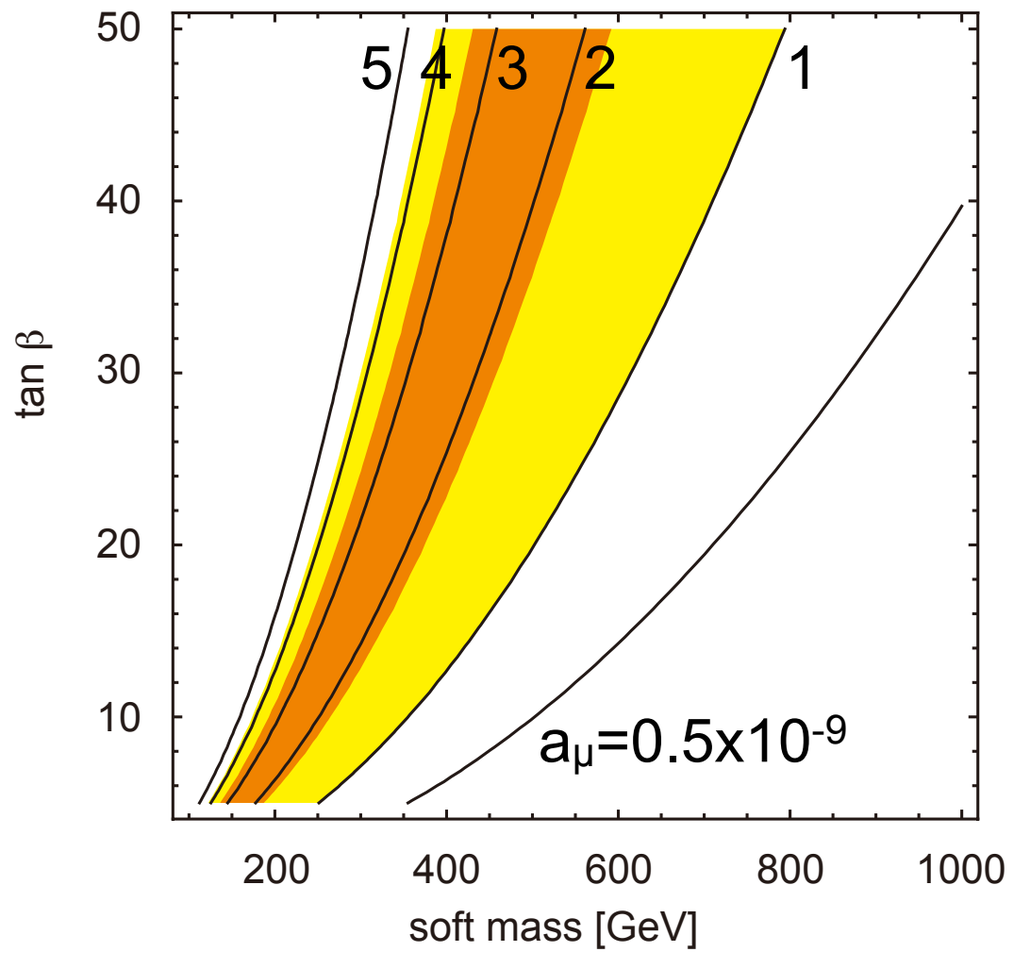
Higgs mass vs muon g-2

- muon g-2:
  - small soft mass
  - large tanβ
- Higgs mass:
  - large soft mass
  - large A_t term

cf. m_h~125GeV is too large for muon g-2 in CMSSM

$$\Delta a_\mu \sim \frac{\alpha_2}{4\pi}\frac{m_\mu^2}{m_{\rm soft}^2}\tan\beta$$



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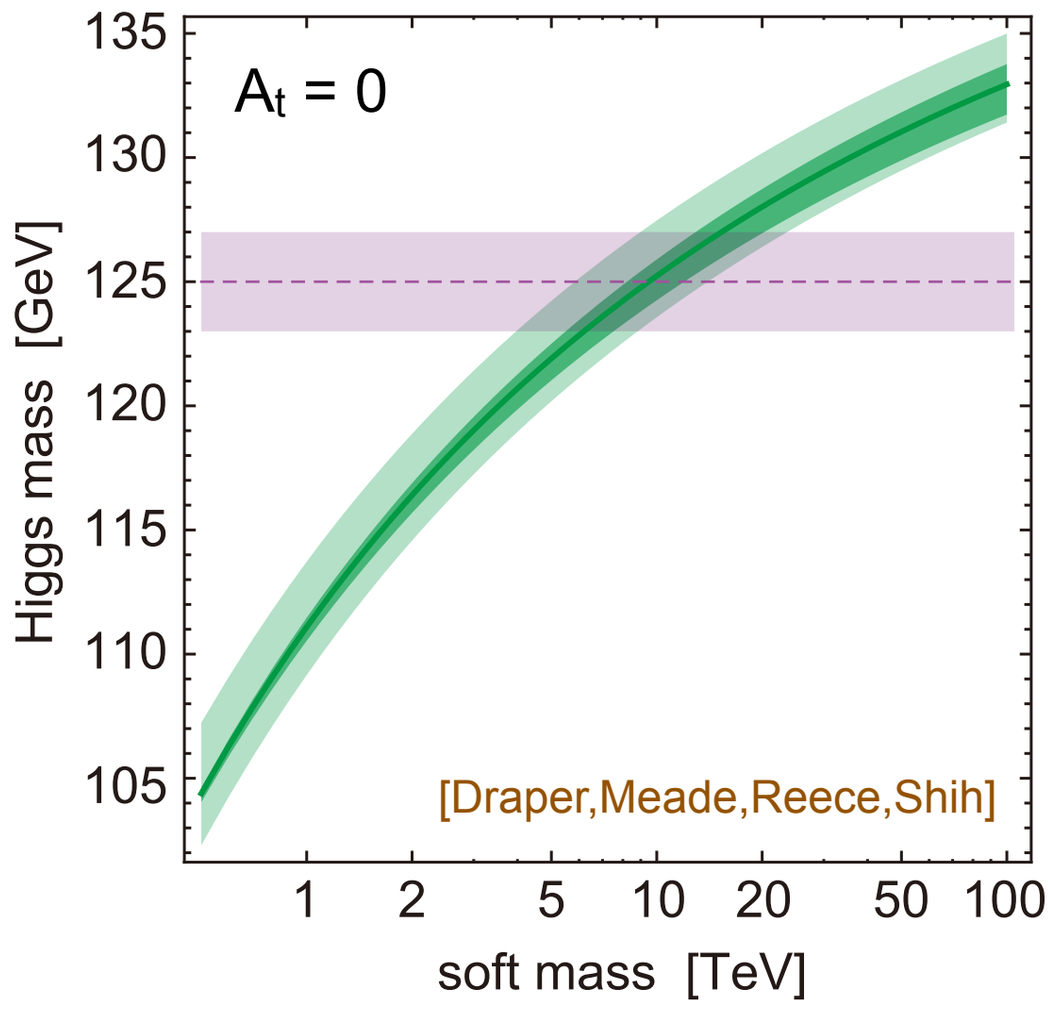
$$\Delta m_h \sim \frac{3m_t^4}{2\pi^2 v^2}\left[\ln\frac{m_{\tilde{t}}^2}{m_t^2} + \left(\frac{A_t^2}{m_{\tilde{t}}^2} - \frac{1}{12}\frac{A_t^4}{m_{\tilde{t}}^4}\right)\right]$$



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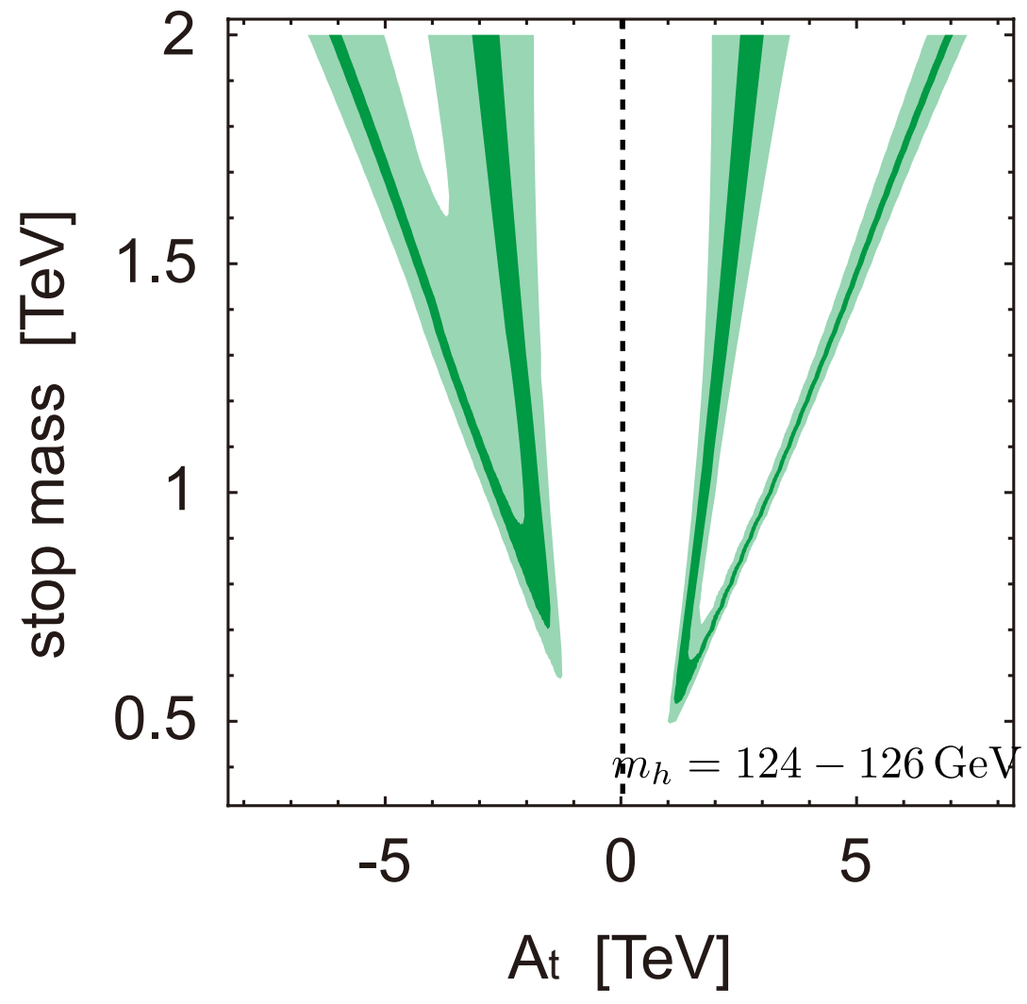

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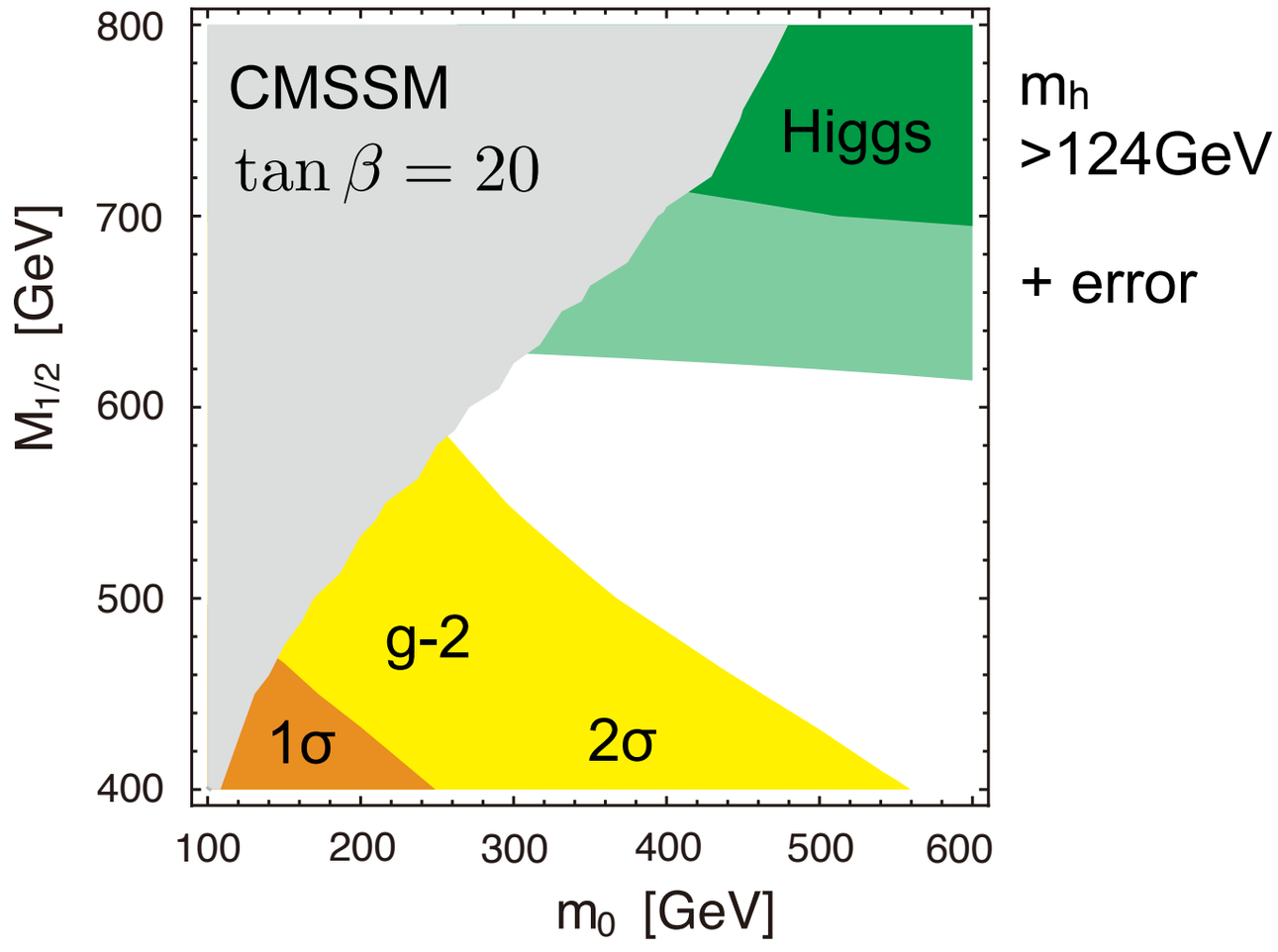

Higgs maximized by A_t w/ Br(b → sγ) @ 2σ

[ME,Hamaguchi,Iwamoto,Nakayama,Yokozaki]

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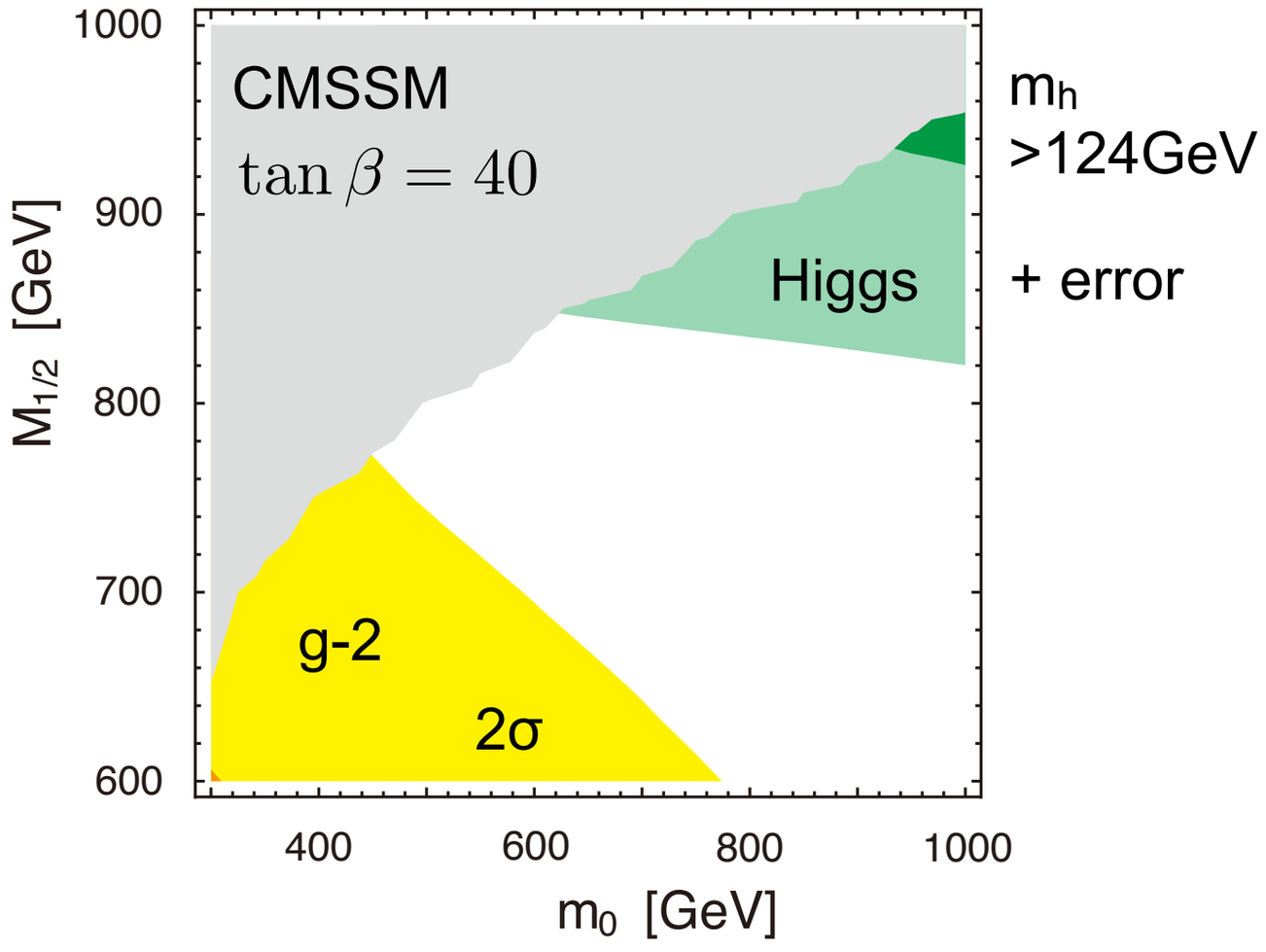

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soft mass is heavy

soft mass is light

Simple Solutions

- Flavor/CP violations
  - large soft mass or GMSB (light gravitino)
- gravitino problems ($m_{3/2}$ ~ 1TeV)
  - heavy gravitino (SUSY scale) or light gravitino
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soft mass is heavy

hopeless...

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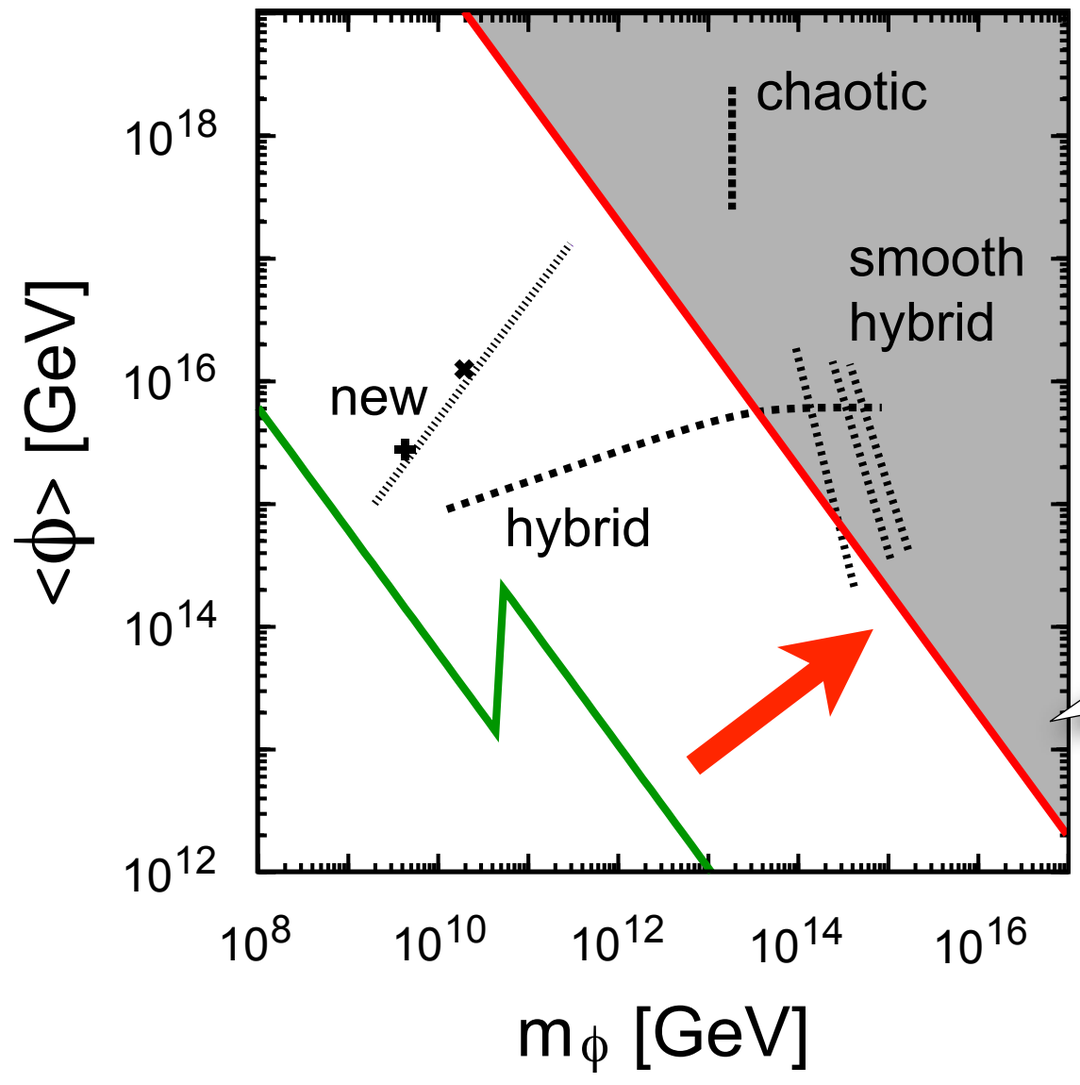
Extended GMSB

soft mass is light

Gravitino Problems

heavy soft mass or light gravitino relaxes constraints



gravitino is stable

$$m_{3/2} = 1\mathrm{GeV}$$

Simple Solutions

- Flavor/CP violations
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- gravitino problems ($m_{3/2}$ ~ 1TeV)
  - heavy gravitino (SUSY scale) or light gravitino
- tension bet. Higgs mass ~125GeV & muon g-2

Extended GMSB

soft mass is light

Extended GMSB

- large A_t term

  [Evans,Ibe,Yanagida;Evans,Ibe,Shirai,Yanagida;ME,Hamaguchi,Iwamoto,Yokozaki]

  - messenger-top coupling
- extra vector-like matter

  [ME,Hamaguchi,Iwamoto,Yokozaki;Evans,Ibe,Yangida]

  - coupling with Higgs

    [Asano,Moroi,Sato,Yanagida;Moroi,Sato,Yanagida]
- extra gauge symmetry

  [ME,Hamaguchi,Iwamoto,Nakayama,Yokozaki]

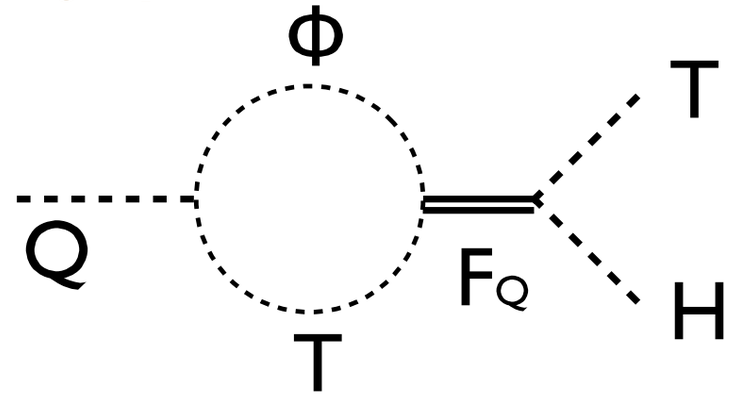
  - charge for Higgs
- singlet Higgs
- triplet Higgs

"price" to be paid will be summarized later

Large A_t term

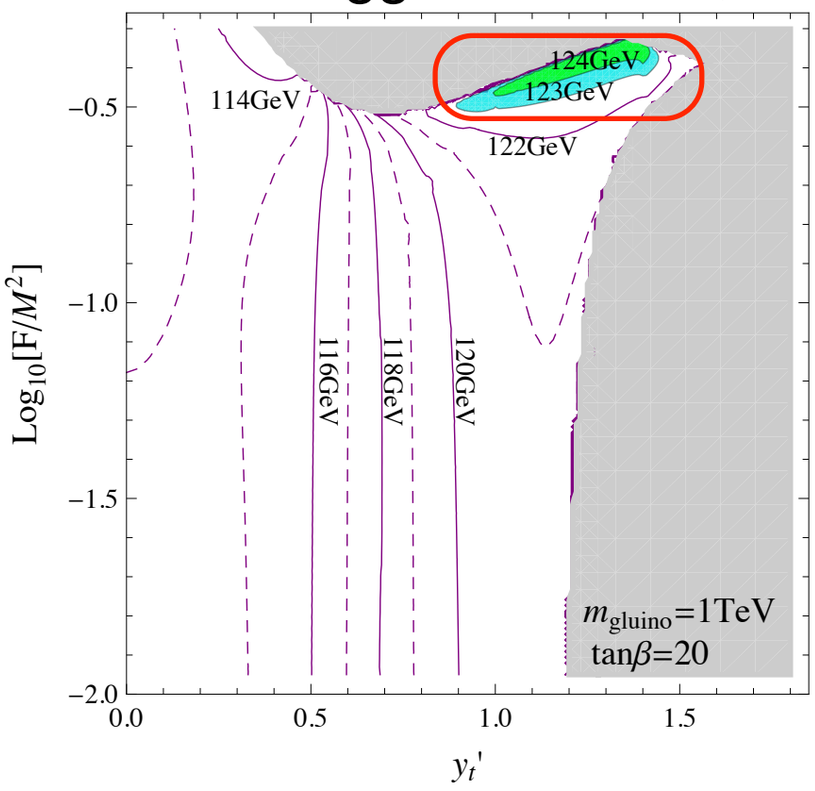
- messenger coupling with top [Evans,Ibe,Yanagida]

$$W = y_t' \Phi_{\bar{L}} Q_T T_R$$

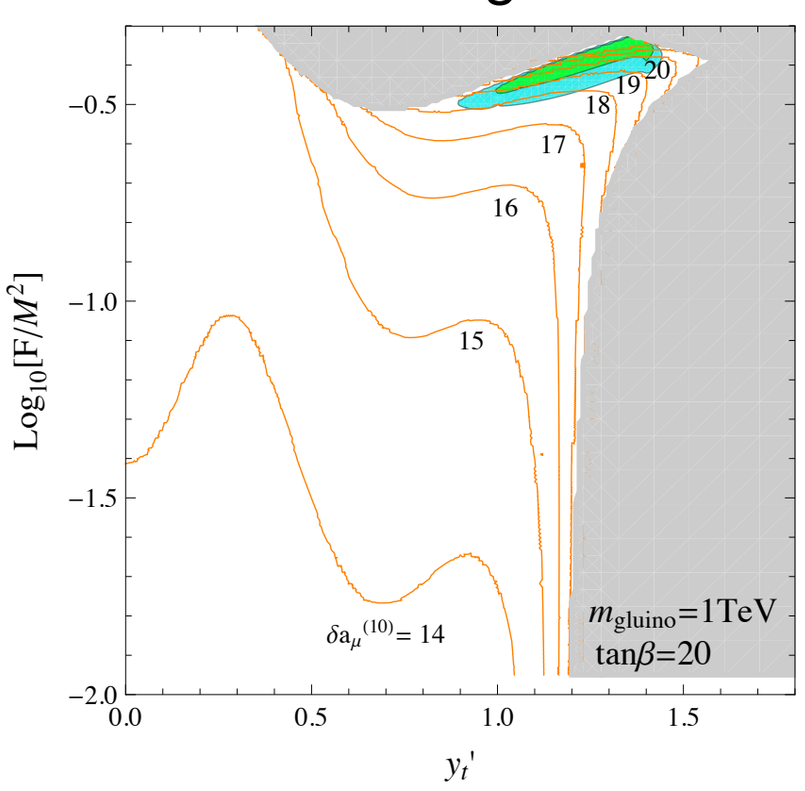


- corrections to $\underline{A_t}, \underline{m^2_{\tilde{t}}}, \underline{m^2_{H_u}}, \ldots$

Higgs mass



muon g-2



+ Q ↔ T

$$a_\mu^{\rm exp} - a_\mu^{\rm SM} = (26.1 \pm 8.0) \cdot 10^{-10}$$

μ is relatively large

[Evans,Ibe,Yanagida]

Large A_t term

- vacuum is destabilized

[ME,Hamaguchi,Iwamoto,Yokozaki]

$$\mathcal{L} \simeq \frac{g m_\tau}{2 M_W} \mu \tan\beta \tilde{\tau}_L^* \tilde{\tau}_R h^0 + \text{h.c.}$$

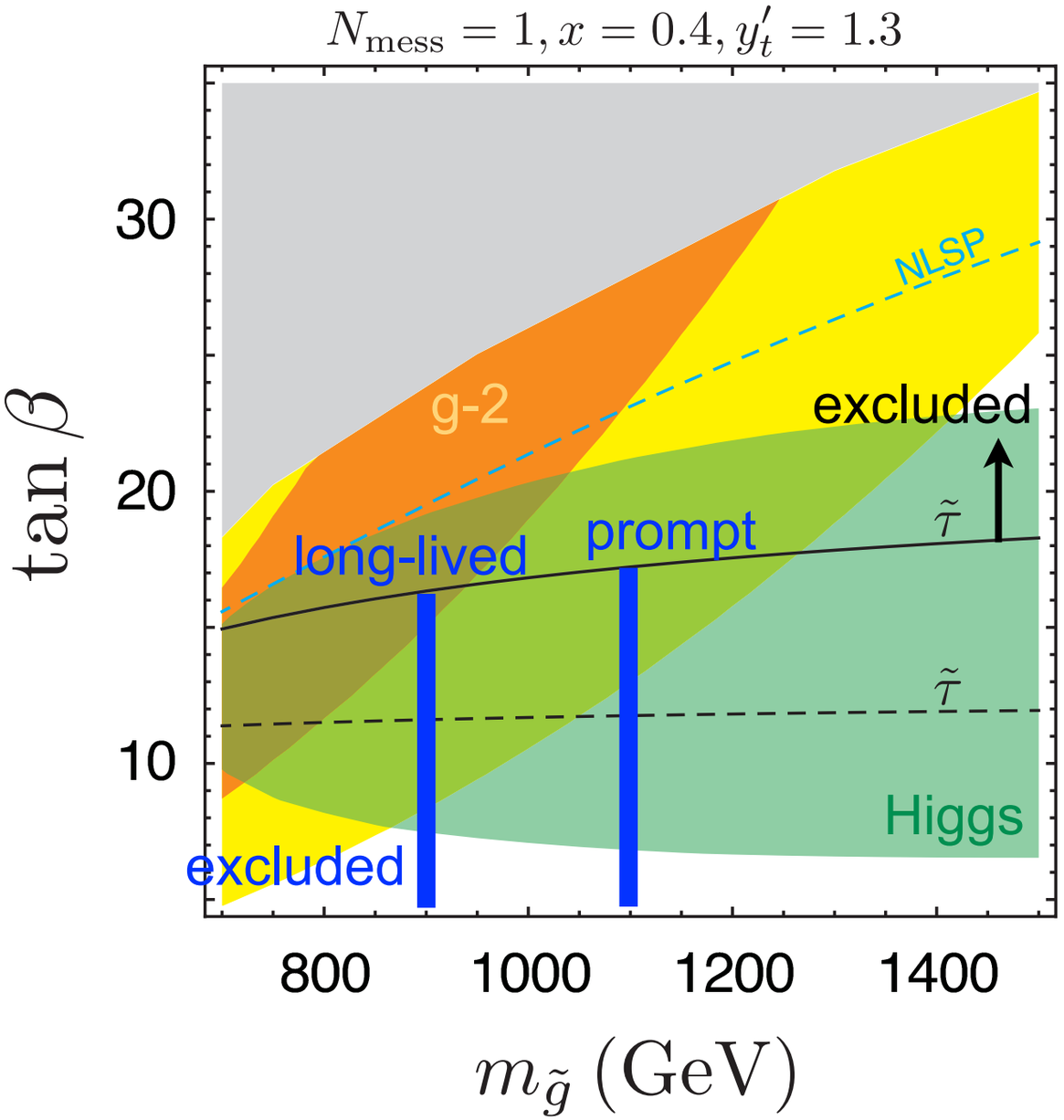
- upper bound on gluino mass

$$m_{\tilde{g}} \lesssim 0.9 \text{ or } 1.3\,\text{TeV}$$

(N_{mess}=1)

- neutralino NLSP (N_{mess}=1)
- LHC discovery expected for 14TeV O(1-10)fb^{-1}

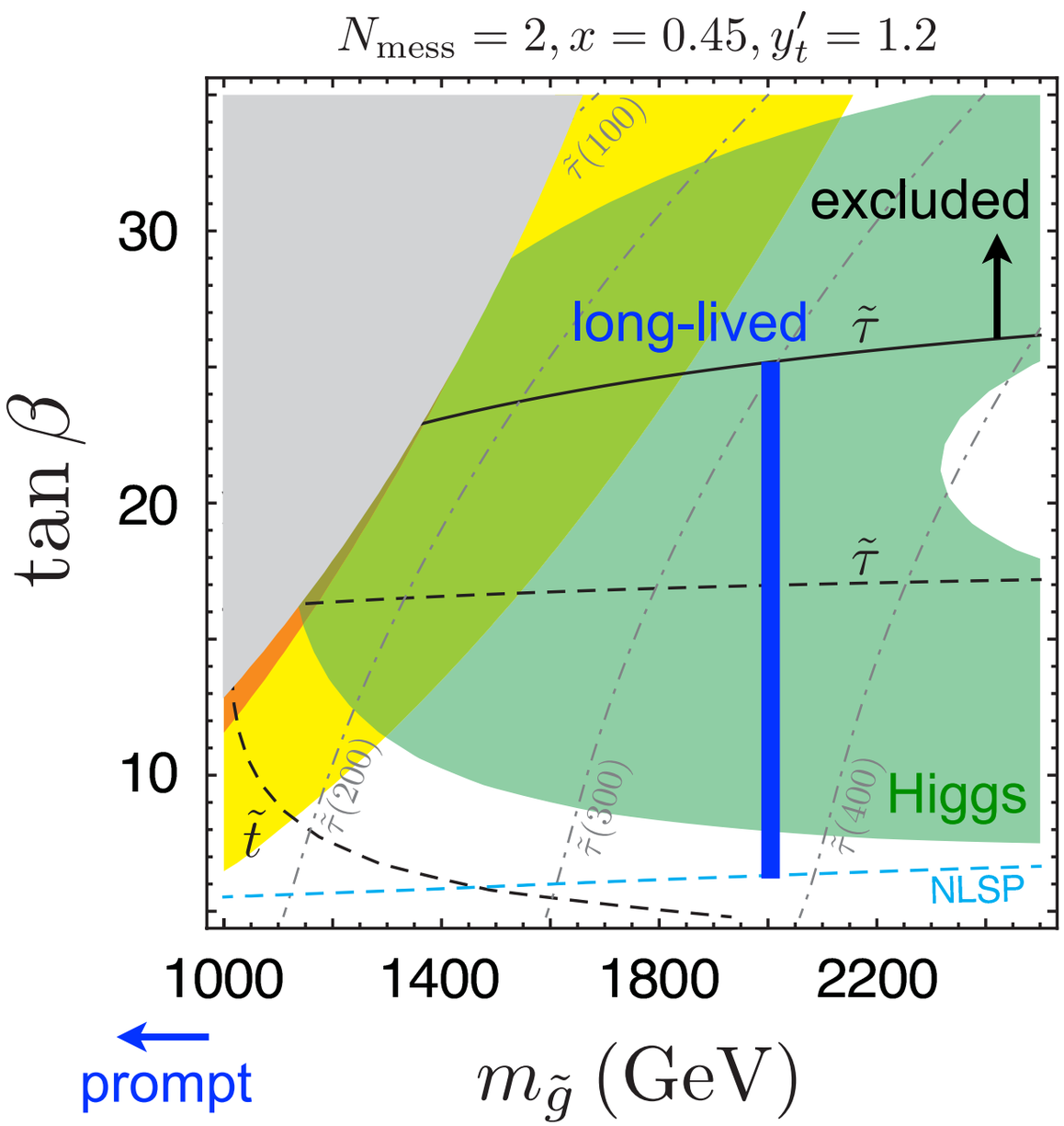
according to Baer,Barger,Lessa&Tata

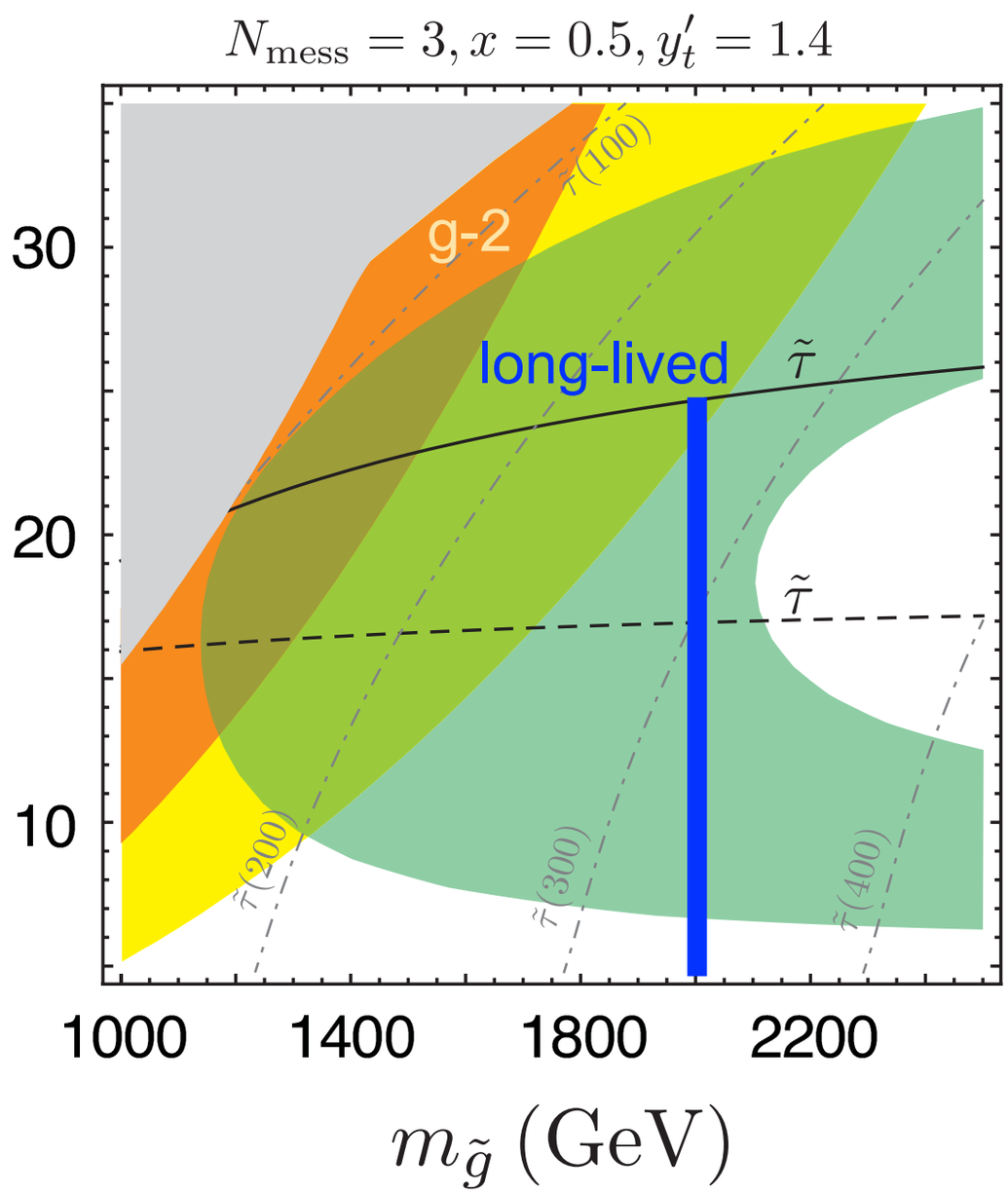


Large A_t term

larger N_{mess}: stau NLSP

[ME,Hamaguchi,Iwamoto,Yokozaki]





Extra Vector-like Matter

c.f. talk by Iwamoto

- extra matter coupling to Higgs [Moroi,Okada]

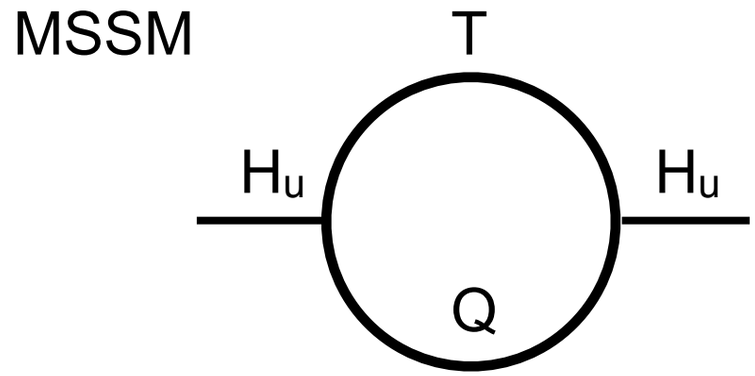
$$W = Y' H_u Q' U' + M'(Q'\bar{Q}' + U'\bar{U}')$$

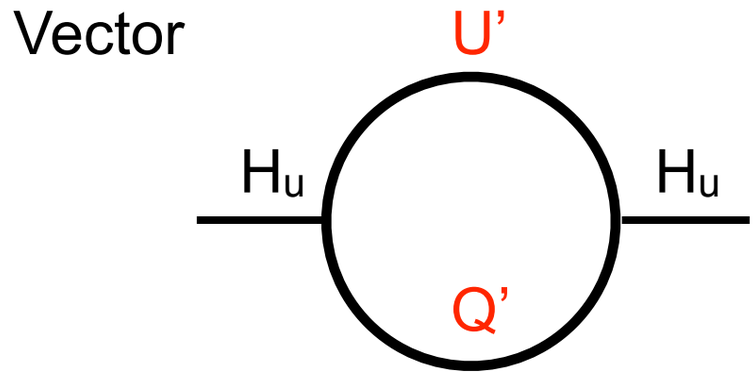
- Higgs mass raised by U', Q' loop

$$\Delta m_h \simeq \frac{3v^2}{4\pi^2} Y'^4 \ln \frac{m_S^2}{m_F^2} + \dots$$

$m_{S(F)}$: vector scalar(fermion) mass

- A' is suppressed by RG running and irrelevant for Higgs mass



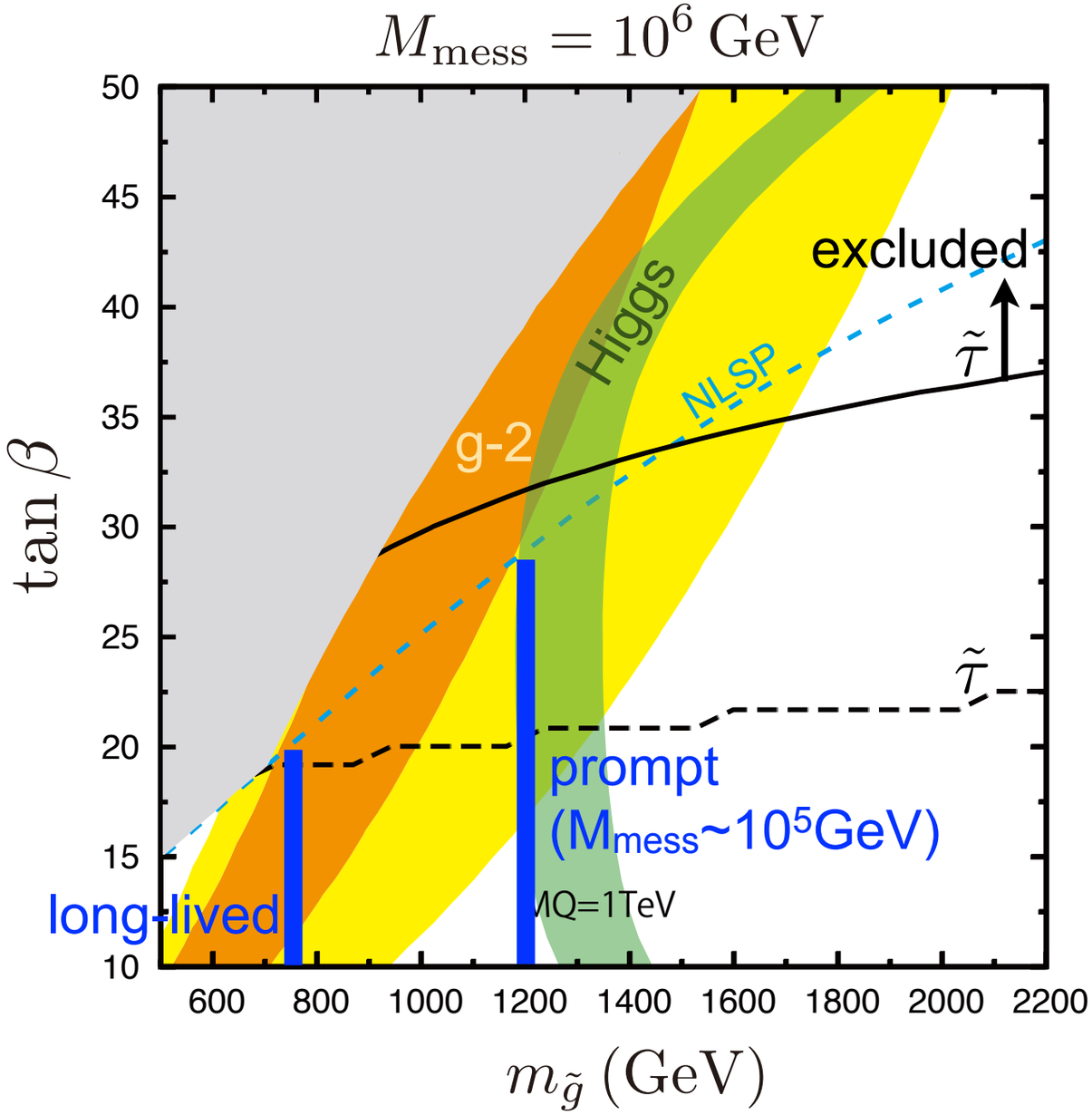


Extra Vector-like Matter

c.f. talk by Iwamoto

- muon g-2 region is covered by varying $M_{Q,U}$
- vacuum is destabilized by large μ
- stau NLSP is excluded by LHC if it is long-lived
- upper bound on gluino mass

$$m_{\tilde{g}} \lesssim 1.2 \text{ or } 1.7\,\text{TeV} \quad (\tilde{\chi}^0)$$
$$m_{\tilde{g}} \lesssim 1.5\,\text{TeV} \quad (\tilde{\tau})$$



[ME,Hamaguchi,Iwamoto,Yokozaki]

Extra Vector-like Matter

c.f. talk by Iwamoto

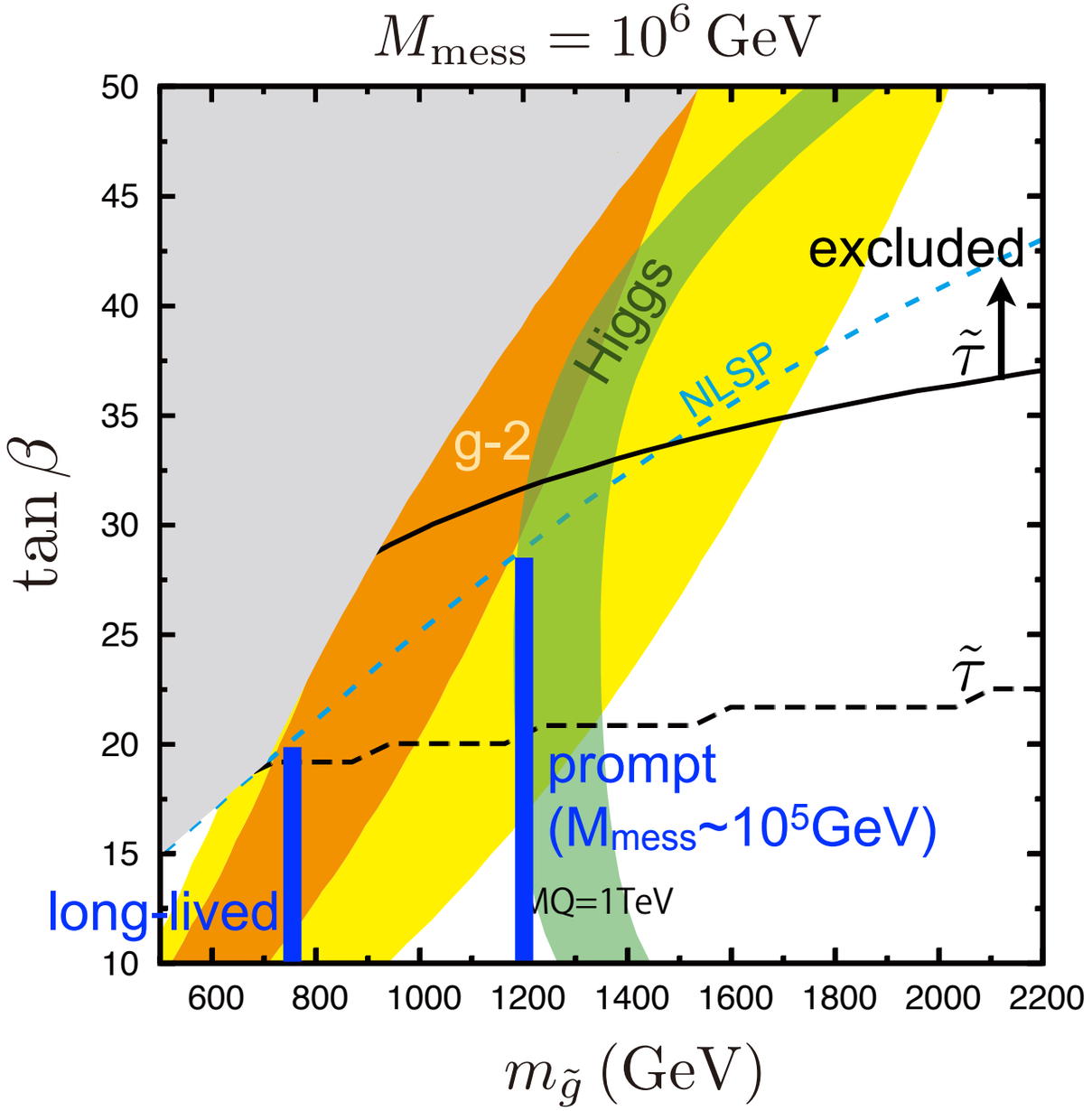
... contd.

- regions are in reach of 14TeV LHC w/ ~10fb^{-1}
- severer for larger M_{mess}
- relatively light ext matter

$$M_V \lesssim 1.5\,\mathrm{TeV}$$

- need study on discovery potential of extra matter

cf. talk by Harigaya



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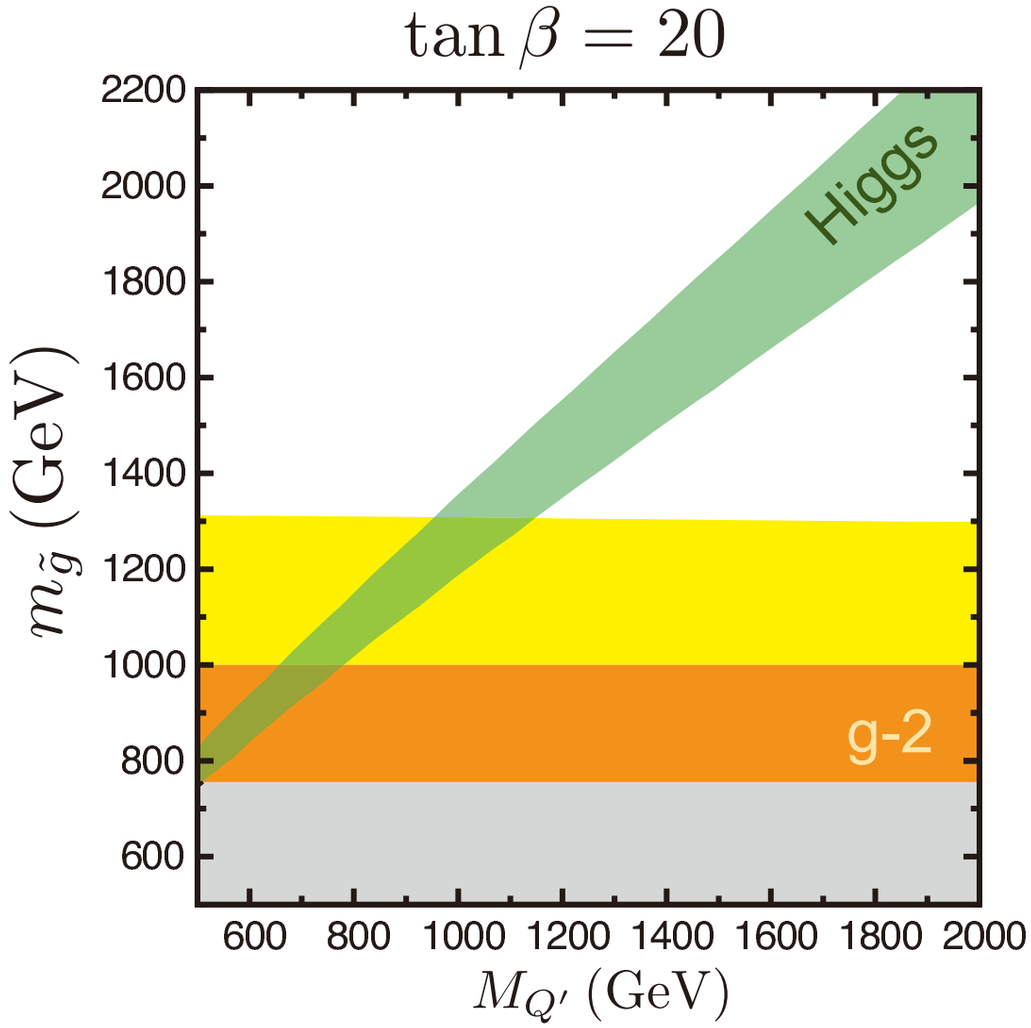
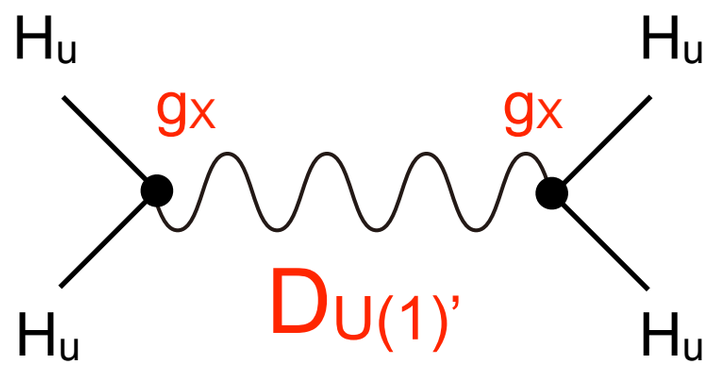


[ME,Hamaguchi,Iwamoto,Yokozaki]

Extra Gauge [U(1)']

- Higgs is charged under U(1)'
- Higgs mass raised by D-term

$$\Delta m_h^2 \simeq 2 g_X^2 x^2 (v_{H_u}^2 + v_{H_d}^2) \cos^2(2\beta) \frac{2m_S^2}{2m_S^2 + m_{Z'}^2}$$



  - unsuppressed by tanβ
  - decoupled if $m_S \ll m_{Z'}$

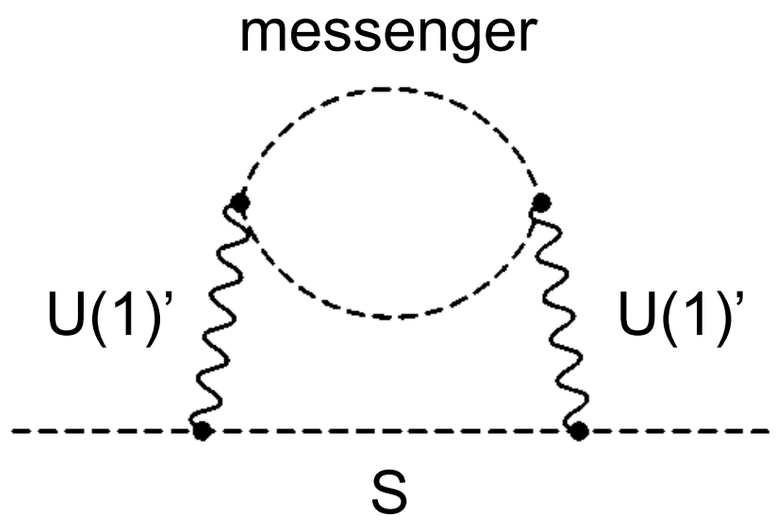
S: SSB of U(1)'

m_S: soft mass of S

- messenger needs to be charged

$$m_S^2 = m_{\bar{S}}^2 \simeq \left(\frac{g_X^2}{16\pi^2}\right)^2 10 y^2 \Lambda^2$$

y: U(1)' charge of messenger



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  - decoupled if $m_S \ll m_{Z'}$

- messenger needs to be charged

$$m_S^2 = m_{\bar{S}}^2 \simeq \left(\frac{g_X^2}{16\pi^2}\right)^2 10y^2\Lambda^2$$

y: U(1)' charge of messenger

GUT-inspired charge assignment

$U(1)_x$: SO(10), $U(1)_T$: Pati-Salam

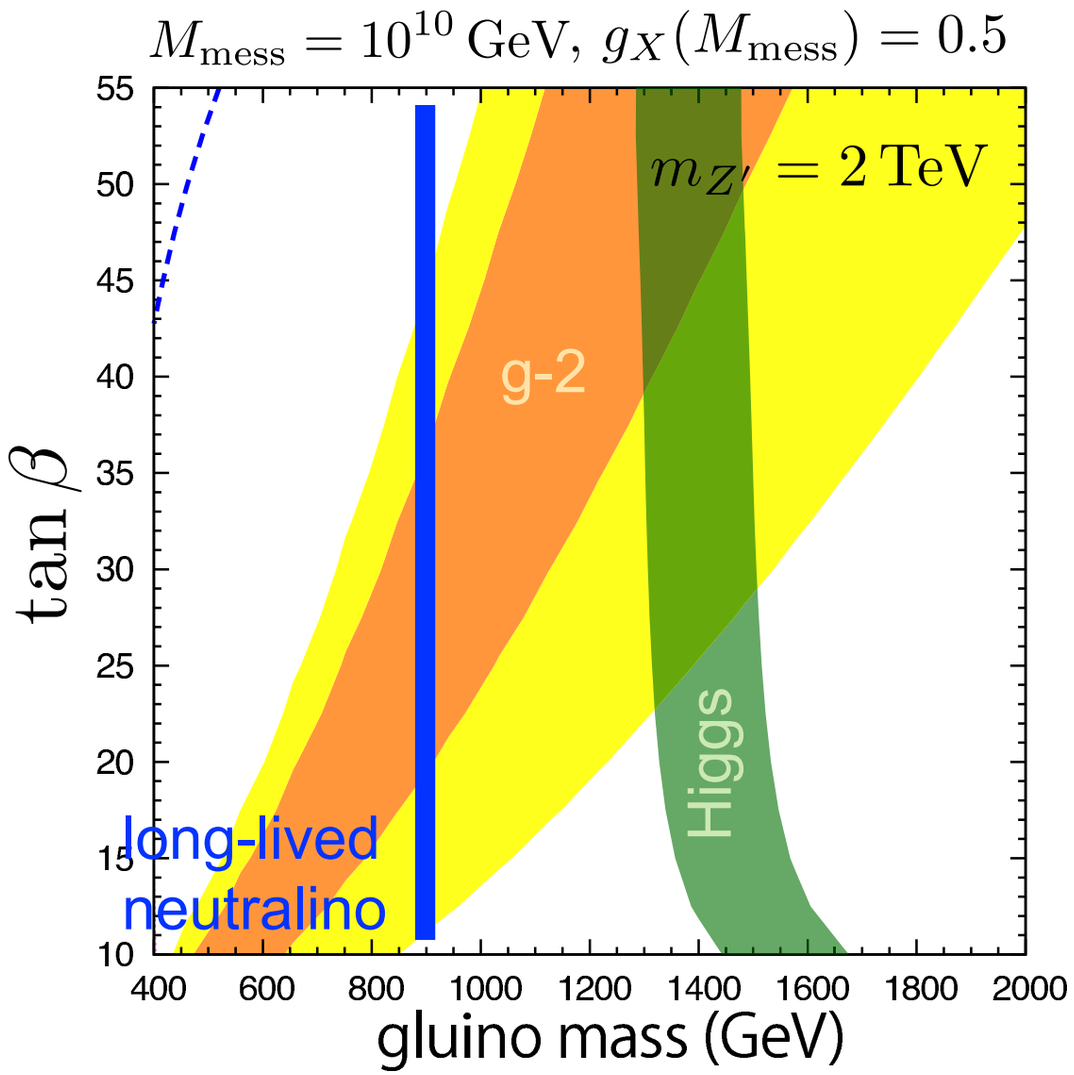
	$U(1)_Y$	$U(1)_{B-L}$	$2\sqrt{10}\times U(1)_\chi$	$U(1)_T$
Q	$1/6$	$1/3$	-1	0
$\bar{U}$	$-2/3$	$-1/3$	-1	-1
$\bar{D}$	$1/3$	$-1/3$	3	1
L	$-1/2$	-1	3	0
$\bar{E}$	1	1	-1	1
$\bar{N}$	0	1	-5	-1
H_u	$1/2$	0	2	1
H_d	$-1/2$	0	-2	-1
S	0	0	$-y$	$+y$
$\bar{S}$	0	0	$+y$	$-y$

Table 1: Anomaly-free U(1) charge assignments on the fields

y = 1

Extra Gauge [U(1)']

- muon g-2 region is covered by varying $m_{Z'}$
- SUSY mass is in reach of 14TeV LHC
- EWSB is spoiled:
  - smaller M_{mess}
  - too large g_x
- light Z' is favored (<3TeV)
- Z' discovery is expected for LHC



[ME,Hamaguchi,Iwamoto,Nakayama,Yokozaki]

“Prices”

There is no “perfect” model from my perspective...

Model	Flavor/CP	gravitino problems	Higgs mass muon g-2	perturbativity	LHC
GMSB	OK	OK	NOT	OK	hopeless for m_h~125GeV
A_t term	model [EIY]	OK	OK	up to M_{mess}	SUSY
vector-like matter	need model	OK	OK	OK	SUSY ext matter
extra U(1)’	OK	OK	OK	up to M_{mess}	SUSY Z’

μ problem

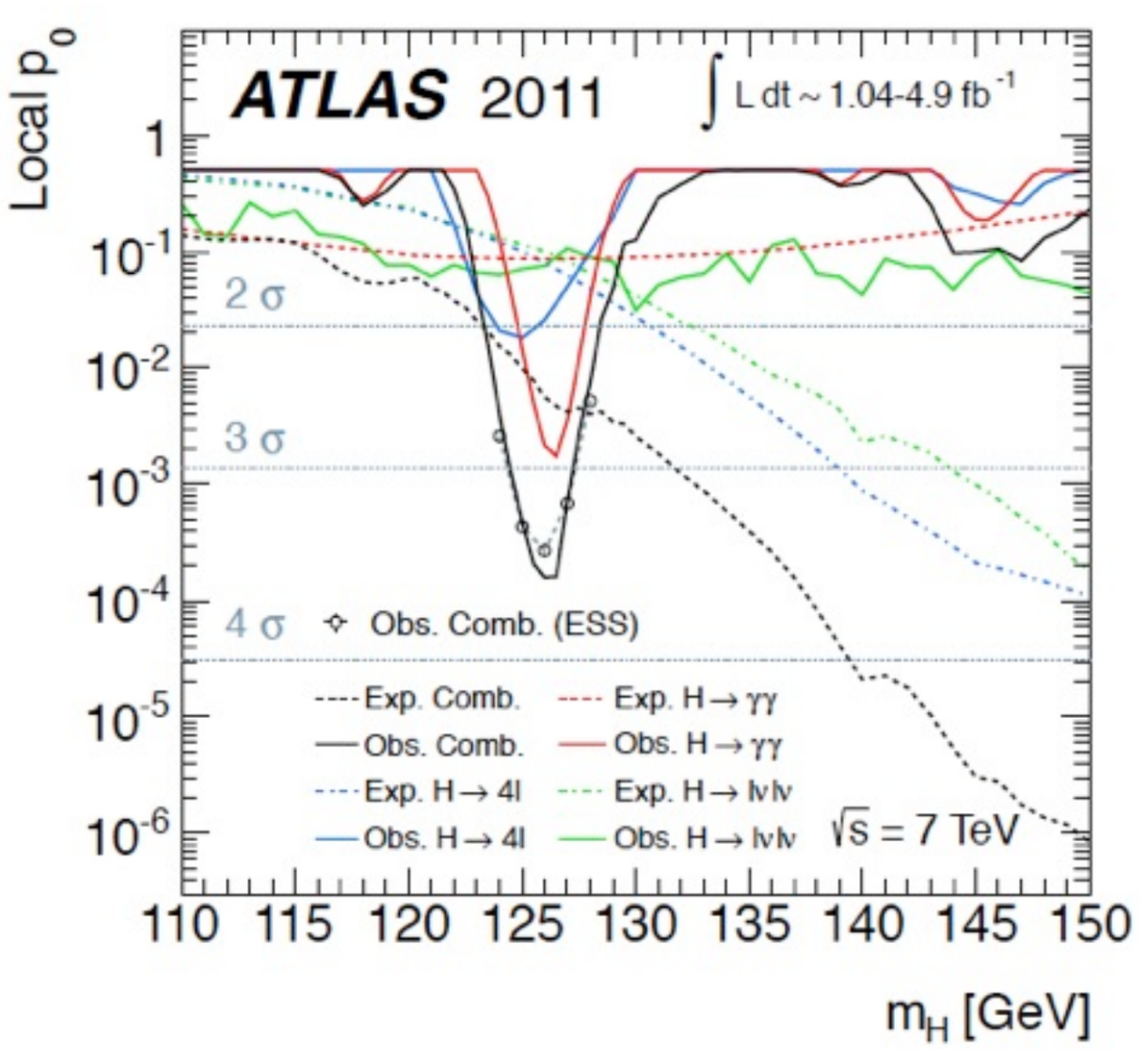
The “best” model is expected to be selected by LHC.

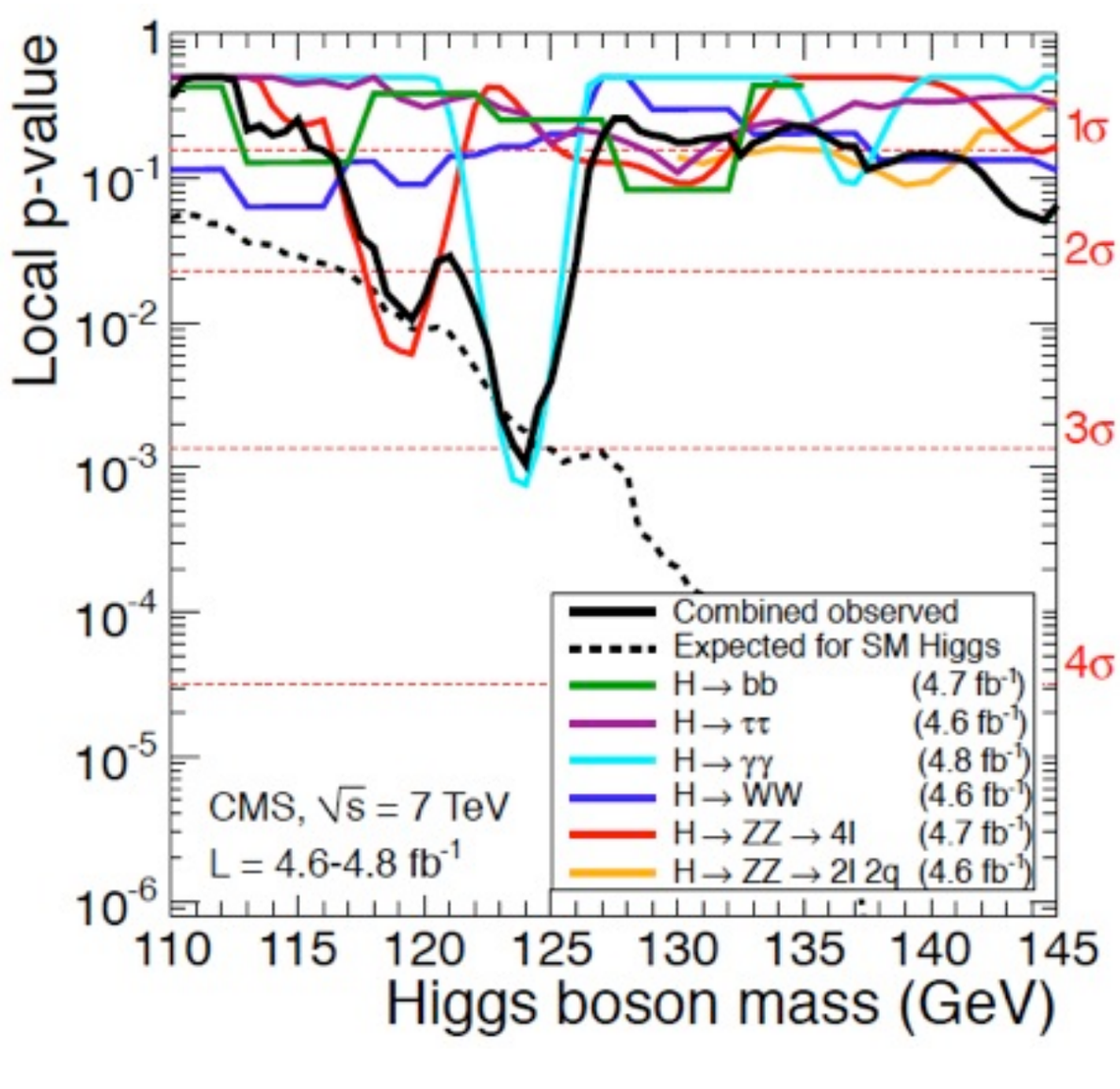
Summary

- Extended GMSB is implied by
  - low energy phenomena and cosmology
  - Higgs mass of ~125GeV & muon g-2
- GMSB + large A_t term
- GMSB + vector-like matters
- GMSB + extra U(1) gauge symmetry
- gluino mass is bounded by muon g-2
- introductions of light extra matters or Z'
- LHC search is interesting!!

Backup Slides

Higgs Local p-value

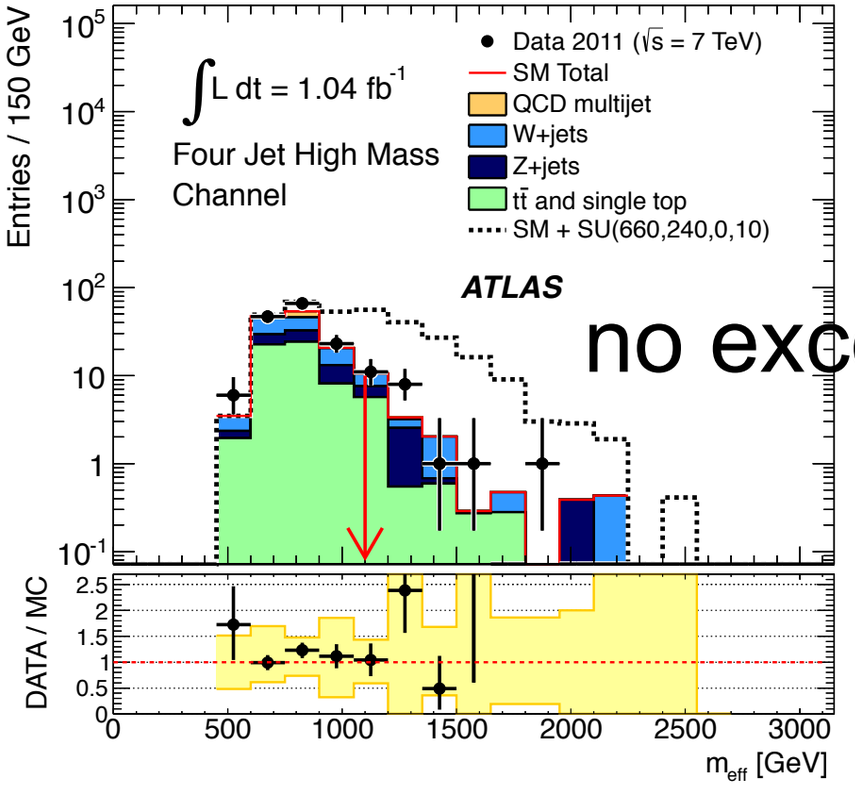




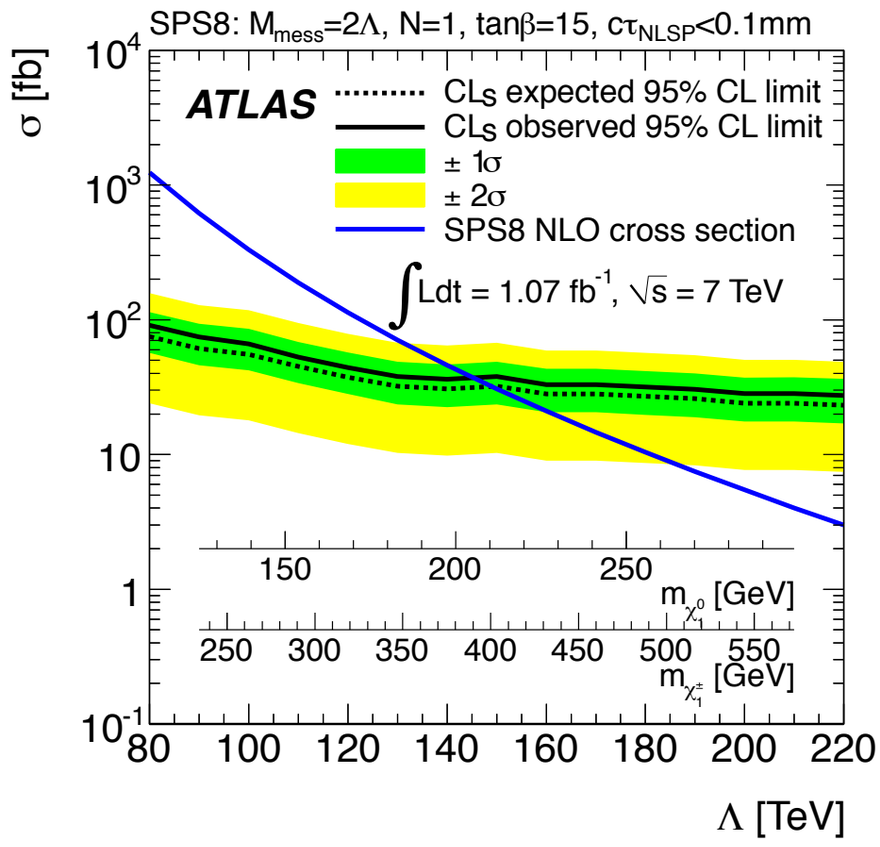
Neutralino NLSP in LHC

$pp \longrightarrow \tilde{g}\tilde{q},\ \tilde{q}\tilde{q},\ \tilde{g}\tilde{g}$

Signal Region	≥ 2-jet	≥ 3-jet	≥ 4-jet	High mass
$E_{\mathrm{T}}^{\mathrm{miss}}$	> 130	> 130	> 130	> 130
Leading jet p_{T}	> 130	> 130	> 130	> 130
Second jet p_{T}	> 40	> 40	> 40	> 80
Third jet p_{T}	–	> 40	> 40	> 80
Fourth jet p_{T}	–	–	> 40	> 80
$\Delta\phi(\mathrm{jet}, \vec{P}_{\mathrm{T}}^{\mathrm{miss}})_{\mathrm{min}}$	> 0.4	> 0.4	> 0.4	> 0.4
$E_{\mathrm{T}}^{\mathrm{miss}}/m_{\mathrm{eff}}$	> 0.3	> 0.25	> 0.25	> 0.2
m_{eff}	> 1000	> 1000	> 500/1000	> 1100



no excess

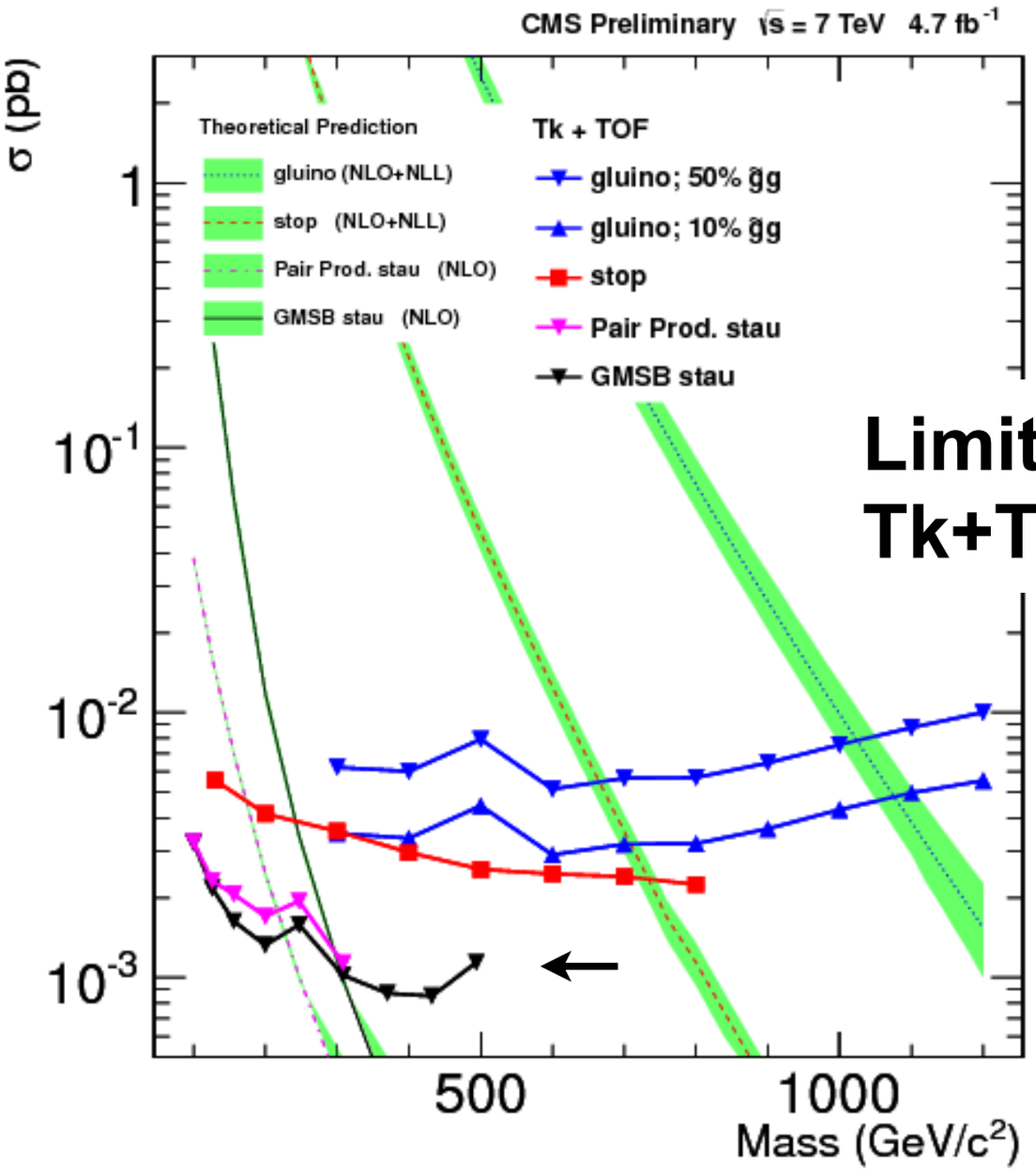


$pp \longrightarrow \chi^{\pm}\chi^{0},\ \chi_1^0 \longrightarrow \gamma\tilde{G}$

diphoton + MET

cf. similar analysis by CMS

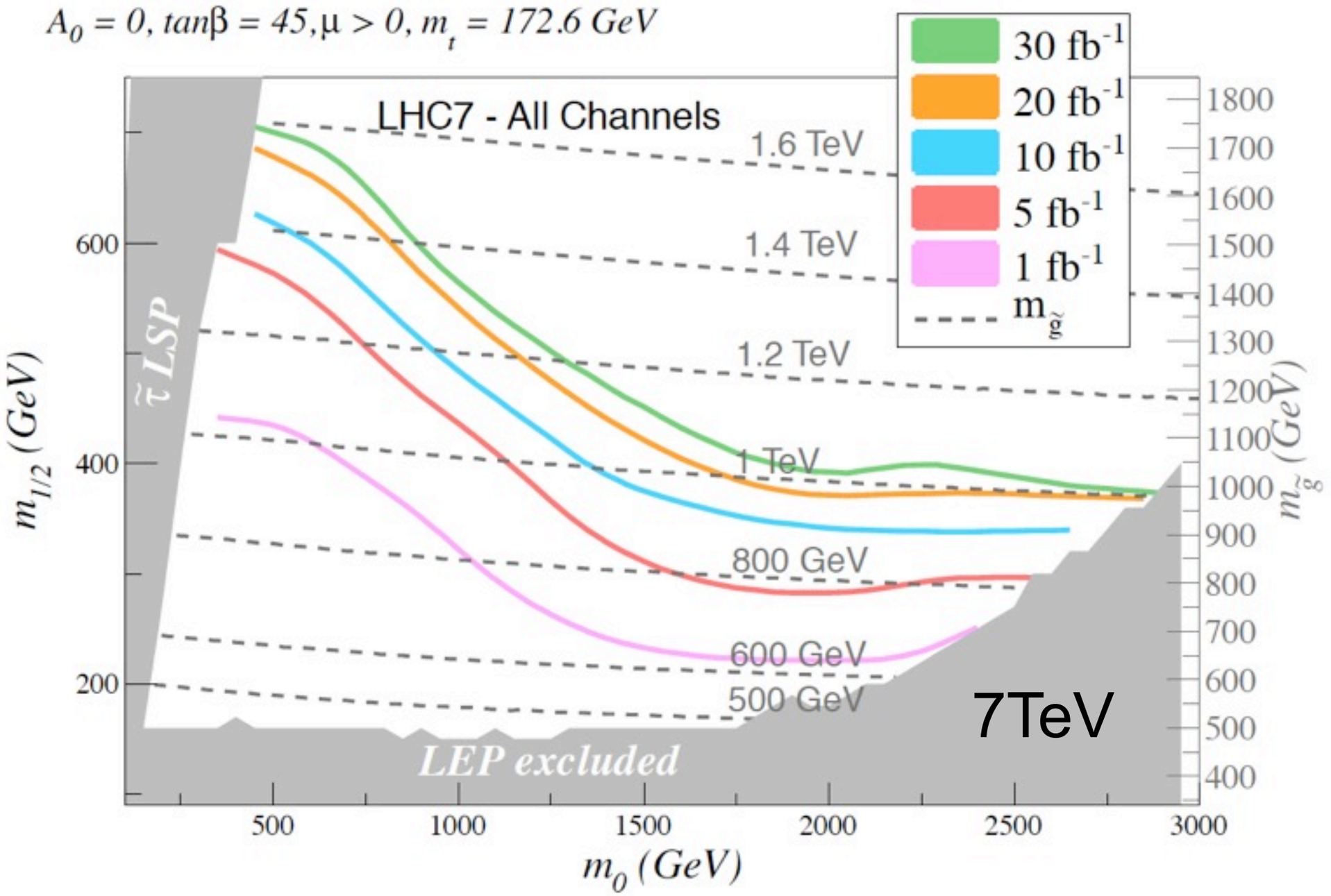
Long-Lived Stau



$$pp \to \chi^{\pm}\chi^{0} \to \tilde{\tau} + \ldots$$

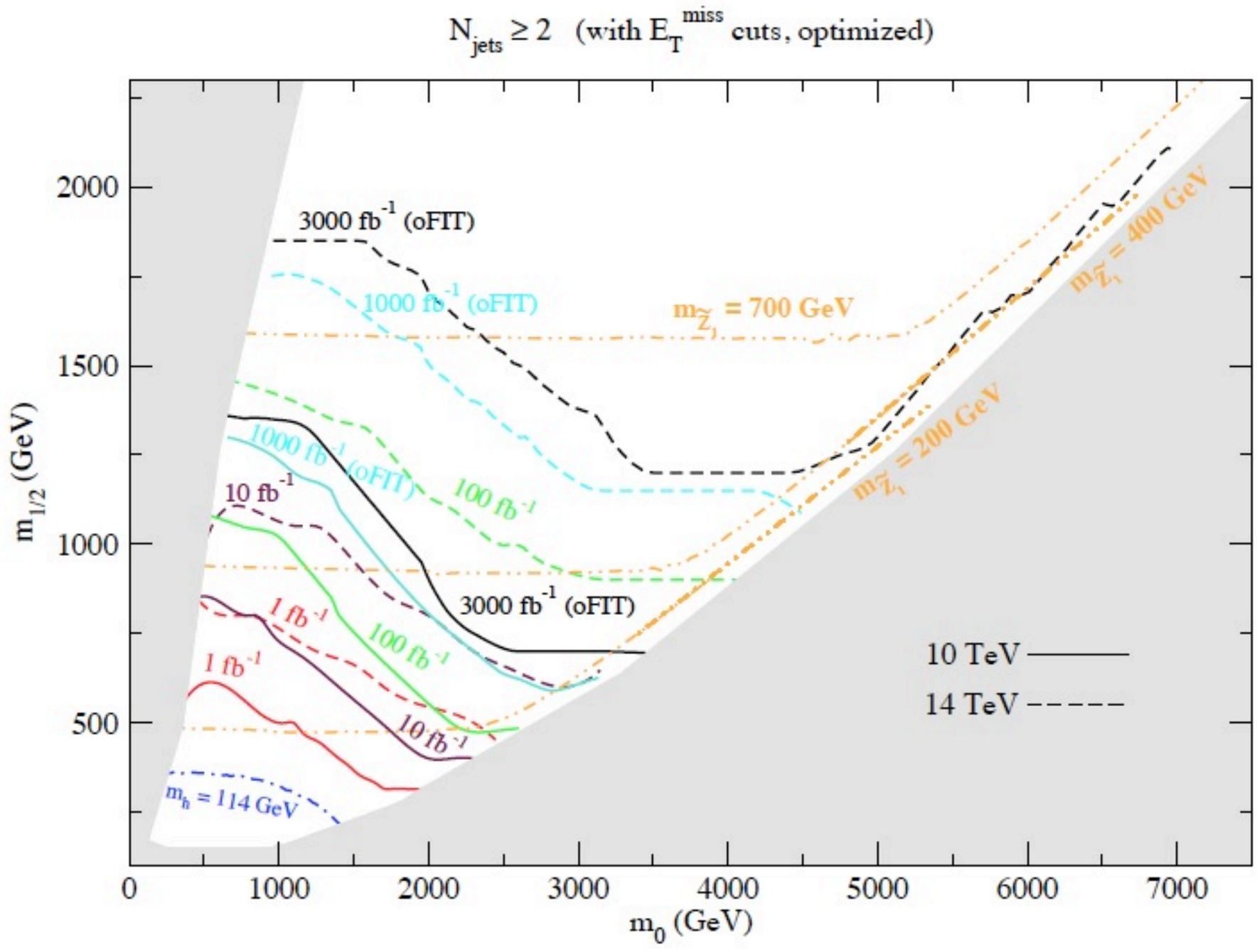
Limits for Tk+TOF

Discovery Potential



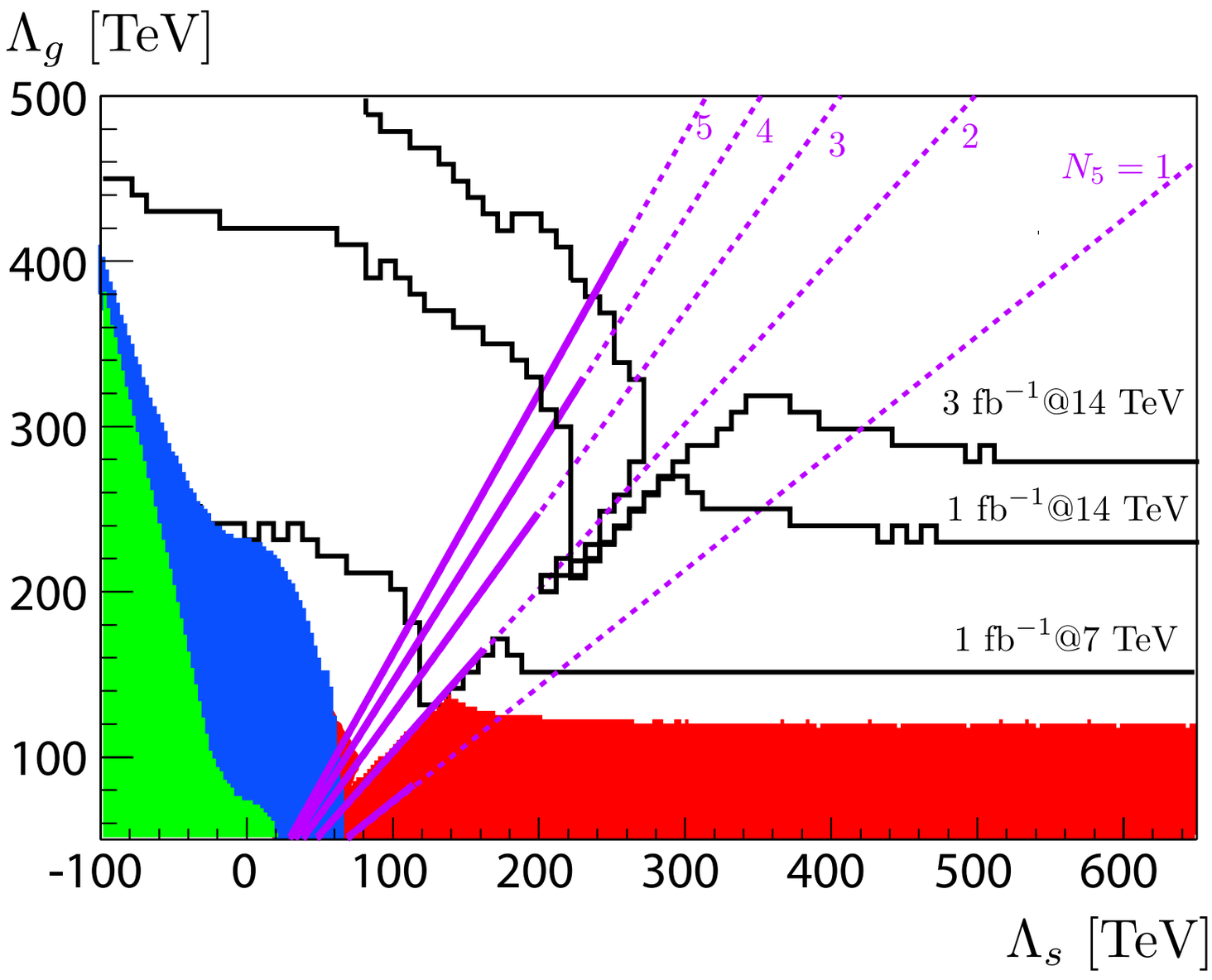
[Baer,Barger,Lessa,Tata]

Discovery Potential



[Baer,Barger,Lessa,Tata]

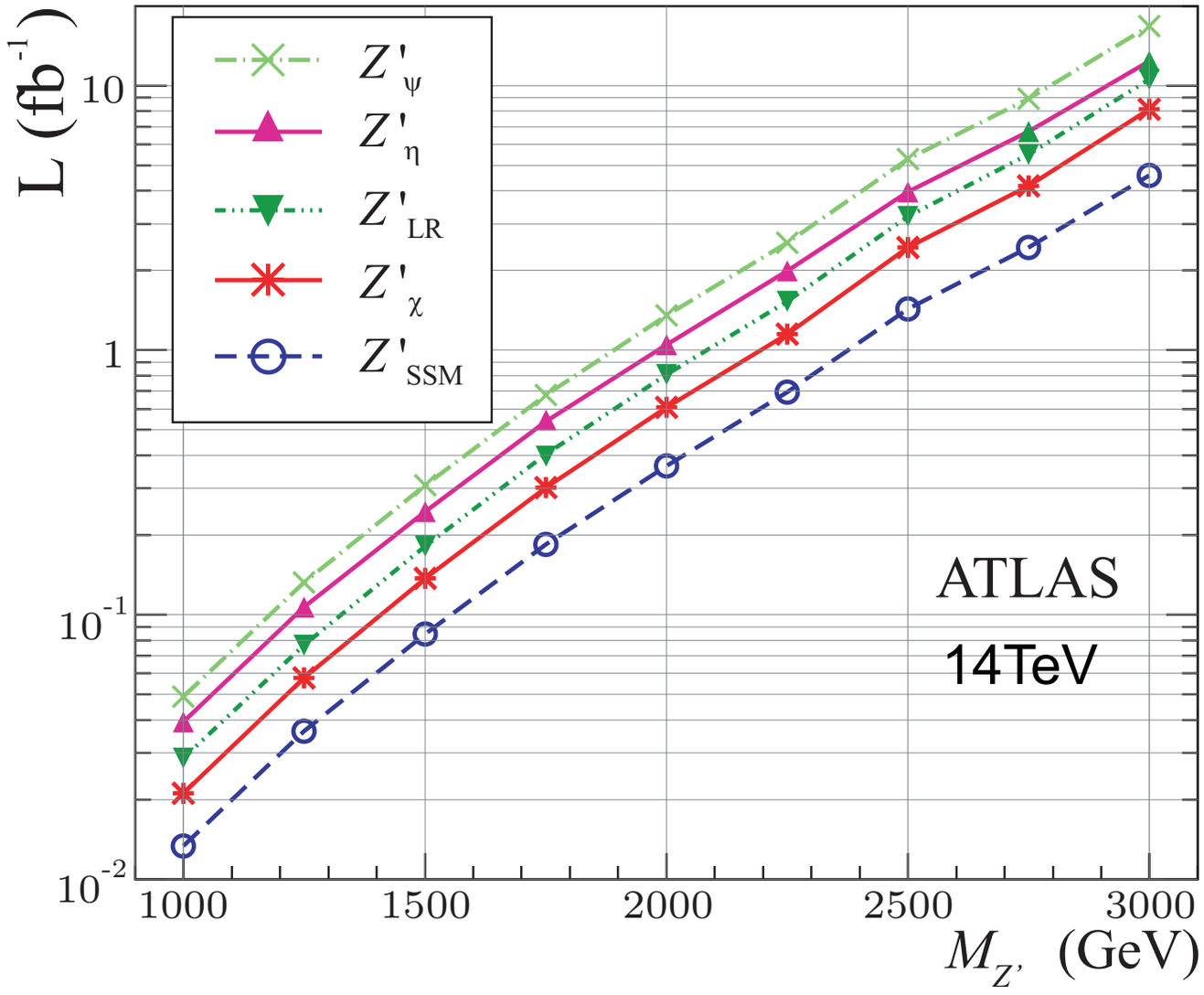
Discovery Potential of GMSB



(a) $\tan\beta = 10$

[Shirai,Nakamura]

Discovery Potential of Z’



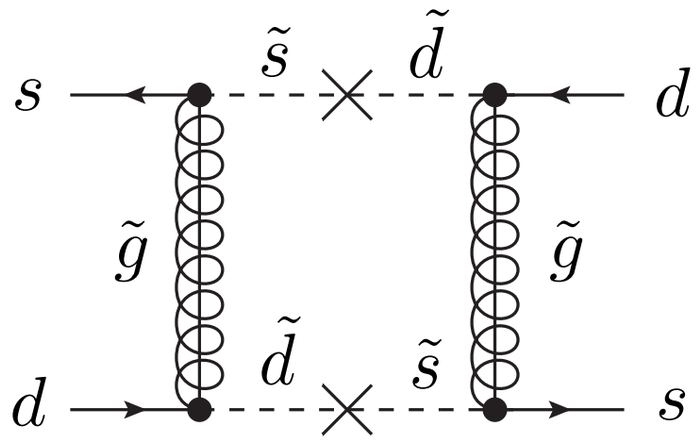
5σ discovery of Z‘ → e^+e^-

[ATLAS-CSC]

Flavor Violations

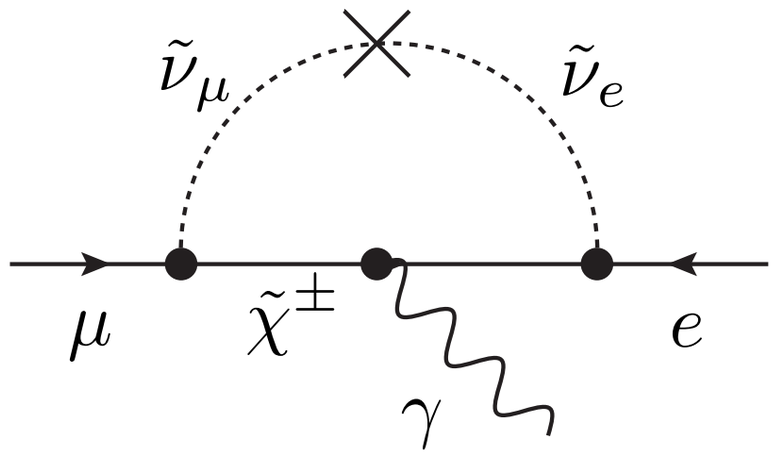
- new sources: $(\tilde{m}^2)_{ij}, A_{ij}$
- quark sector

$$K^0 - \bar{K}^0,\ \epsilon_K,\ B_d - \bar{B}_d,\ \ldots$$



- lepton sector

$$\mu \to e\gamma,\ \tau \to \mu(e)\gamma,\ \ldots$$



- constraints

$$(\delta_{\tilde{q},\tilde{\ell}})_{12} \equiv \frac{(m^2_{\tilde{q},\tilde{\ell}})_{12}}{\tilde{m}^2_{\tilde{q},\tilde{\ell}}} \lesssim O(10^{-(2-4)})$$

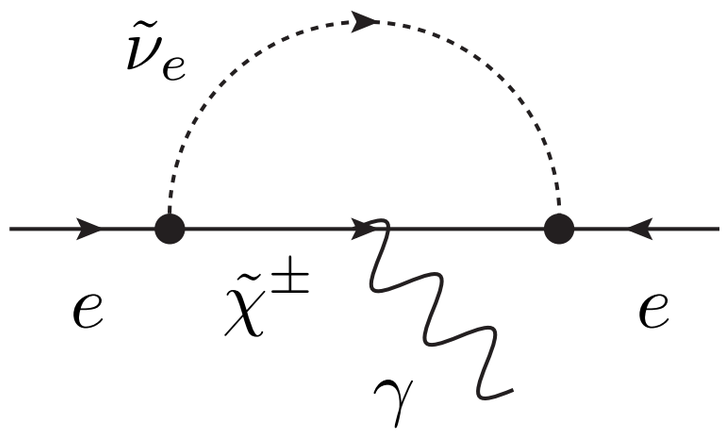
CP Violations

- new phases: $M_i,\ B(\mu),\ A_{ij},\ F_\phi (\simeq \langle W \rangle / M_P^2)$
- EDMs: electron, neutron, mercury, ...
- constraints

$$\arg(M_i B^*) \lesssim 10^{-(2-3)}$$

$$\arg(M_i A^*) \lesssim 10^{-(1-2)}$$

$$\arg(M_i F_\phi^*) \lesssim 10^{-(2-3)}$$



$\longleftarrow$

$$M_i = M_{1/2} + \frac{\alpha_i b_i}{4\pi} F_\phi \quad \sim 10^{-2} M_{1/2}$$

$$\frac{\mathrm{d}B}{\mathrm{dt}} = \frac{1}{4\pi}\left[6\alpha_t A_t + 6\alpha_2 M_2 + \frac{6}{5}\alpha_1 M_1 + \ldots\right]$$