Top squarks from the landscape at high luminosity LHC[1]

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[1]Based on work 2307.08067.

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Old guidances led to the formulation of SM

- Two principles that lead to the Standard Model:
  - *Symmetry*: both global and gauge symmetry
    - *Symmetry:* what forms of terms can appear in Lagrangian
  - *Renormalizability*:
    - *Renormalizability:* only finite number of terms one can write down.
- $\Longrightarrow$ SM: self-consistent, elegantly simple, fully renormalizable QFT.
  - So far classifies all know particle physics (except for neutrinos).

Hierarchy problem in the SM

Look deep into the SM

- Renormalizable: low-energy measurements insensitive to UV completion.
  - low-energy effect is determined by the symmetries the system has.
  - Contrasted with the situation before the SM.
    - Weak theory with massive vector boson is non-renormalizable. Unitarity bound violated unless there is a Higgs boson[1]: $m_h \leq 1 TeV$.
    - One of the reasons people believe Higgs boson had to be found in LHC long before its construction.
  - Non-renormalizable theory tells where itself breaks down.
  - Pessimistic view: in principle, SM could be valid up to $M_{planck} \sim 10^{19}$ TeV without self-inconsistency.

[1] or entities playing the similar role like top condensate

Hierarchy problem in the SM

Don’t be pessimistic

- Mass terms in a Lagrangian is always super-renormalizable. For a scalar boson, quantum corrections to its mass terms is quadratic sensitive to the theory UV cutoff Λ.
- $$m_h^2 = m_0^2 + \frac{3\Lambda^2}{8\pi^2 v_{SM}^2}\left[c_h\left(\frac{m_h^2}{v_{SM}^2}\right)m_h^2 + 2c_W g^2 m_W^2 + c_Z\frac{g^2}{\cos^2\theta_W}m_Z^2 - c_t y_t^2 m_t^2 + \cdots\right] + \cdots$$
- The SM, if viewed as a low energy EFT, whose UV completion lives at Planck scale $M_{planck} \sim 10^{19}$ TeV leads to uncomfortable implication.
  - On the LHS: $m_h^2 \sim (100\ \text{GeV})^2$
  - On the RHS: If the cutoff is at Planck scale, terms $\sim (10^{19}\ \text{GeV})^2$. They need to be tuned to $\frac{\Lambda_{SM}^2}{\Lambda_{Planck}^2} \sim 10^{-34}$ precision to miraculously cancel each other to give out such a tiny LHS $\sim (100\ \text{GeV})^2$.

Hierarchy problem in the SM

- Why masses of fermions or gauge bosons are not problematic?
  - Protected by *custodial symmetry*:
    - Fermions: *chiral symmetry*.
    - Gauge bosons: *gauge symmetry*.
  - Protected even if the custodial symmetry is broken
  - Either case, UV scale decouples.

New guidance to search for theory — *Naturalness*

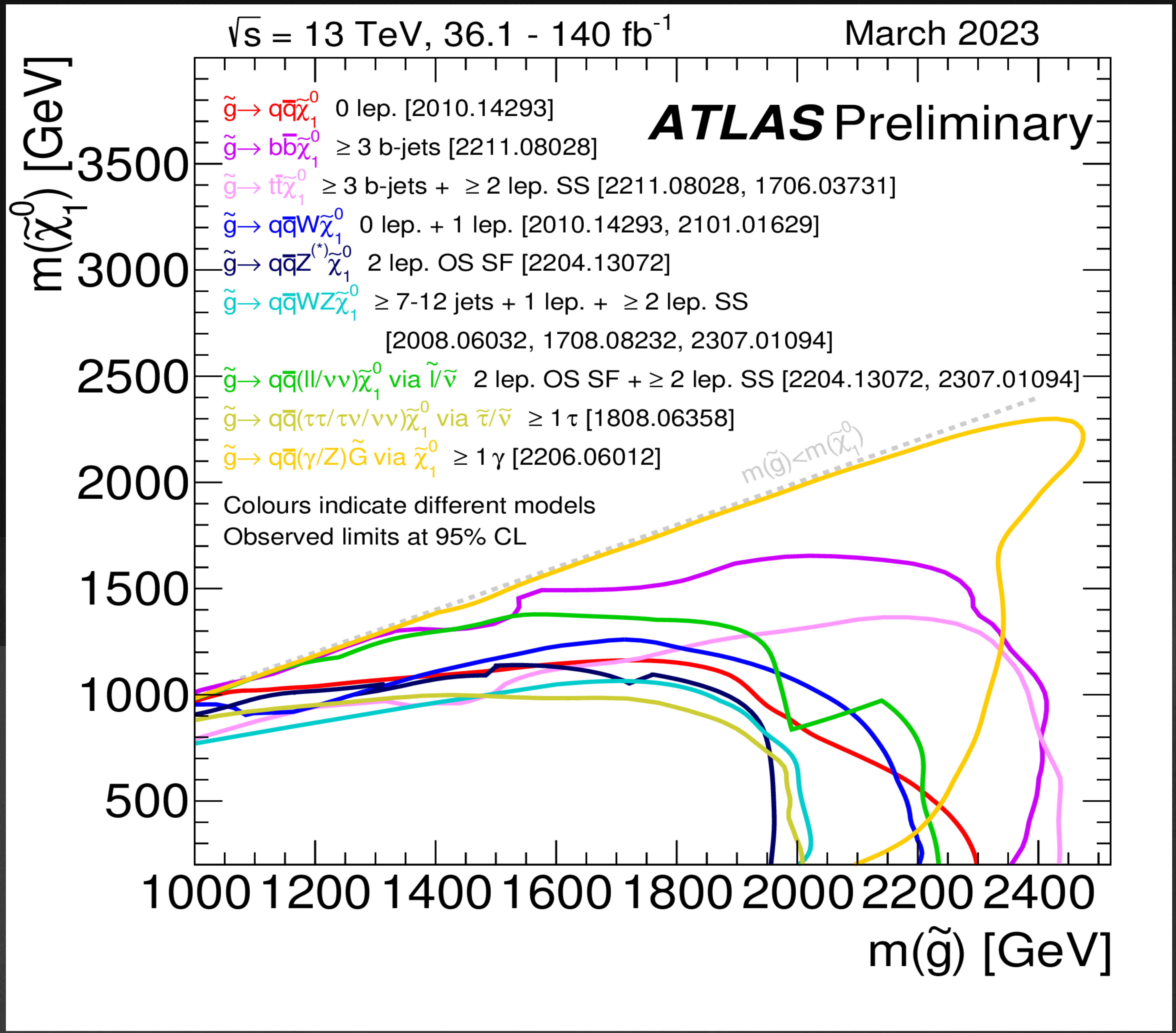
- Just the *symmetry principle* and *renormalizability* are not enough now for BSM physics.
- New tool: *Naturalness*— no fine tuning!
  - Hints the SM needs an extension.
- Look back the radiative correction to the Higgs boson mass

$$m_h^2 = m_0^2 + \frac{3\Lambda^2}{8\pi^2 v_{SM}^2}\left[c_h\left(\frac{m_h^2}{v_{SM}^2}\right)m_h^2 + 2c_W g^2 m_W^2 + c_Z \frac{g^2}{\cos^2\theta_W} m_Z^2 - c_t y_t^2 m_t^2 + \cdots\right] + \cdots$$

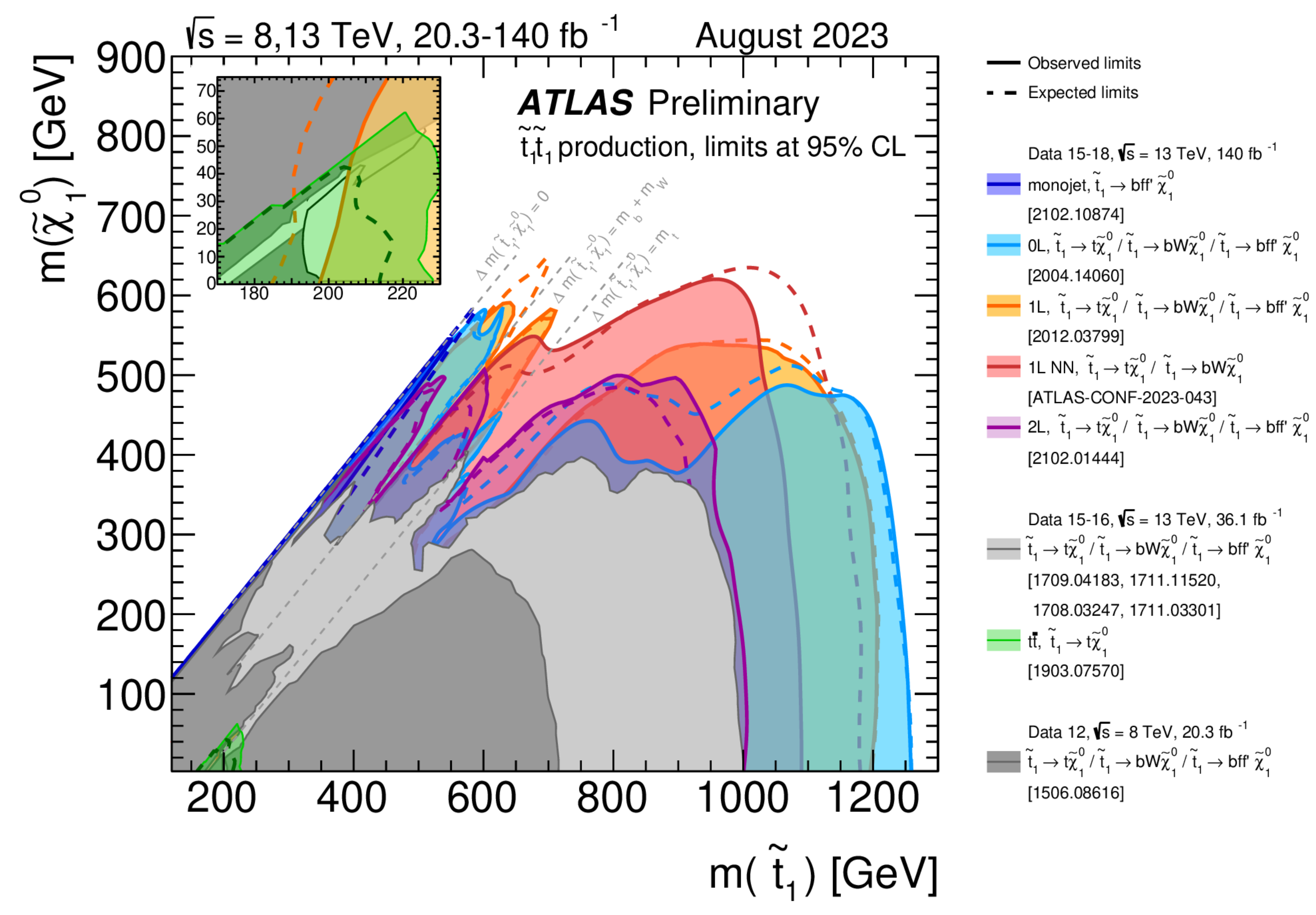
The corrections due to fermion loop and that of bosons loop are always opposite in signs.

- A new custodial symmetry connects fermion with boson to protect Higgs mass from radiative correction? — (weak-scale) SUSY!

Experiment says?



$m(\tilde{g}) > 2.4$ TeV



$m(\tilde{t}_1) > 1.2$ TeV

A Whisper from Naturalness — is WSS itself facing a fine tuning crisis?

Not just hints extension for SM but also guides on MSSM and SUSY breaking search

- Exact SUSY breaking mechanism is still missing….
- But common to assume some soft SUSY breaking parameters are unified at GUT scale
  - For example, in mSUGRA
    - Gauge unification, gaugino mass unification, scalar mass unification, trilinear scalar self-interactions coupling unification, etc…
    - Thus, fixed by 5 parameters: $m_{1/2}, m_0, A_0, \tan\beta, sign(\mu)$
    - One might think they are independent and take the RGE down to the weak scale…
- Yet, these high-scale soft terms should not be expected to be independent but depends on the exact SUSY breaking mechanism and details of hidden sectors.
  - For example, in more fundamental dilaton-dominated SUSY breaking model: $m_0^2 = m_{3/2}^2, m_{1/2} = -A_0 = \sqrt{3}m_{3/2}$.
  - Naively taking the SUSY breaking soft terms to be independent could overestimate the fine tuning level.

[Baer et al, 2023]

A Whisper from Naturalness

An unambiguous way out

- Only use low-scale independent parameters to quantify the fine-tuning: conservative, model-independent, and easy to calculate.
- With the well known relation in the MSSM:
-
$$\frac{m_Z^2}{2} = \frac{m_{H_d}^2 + \Sigma_d^d - (m_{H_u}^2 + \Sigma_u^u)\tan^2\beta}{\tan^2\beta - 1} - \mu^2 \simeq - m_{H_u}^2 - \Sigma_u^u - \mu^2 \qquad (1)$$

◆ *Practical Naturalness*:

  ◆ an observable $\mathcal{O}$ is natural if all *independent* contributions to $\mathcal{O}$ are comparable to or less than $\mathcal{O}$. [Baer et al, 2012]

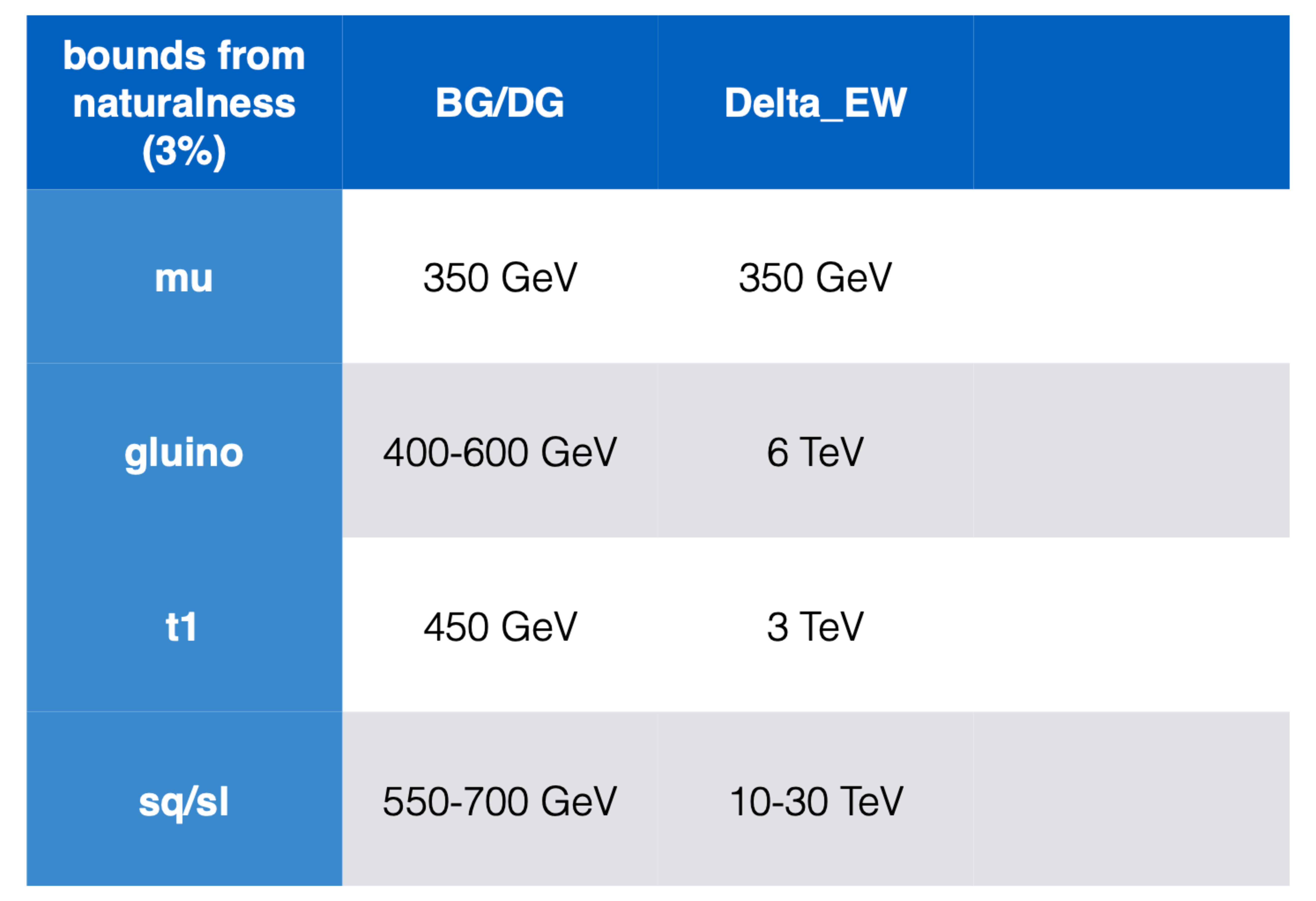
◆ We use the naturalness measure Δ_{EW} defined as

$$\Delta_{EW} \equiv |\text{maximal term on the right} - \text{hand} - \text{side of Eq. } (1)|/(m_Z^2/2)$$

[Baer, Barger, and Savoy, 2016]

- $|\mu| \sim m_Z, m_{H_u}^2 \sim -m_Z$ for EWSB, radiative corrections $\Sigma \sim m_Z$ under weak-scale SUSY.
- μ, typically arise from very different physics than SUSY breaking, is an *independent* contribution from others.
- $\Delta_{EW} < 30$ (3% fine tuning at most) $\Longrightarrow \mu < 350$ GeV: light higgsinos!

Naturalness says?



bounds from naturalness (3%)	BG/DG	Delta_EW	
mu	350 GeV	350 GeV	
gluino	400-600 GeV	6 TeV	
t1	450 GeV	3 TeV	
sq/sl	550-700 GeV	10-30 TeV	

$$\Delta_{BG} \equiv max_i \left| \frac{p_i}{m_Z^2} \frac{\partial m_Z^2}{\partial p_i} \right|,$$

where p_i represent high scale soft SUSY breaking terms. (Ambiguous and model-dependent!)

Experiment says:

$m(\tilde{t}_1) > 1.2$ TeV ✓

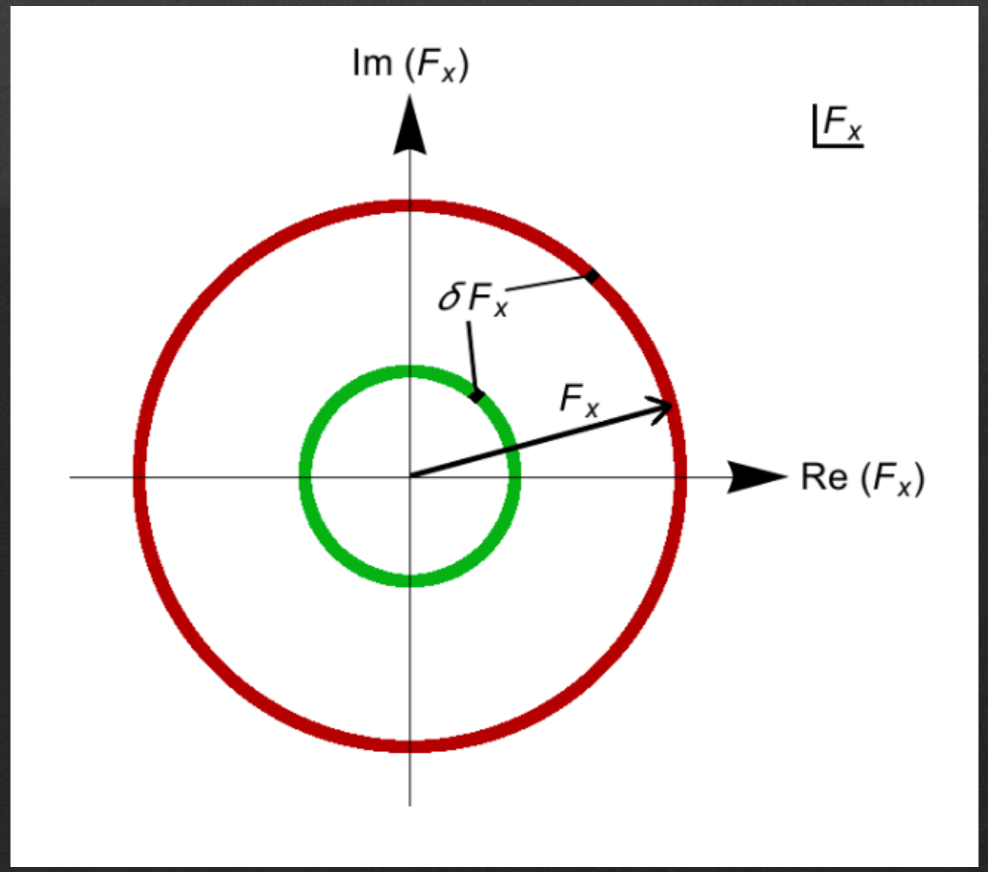
$m(\tilde{g}) > 2.4$ TeV ✓

$(m(h) \sim 125$ GeV)

Δ_{EW} is perfectly well safe from current experimental SUSY search bound!

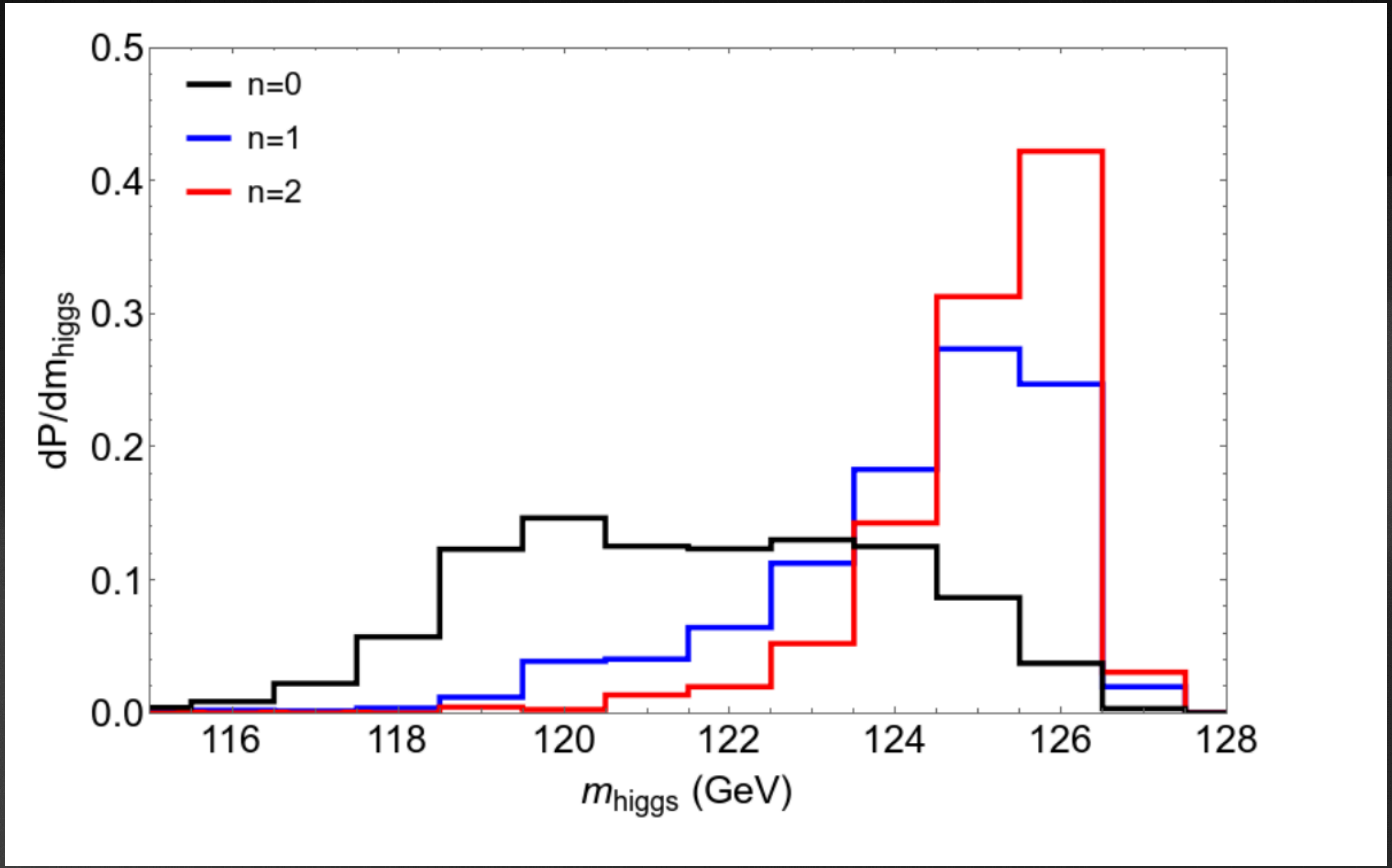
String Landscape

- 10^{500} string vacua states from compactification from 11d to 4 d. Some of them are close to our universe:
  - Visible sector contains MSSM as LEFT
- In fertile patch of vacua with MSSM as weak scale effective theory but with no preferred SUSY breaking scale:
  - $dN_{vac} \sim f_{SUSY} \cdot f_{EWSB} \cdot dm_{soft}$
  - Douglas ansatz:
    - $f_{SUSY} \sim m_{soft}^{2n_F+n_D-1}$
- For example, in the simplest situation, a single F-type breaking: $f_{SUSY} \sim m_{soft}^{1}$.
- But this should be balanced by the ABDS window: $m_{weak}^{PU} \sim (0.5-5)\ m_{weak}^{OU}$, or complex nuclei is not formable.



$m_h \sim 125$ GeV for n=1, 2 power law

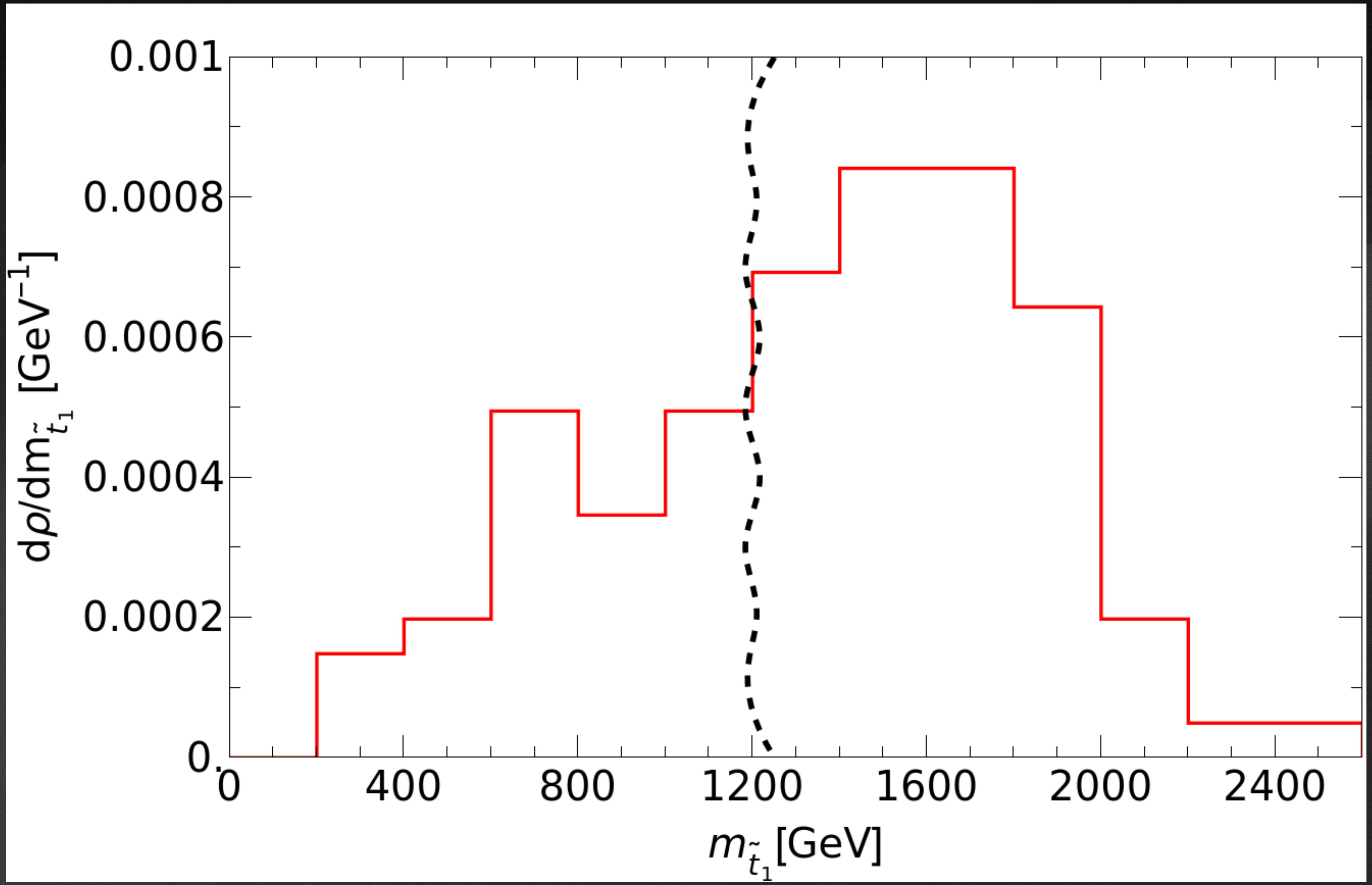
$f_{SUSY} \sim m^n_{soft}$



$(m(h) \sim 125$ GeV) ✓

[Baer,Barger, Serce, Sinha, arXiv:1712.01399]

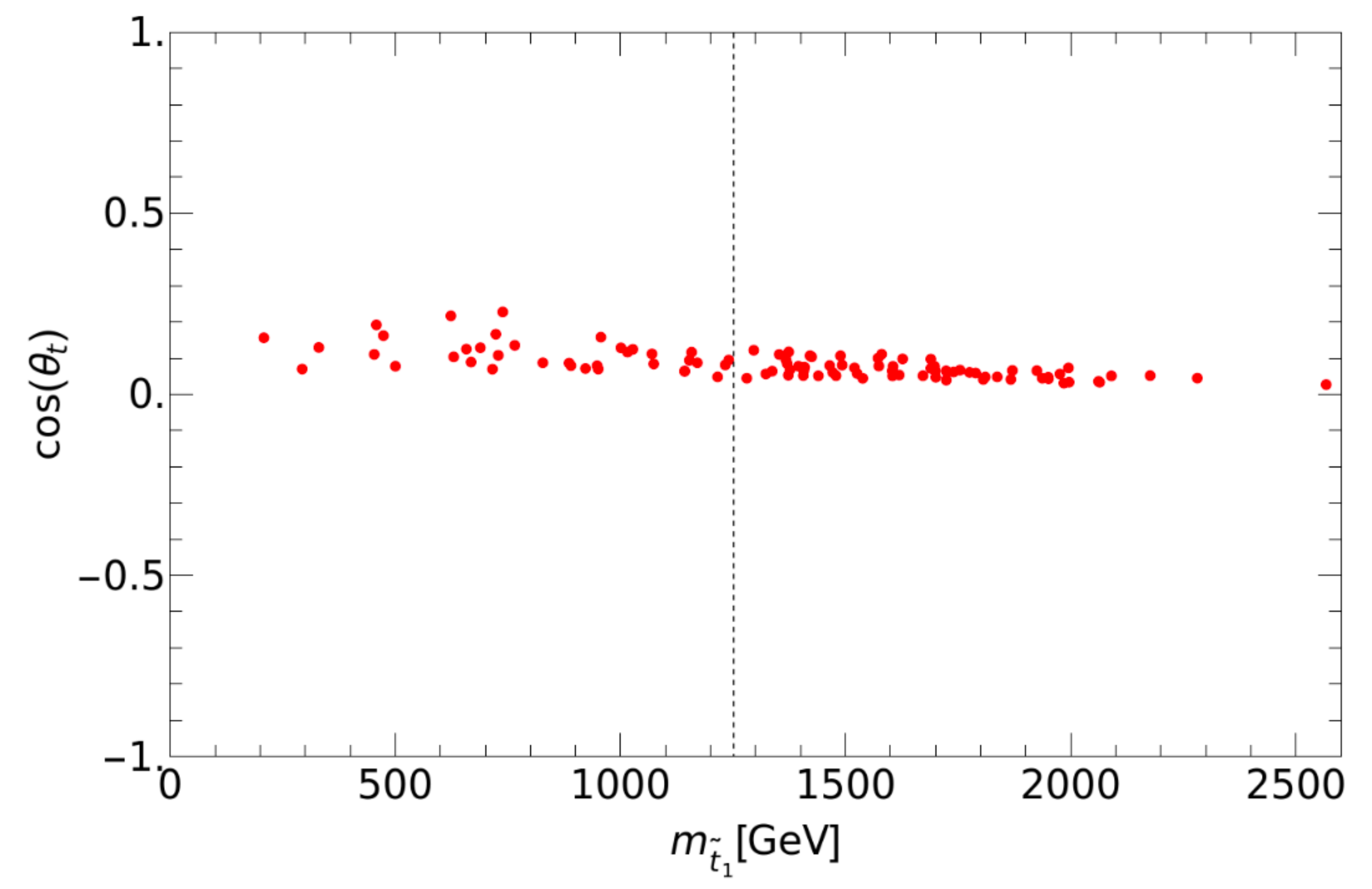
Top squark from landscape prediction



Probability distribution for $m_{\tilde{t}_1}$ under n=1 power-law draw on large soft terms in SUGRA

String landscape also predicts $m_{\tilde{t}_1} \sim 0.2 - 2.6$ TeV, peaked around 1.6 TeV due to the landscape pulls a large A_0 term.

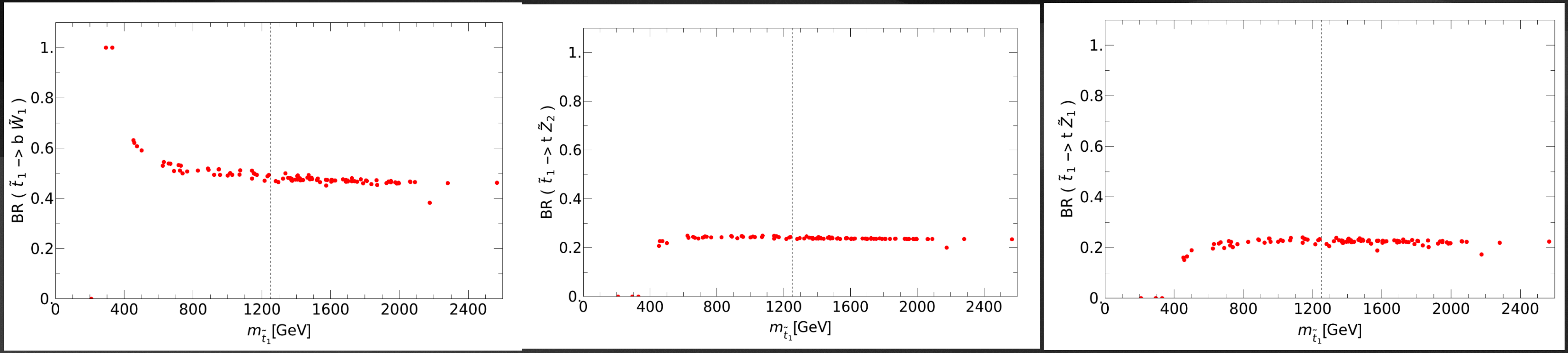
Large A_0 -> maximal stop mixing -> mostly right $\tilde{t}_1$ and $m_h \sim 125$ GeV



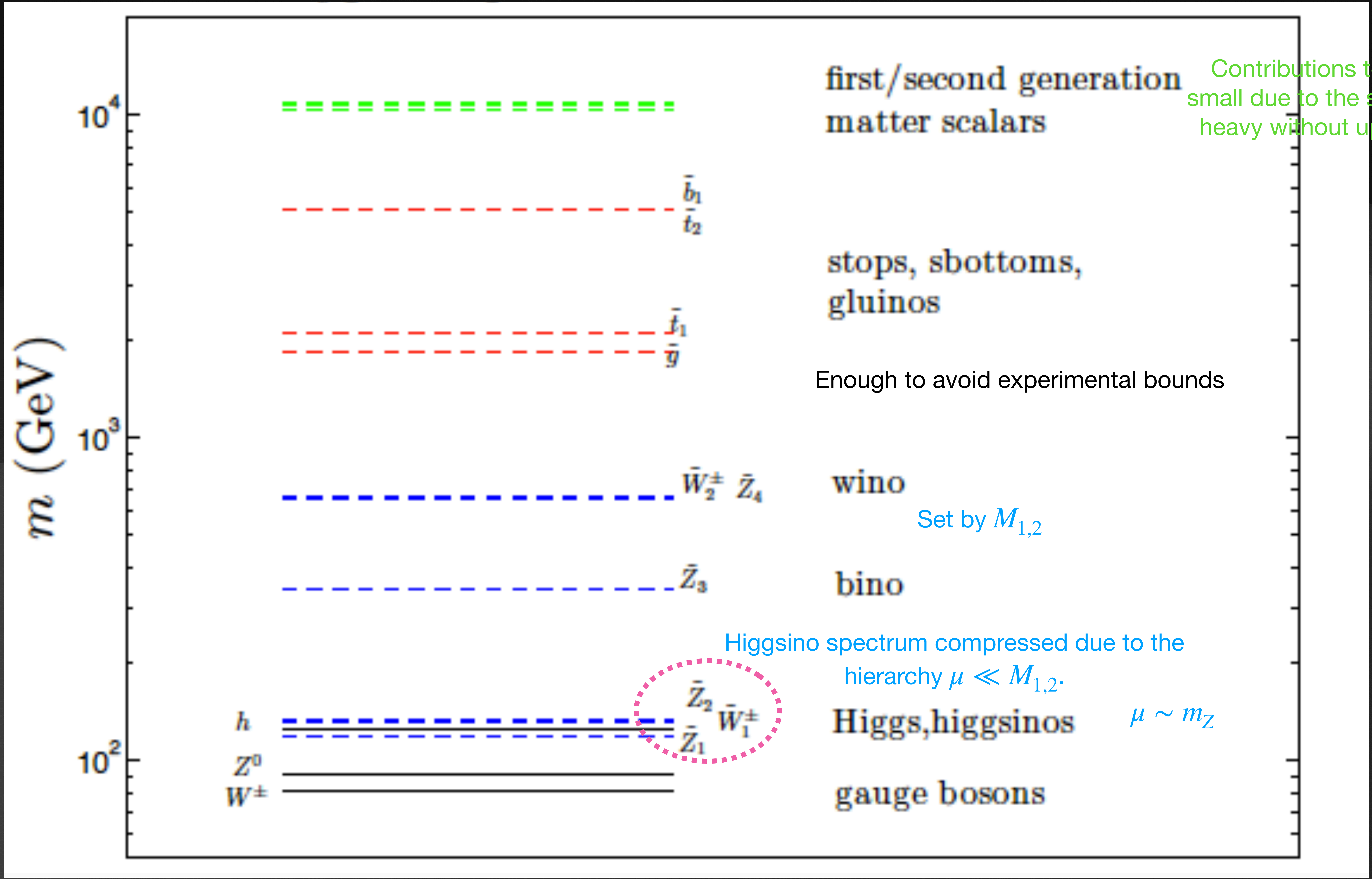
Probability distribution for $m_{\tilde{t}_1}$ vs. $\cos\theta_t$, where $\tilde{t}_1 = \cos\theta_t \tilde{t}_L - \sin\theta_t \tilde{t}_R$,
under n=1 power-law draw to large soft terms predicted by string landscape.

$\tilde{t}_1$ BFs: mostly right -> decouple from winos

BF($\tilde{t}_1 \rightarrow b + \tilde{\chi}_1^+$) : BF($\tilde{t}_1 \rightarrow t + \tilde{\chi}_2^0$): BF($\tilde{t}_1 \rightarrow t + \tilde{\chi}_1^0$) = 2:1:1



Typical spectrum for stringy natural models



Contributions to the weak scale is small due to the small Yukawa, can be heavy without upsetting naturalness

Enough to avoid experimental bounds

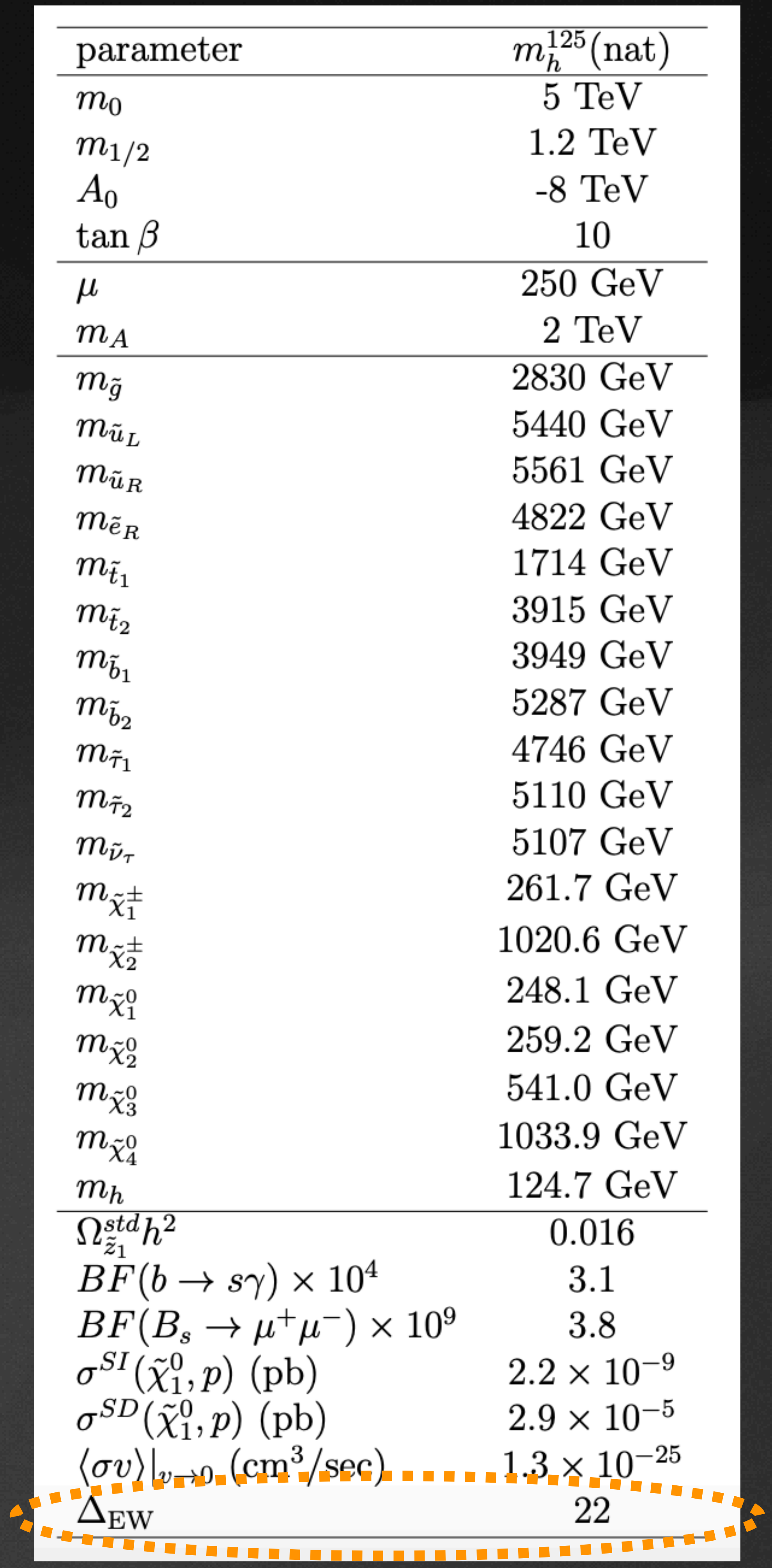
Set by $M_{1,2}$

Higgsino spectrum compressed due to the hierarchy $\mu \ll M_{1,2}$.

$\mu \sim m_Z$

1. Small Δ_{EW}.
2. Soft term being draw to large by power law.
3. But m_{weak} in ABDS window.

Input Parameters and Spectrum for Natural SUSY Search



parameter	m_h^{125}(nat)
m_0	5 TeV
$m_{1/2}$	1.2 TeV
A_0	-8 TeV
$\tan\beta$	10
μ	250 GeV
m_A	2 TeV
$m_{\tilde{g}}$	2830 GeV
$m_{\tilde{u}_L}$	5440 GeV
$m_{\tilde{u}_R}$	5561 GeV
$m_{\tilde{e}_R}$	4822 GeV
$m_{\tilde{t}_1}$	1714 GeV
$m_{\tilde{t}_2}$	3915 GeV
$m_{\tilde{b}_1}$	3949 GeV
$m_{\tilde{b}_2}$	5287 GeV
$m_{\tilde{\tau}_1}$	4746 GeV
$m_{\tilde{\tau}_2}$	5110 GeV
$m_{\tilde{\nu}_\tau}$	5107 GeV
$m_{\tilde{\chi}_1^\pm}$	261.7 GeV
$m_{\tilde{\chi}_2^\pm}$	1020.6 GeV
$m_{\tilde{\chi}_1^0}$	248.1 GeV
$m_{\tilde{\chi}_2^0}$	259.2 GeV
$m_{\tilde{\chi}_3^0}$	541.0 GeV
$m_{\tilde{\chi}_4^0}$	1033.9 GeV
m_h	124.7 GeV
$\Omega_{\tilde{z}_1}^{std}h^2$	0.016
$BF(b \to s\gamma) \times 10^4$	3.1
$BF(B_s \to \mu^+\mu^-) \times 10^9$	3.8
$\sigma^{SI}(\tilde{\chi}_1^0, p)$ (pb)	2.2×10^{-9}
$\sigma^{SD}(\tilde{\chi}_1^0, p)$ (pb)	2.9×10^{-5}
$\langle\sigma v\rangle\|_{v\to 0}$ (cm^3/sec)	1.3×10^{-25}
Δ_{EW}	22

Low fine tuned!

Inputs for NUHM2 model with $m_t = 173.2$ GeV using Isajet 7.88

For the subsequent phenomenological SUSY study, NUHM2 is very convenient for weak scale study. The NUHM2 are fixed by:

$m_0, m_{1/2}, A_0, \tan\beta, \mu, m_A$

For top squark search, vary

- A_0: -7- (-9) TeV

$\Longrightarrow$ $m_{\tilde{t}_1}$: $1 - 2.5$ TeV

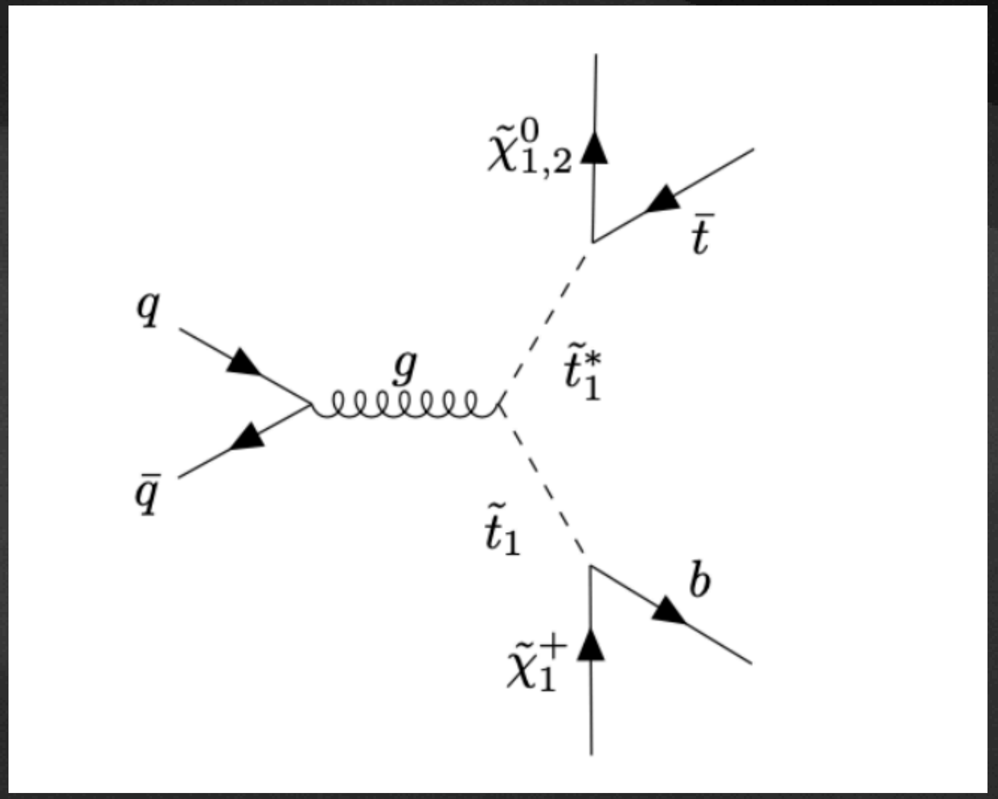
μ fixed to 250 GeV

$\Longrightarrow$ $m_{\tilde{\chi}_{1,2}^0} \sim m_{\tilde{\chi}_1^\pm} \sim 250$ GeV

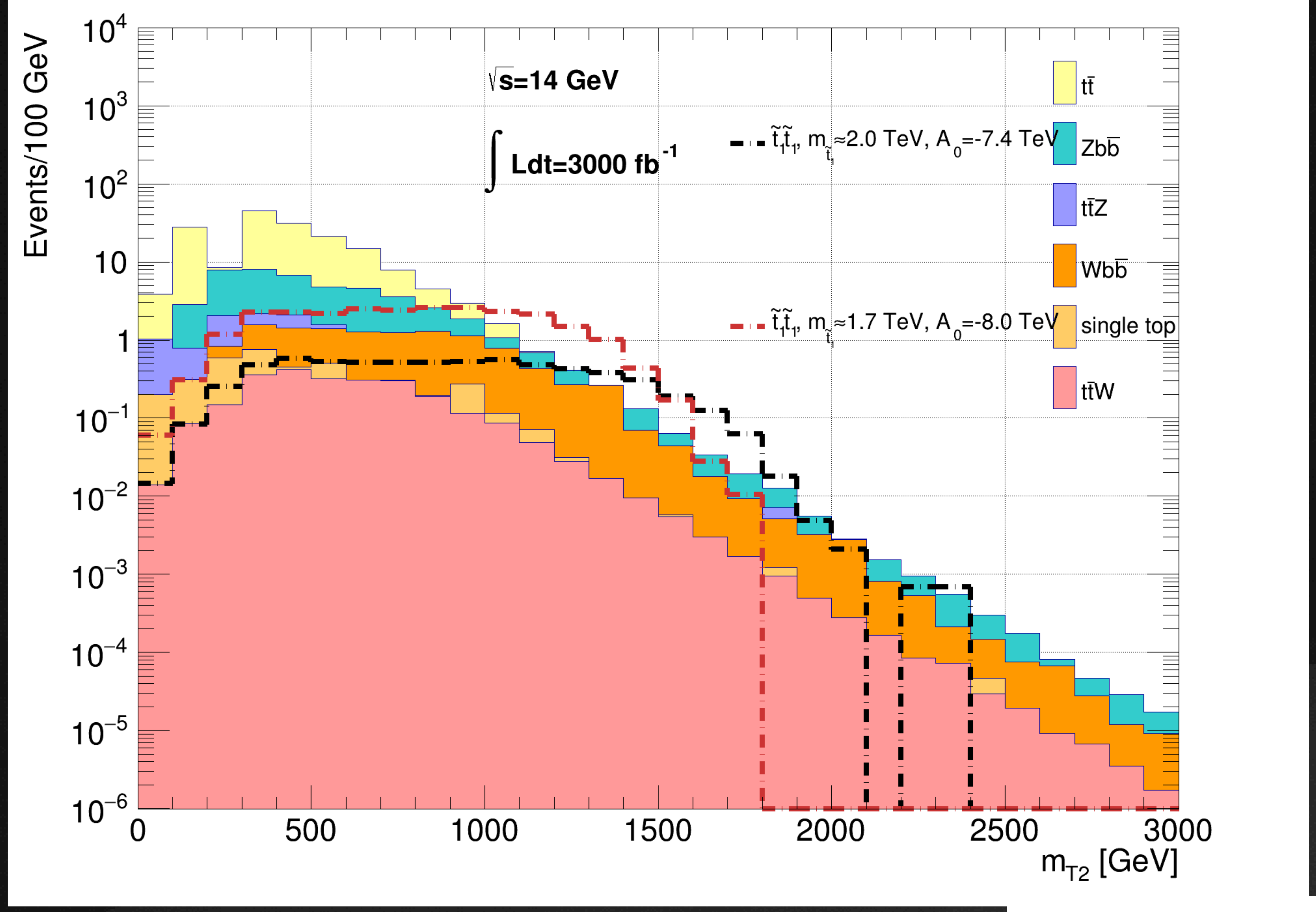
Top Squark Pair Production

$\tilde{t}_1 \rightarrow b + \tilde{\chi}_1^+$ and $\tilde{t}_1 \rightarrow t + \tilde{\chi}_{1,2}^0$

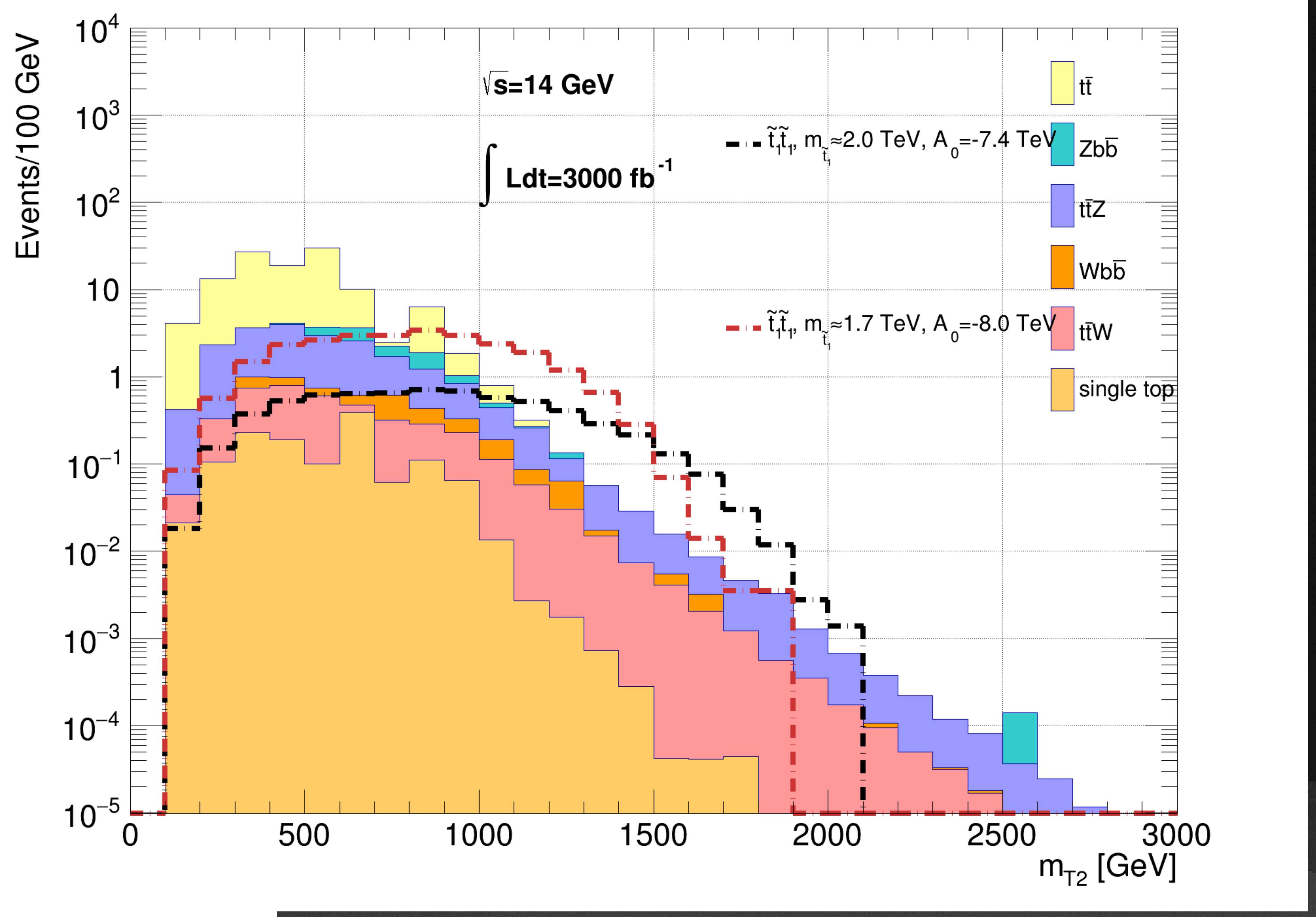
- Natural SUSY favors a specific BFs ratio for $m_{\tilde{t}_1} > 1$ TeV:
  - BF($\tilde{t}_1 \rightarrow b + \tilde{\chi}_1^+$) : BF($\tilde{t}_1 \rightarrow t + \tilde{\chi}_2^0$): BF($\tilde{t}_1 \rightarrow t + \tilde{\chi}_1^0$) = 2:1:1
- 3 Channels we considered:
  - $b\bar{b} + MET$
  - $tb + MET$
  - $t\bar{t} + MET$
- SM backgrounds considered: ttbar, Zbb, Wbb, ttZ, ttW, single top.
- m_{T2} are reconstructed for all channels.
- Kinematics cuts such as MET, angular separations, pT cuts, etc… are then implemented to improve sensitivity.



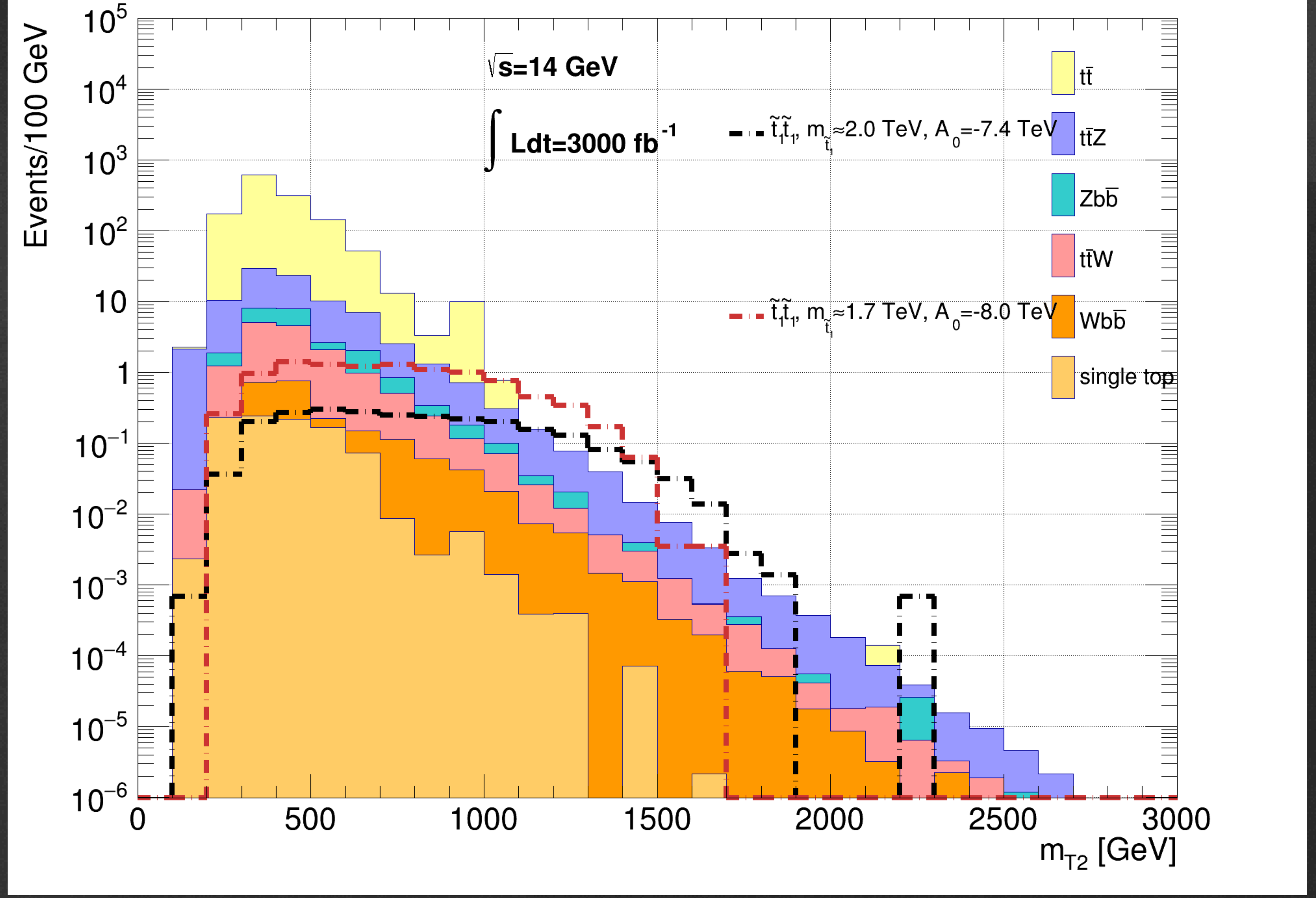
MT2 distribution



$b\bar{b} + MET$

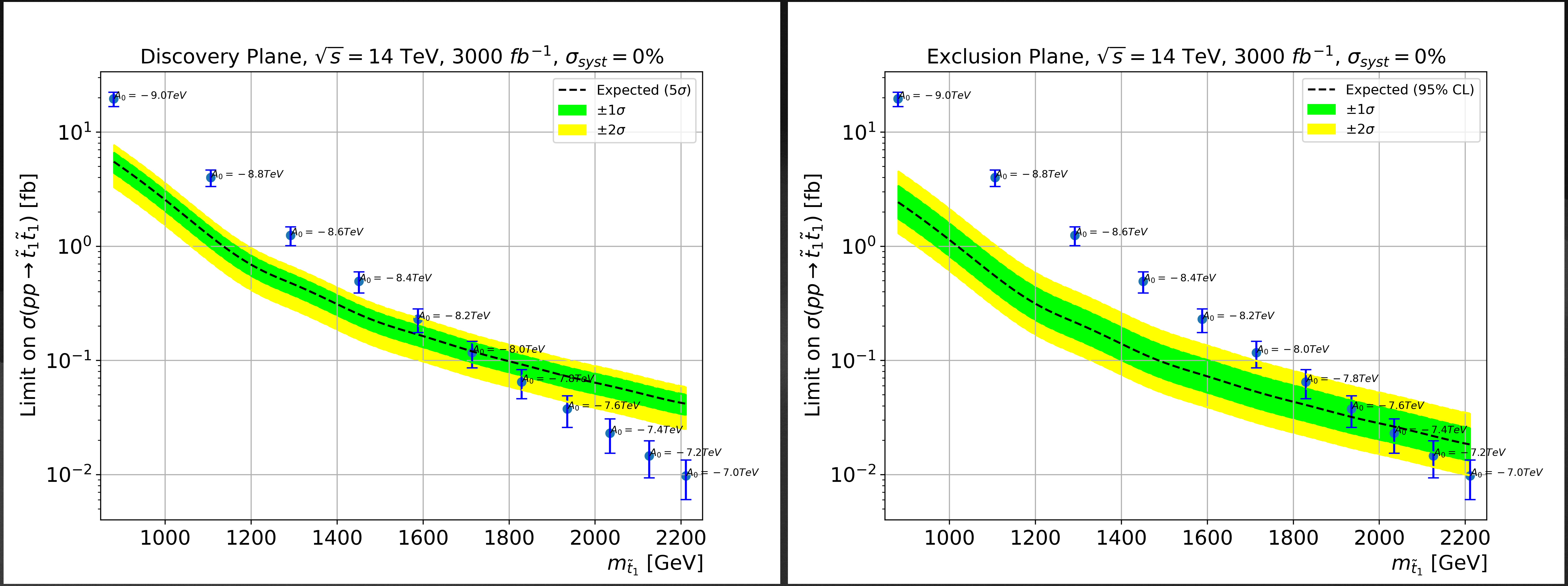


$tb + MET$



$t\bar{t} + MET$

Reach on $\sigma \times BF$ vs. $m_{\tilde{t}_1}$ plane combining all stop channels

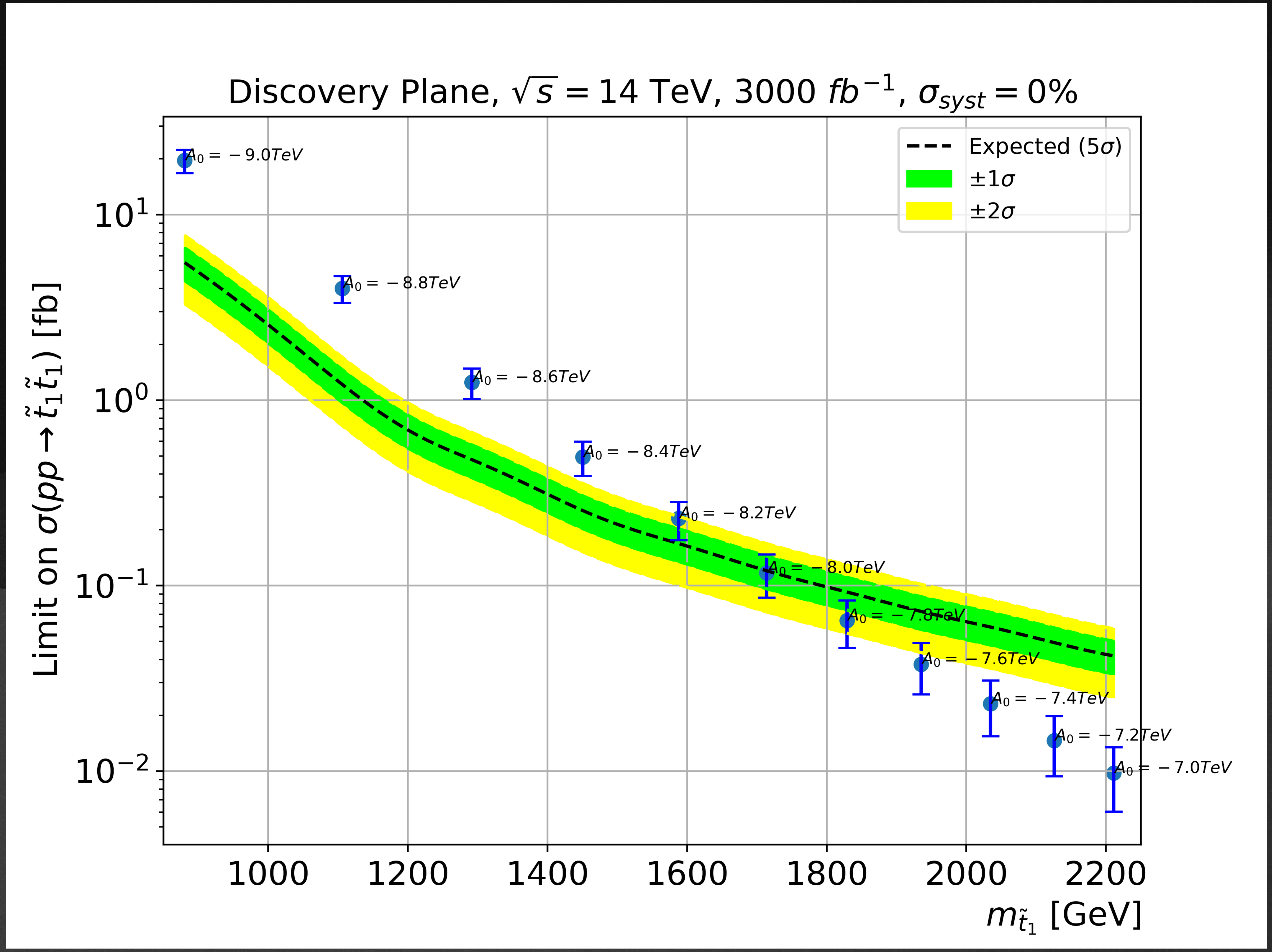


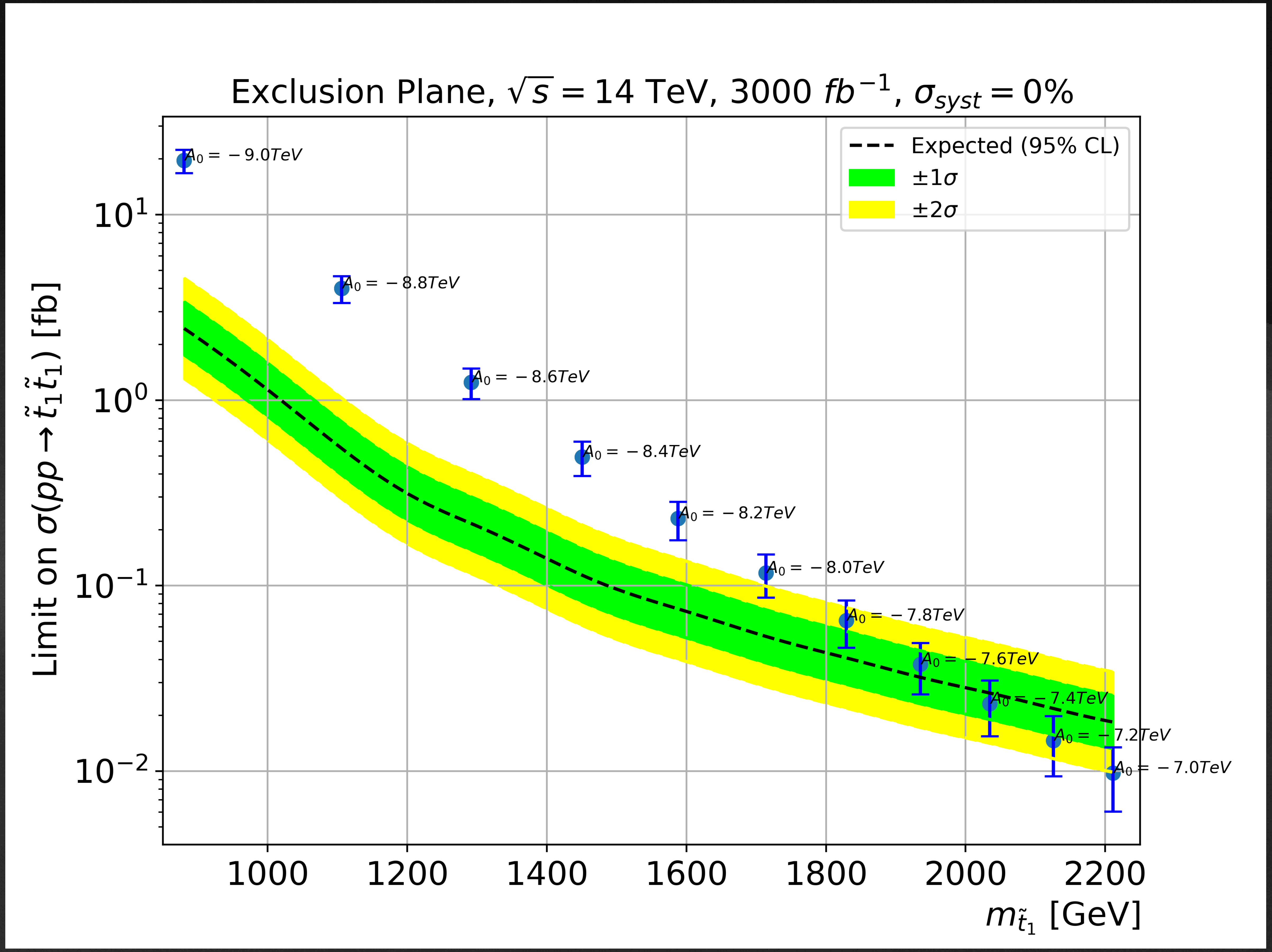
HL-LHC could exclude (discover) reach up to $m_{\tilde{t}_1} \sim 2.0\ (1.7)$ TeV under natural SUSY.

Points are our natural SUSY model lines.
Bar is signal uncertainty*

Taken from https://twiki.cern.ch/twiki/bin/view/LHCPhysics/SUSYCrossSections14TeVstopsbottom.

Reach on $\sigma \times BF$ vs. $m_{\tilde{t}_1}$ plane combining all stop channels

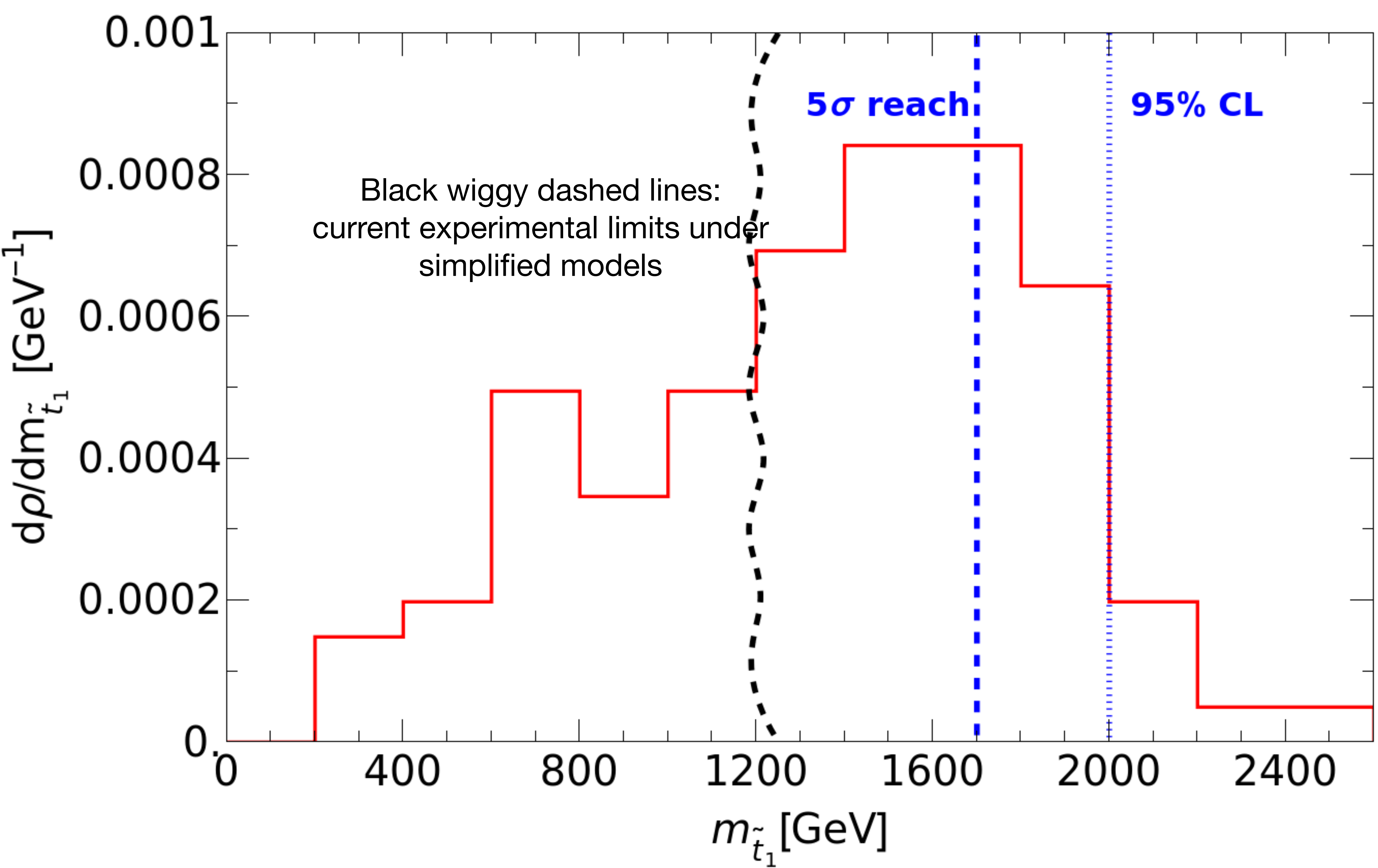




$\tilde{t}_1 \to b + \tilde{\chi}_1^+$

- Experiment searches in ATLAS and CMS usually assume simplified model where BF($\tilde{t}_1 \to t + X$) ~ 100%.
- Our reach can be contrasted with the ATLAS study (ATL-PHYS-PUB-2018- 021 (2018) that out limit is ~200 GeV better even assuming the same systematic uncertainty level.

Prospect of **stringy natural top squark** by the end of HL-LHC



Black wiggy dashed lines:
current experimental limits under
simplified models

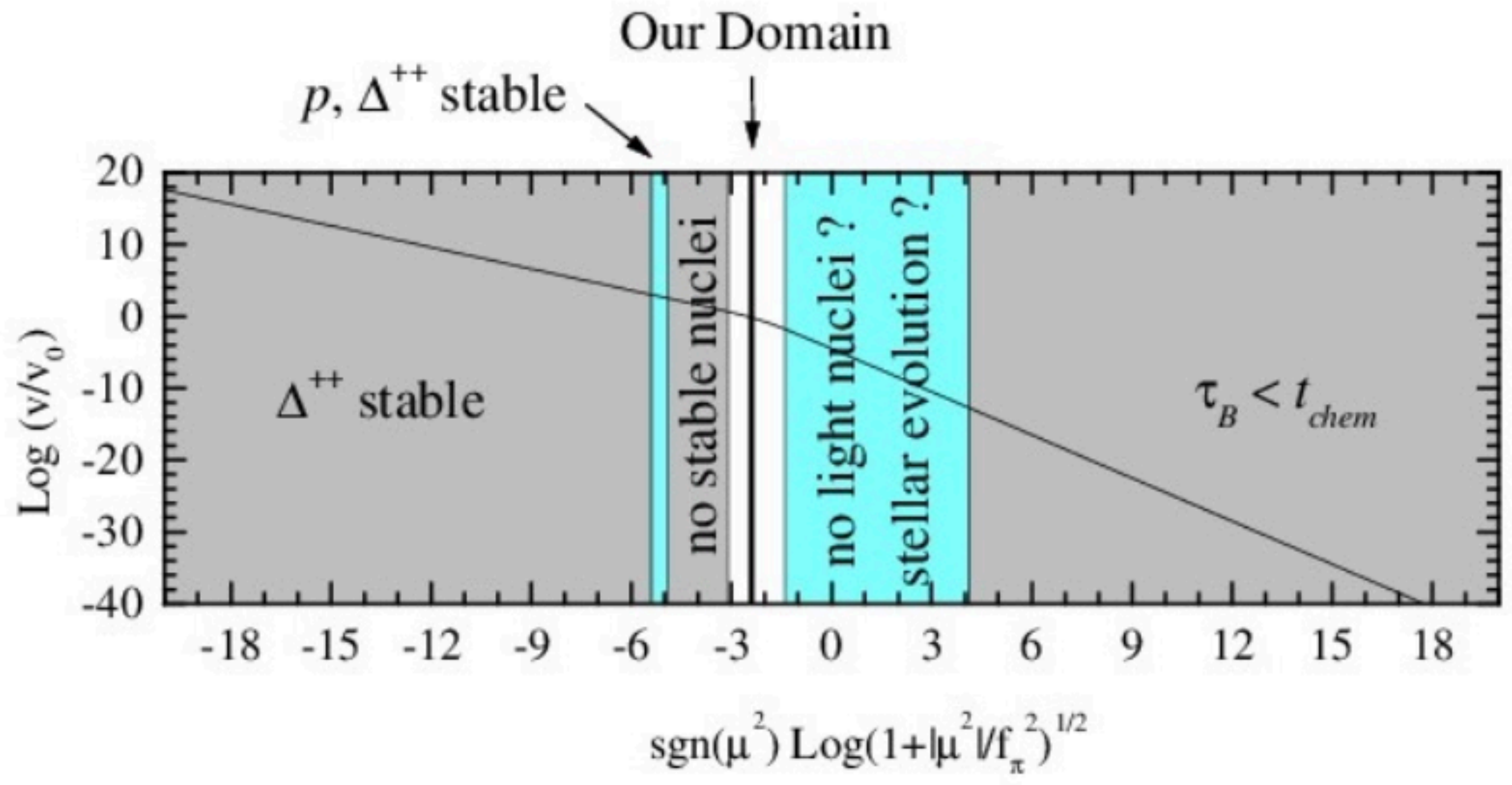
HL-LHC could exclude (discover) reach up to $m_{\tilde{t}_1} \sim 2.0\ (1.7)$ TeV under natural SUSY.

Summary

- Practical naturalness as a guidance to hint new theory.
- Necessary to invoke on model-independent measures of naturalness.
- With the practical naturalness measure Δ_{EW} and statistical view from string landscape, more realistic and robust parameter space in natural SUSY. HL-LHC can start to probe some of the interesting regions.
- Many new and exotic phenomenology under stringy natural SUSY:
  - New search channels.
  - Implies a compressed spectrum of light higgsinos; 2 sigma excess in ATLAS/CMS now.
  - Light higgsino is a NECESSITY of natural SUSY model. They can be generated abundantly in future lepton colliders such as ILC, muon collider, CEPC, and FCC-ee. In turn, this means the natural SUSY is FALSIFIABLE in near future.
  - Specific BF patterns are predicted.
  - Most have been overlooked in the current or previous experimental studies assuming simplified models.

Backup

Agrawal, Barr, Donoghue, Seckel (ABDS) window (1997)

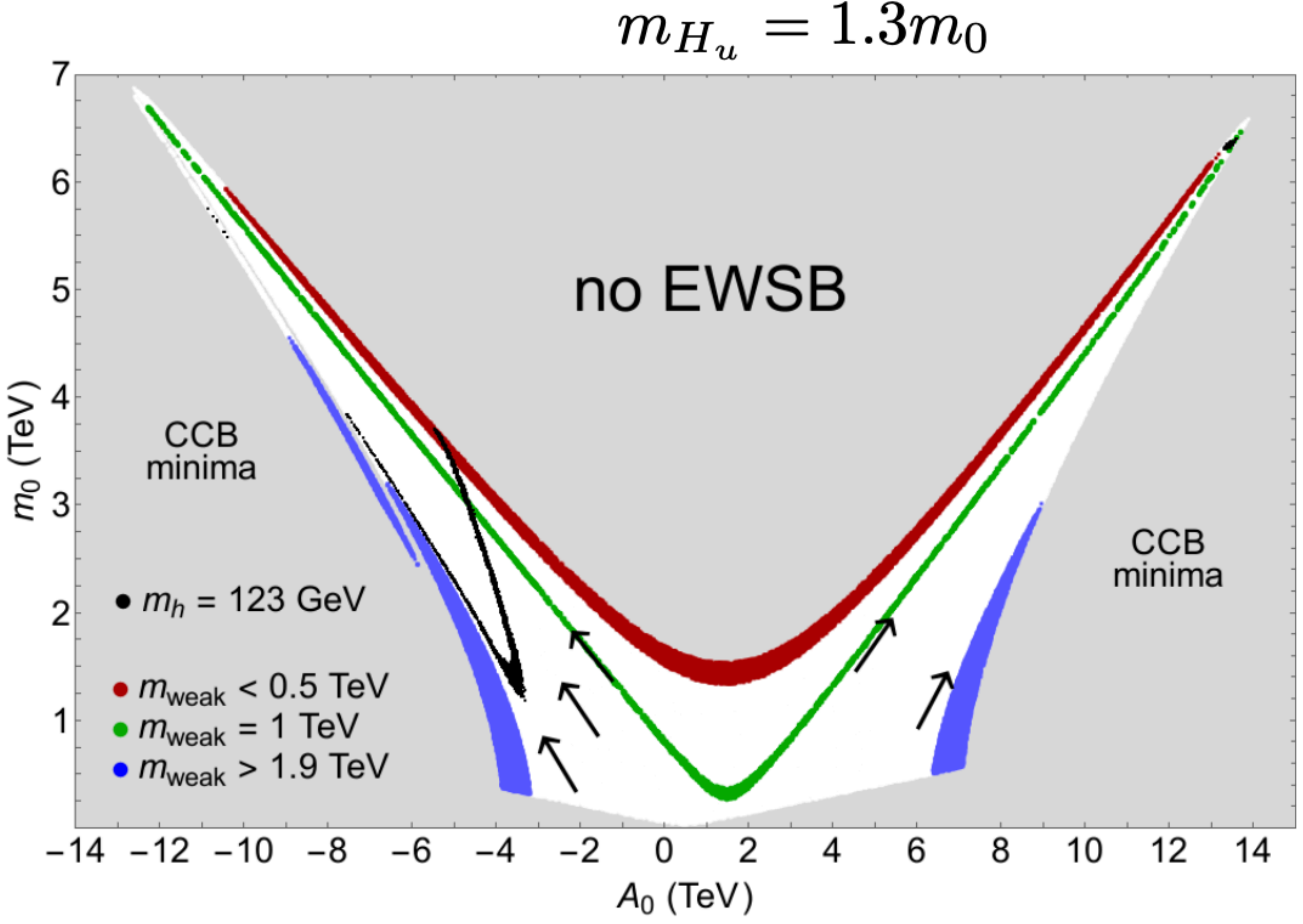


for complex nuclei (hence atoms) to exist (atomic principle/anthropic requirement), then

$$m_{weak}^{OU}/2 <\sim m_{weak}^{PU} <\sim (2-5)m_{weak}^{OU}$$

value of mweak in pocket universe close to the value measured in our universe; otherwise, no atoms as we know them!

ABDS window:
$m^{PU}_{weak} \sim (0.5-5)m^{OU}_{weak}$



statistical draw to large soft terms balanced by anthropic draw toward red (m(weak)~100 GeV): then m(Higgs)~125 GeV and natural SUSY spectrum!

[Baer, Barger, Savoy, Serce, PLB758 (2016) 113]

Why Large Negative A_0?

- In the MSSM, the mass of the light Higgs boson receives most corrections from top and stop:
- $m_h^2 \simeq m_Z^2 \cos^2 2\beta + \frac{3g^2}{8\pi^2}\frac{m_t^4}{m_W^2}\left[\ln\frac{m_{\tilde{t}}^2}{m_t^2} + \frac{x_t^2}{m_{\tilde{t}}^2}\left(1 - \frac{x_t^2}{12m_{\tilde{t}}^2}\right)\right]$, where $x_t = A_t - \mu \cot\beta$
  - For a given $m_{\tilde{t}}$, the maximum value of m_h^2 is achieved when $x_t^{max} = \pm\sqrt{6}m_{\tilde{t}}$.
- For the observed $m_h \sim 125$ GeV, TeV scale top squarks and large mixing (large A_t) is required. Such heavy top squark also avoid problem with $BF(b \to s\gamma)$, which would rule out top squarks in hundred GeV.

Why Large Negative A_0?

In the mean time, Δ_{EW} says

- In the MSSM, the weak scale is set by
- $$\frac{m_Z^2}{2} = \frac{m_{H_d}^2 + \Sigma_d^d - (m_{H_u}^2 + \Sigma_u^u)\tan^2\beta}{\tan^2\beta - 1} - \mu^2 \simeq -m_{H_u}^2 - \Sigma_u^u - \mu^2$$
- Dominant contribution from Σ_u^u again comes from the top squarks': $\Sigma_u^u(\tilde{t}_{1,2})$. Yet a large negative value of A_t diminishes the contributions from both the $\tilde{t}_1$ and $\tilde{t}_2$.

[Baer, Barger, Mustafayev, and Tata(2012)]

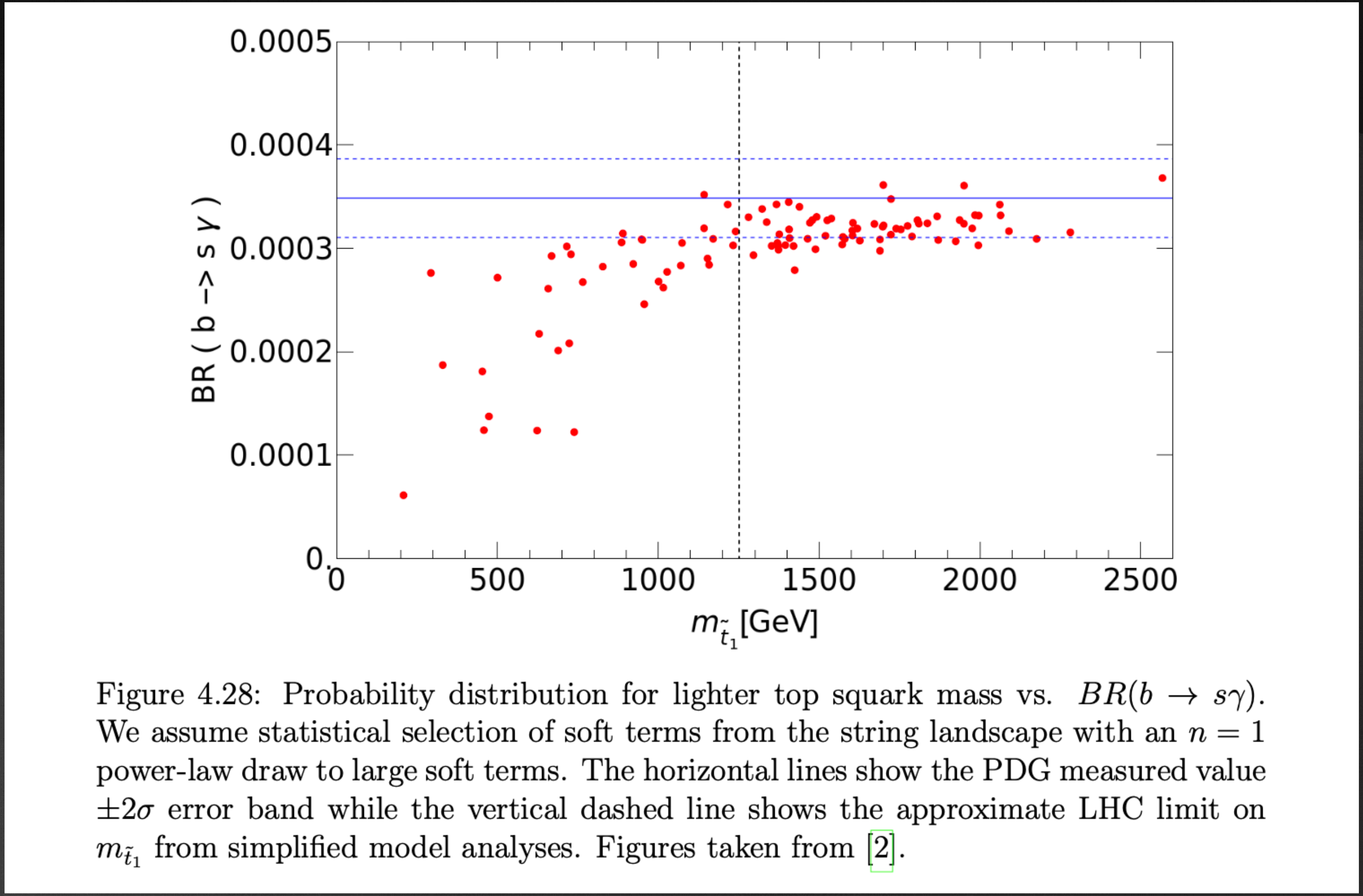
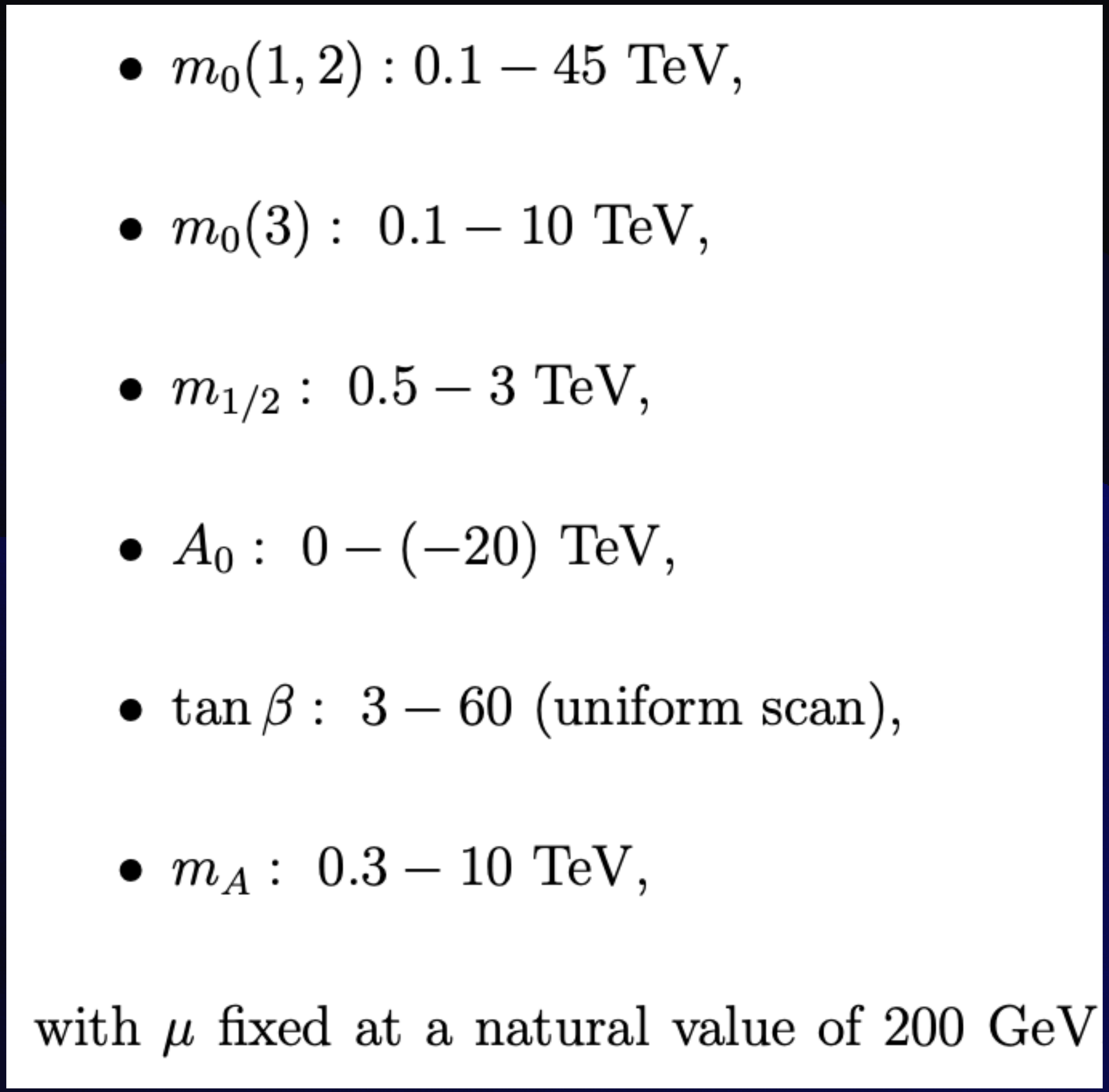
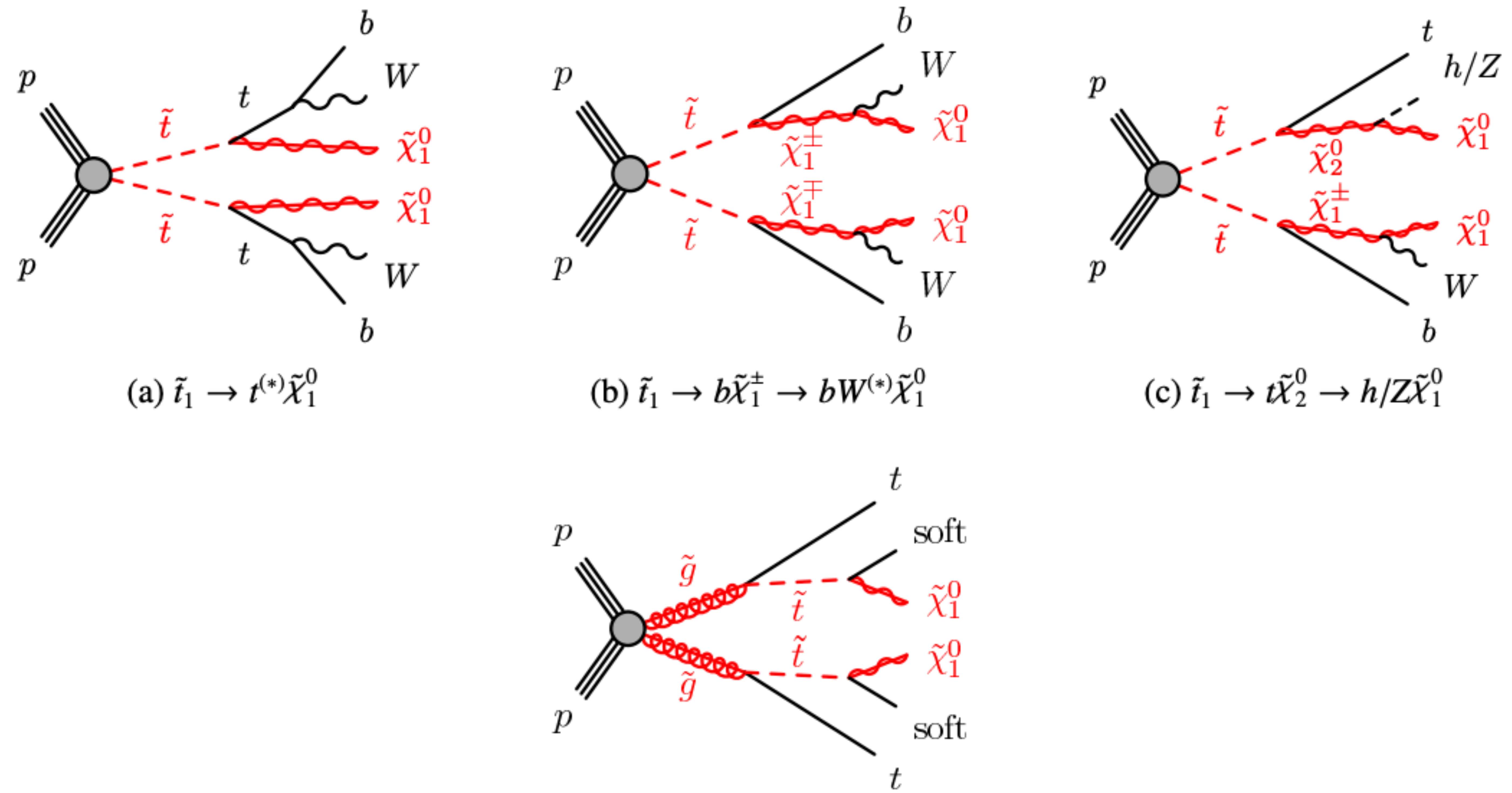


Figure 4.28: Probability distribution for lighter top squark mass vs. $BR(b \to s\gamma)$. We assume statistical selection of soft terms from the string landscape with an $n = 1$ power-law draw to large soft terms. The horizontal lines show the PDG measured value $\pm 2\sigma$ error band while the vertical dashed line shows the approximate LHC limit on $m_{\tilde{t}_1}$ from simplified model analyses. Figures taken from [2].



- $m_0(1,2)$: 0.1 – 45 TeV,
- $m_0(3)$: 0.1 – 10 TeV,
- $m_{1/2}$: 0.5 – 3 TeV,
- A_0 : 0 – (–20) TeV,
- $\tan\beta$: 3 – 60 (uniform scan),
- m_A : 0.3 – 10 TeV,

with μ fixed at a natural value of 200 GeV



(a) $\tilde{t}_1 \to t^{(*)}\tilde{\chi}_1^0$

(b) $\tilde{t}_1 \to b\tilde{\chi}_1^\pm \to bW^{(*)}\tilde{\chi}_1^0$

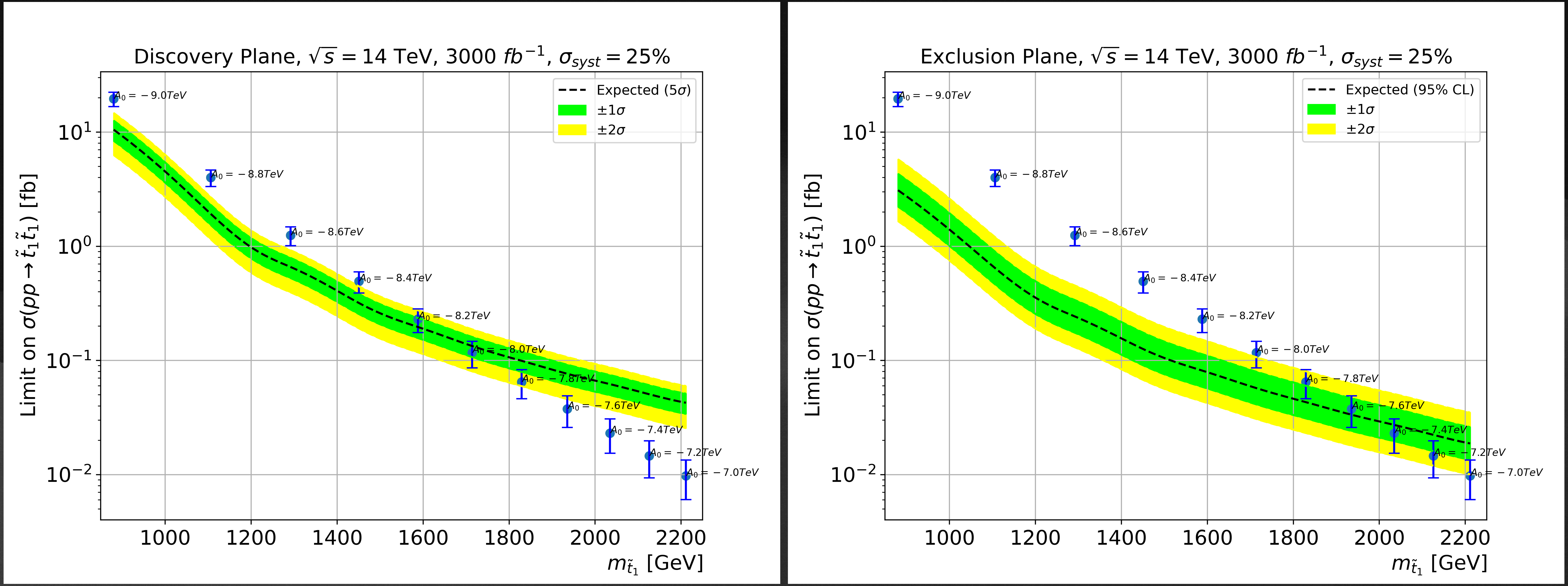
(c) $\tilde{t}_1 \to t\tilde{\chi}_2^0 \to h/Z\tilde{\chi}_1^0$

(d) $\tilde{g} \to t\tilde{t}_1 \to t\tilde{\chi}_1^0$+soft

Figure 1: The decay topologies of the signal models considered with experimental signatures of four or more jets plus missing transverse momentum. Decay products that have transverse momenta below detector thresholds are designated by the term “soft".

[1709.04183]

Reach on $\sigma \times BF$ vs. $m_{\tilde{t}_1}$ plane combining all stop channels



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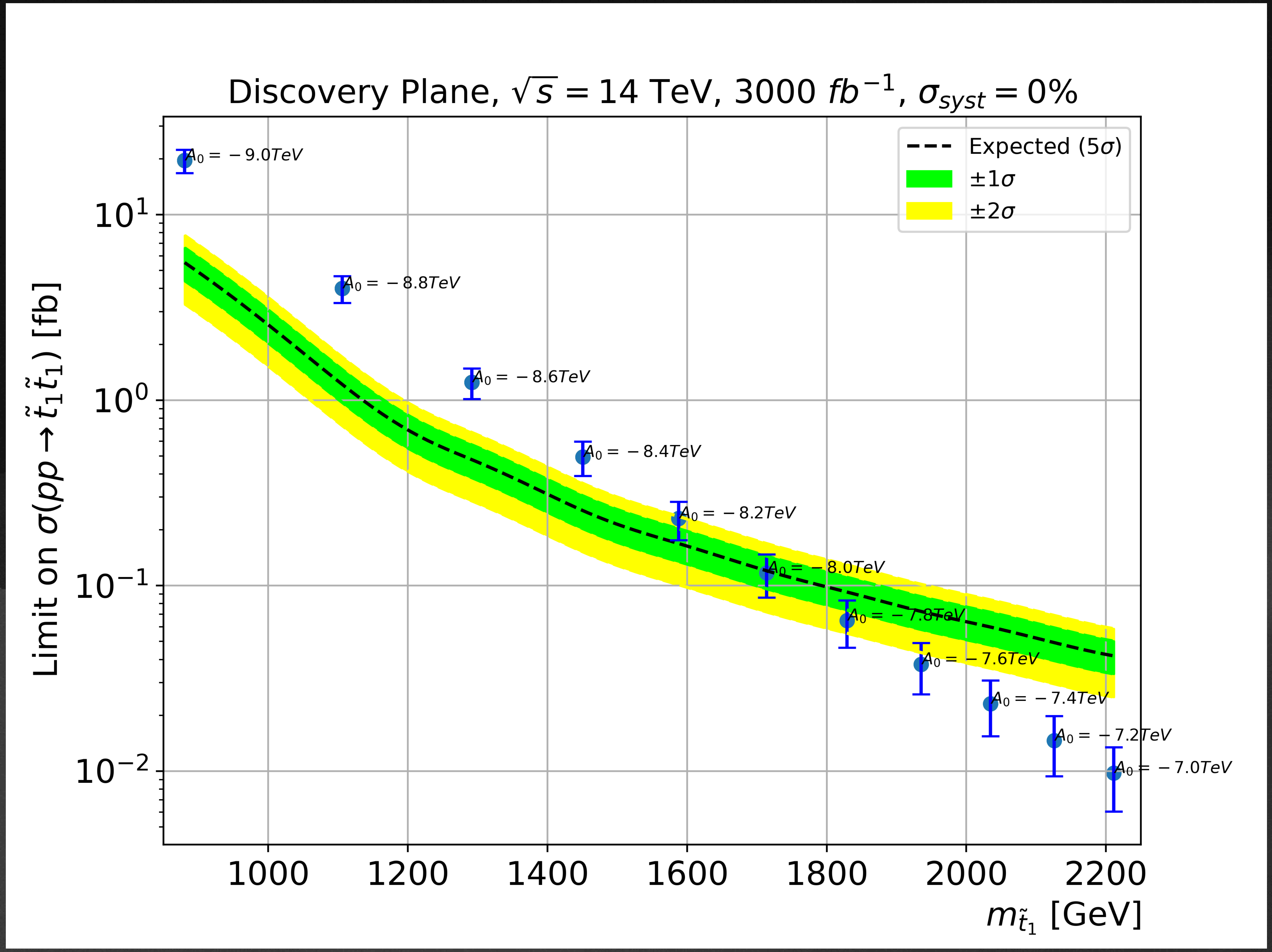
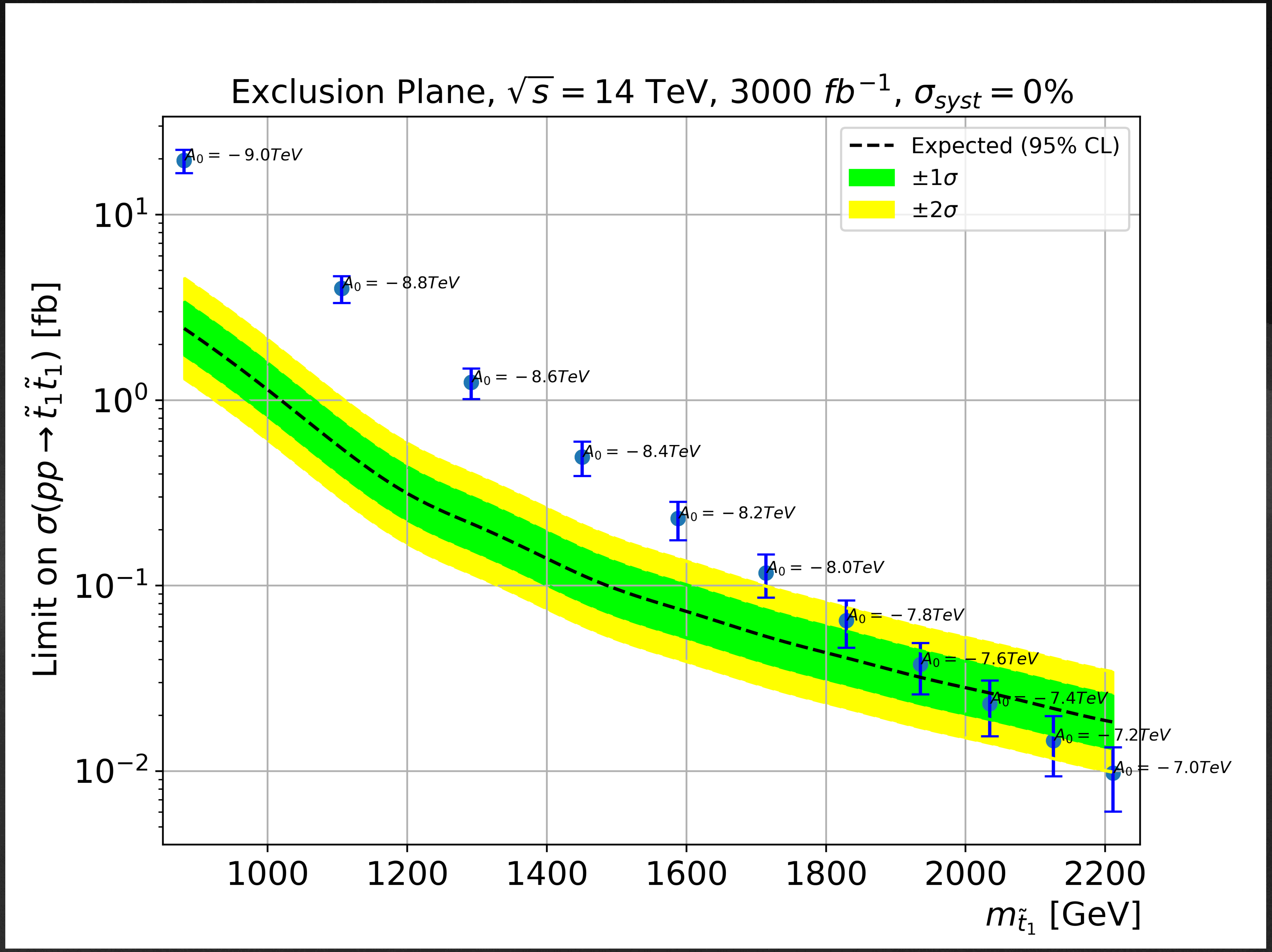
Reach on $\sigma \times BF$ vs. $m_{\tilde{t}_1}$ plane combining all stop channels





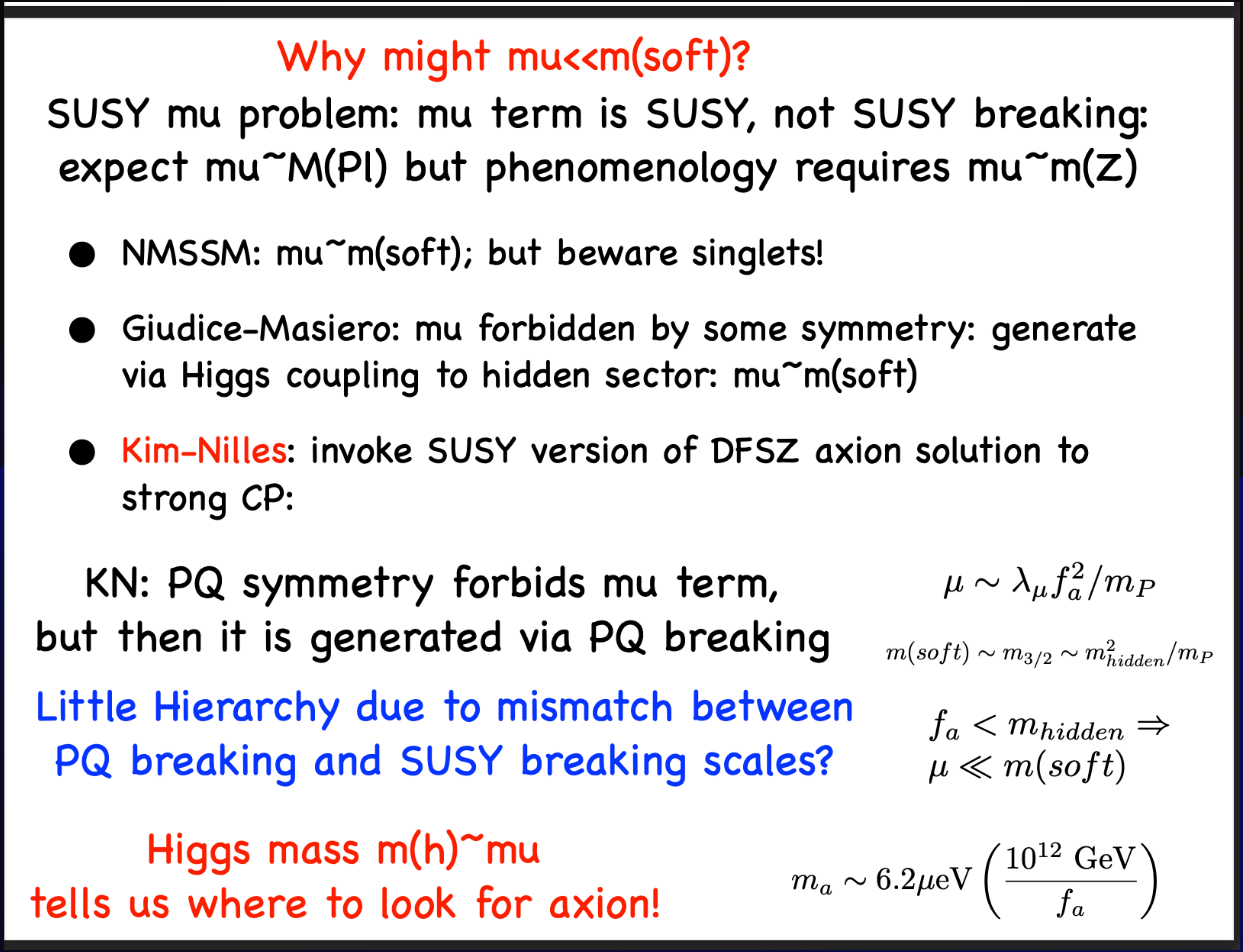
HL-LHC could exclude (discover) reach up to $m_{\tilde{t}_1} \sim 2.0\ (1.7)$ TeV under natural SUSY.

Points are our natural SUSY model lines.
Bar is signal uncertainty*

Taken from https://twiki.cern.ch/twiki/bin/view/LHCPhysics/SUSYCrossSections14TeVstopsbottom.

In DFSZ axion model, the PQ field and the Higgs field interact via a potential that has the same form as the μ term.

It could be that the PQ symmetry prevents a μ term in the Lagrangian and an effective μ term can only be generated after the PQ symmetry breaking.



Why might mu<<m(soft)?

SUSY mu problem: mu term is SUSY, not SUSY breaking: expect mu~M(Pl) but phenomenology requires mu~m(Z)

- NMSSM: mu~m(soft); but beware singlets!
- Giudice-Masiero: mu forbidden by some symmetry: generate via Higgs coupling to hidden sector: mu~m(soft)
- Kim-Nilles: invoke SUSY version of DFSZ axion solution to strong CP:

KN: PQ symmetry forbids mu term, but then it is generated via PQ breaking

$$\mu \sim \lambda_\mu f_a^2/m_P$$

$$m(soft) \sim m_{3/2} \sim m_{hidden}^2/m_P$$

Little Hierarchy due to mismatch between PQ breaking and SUSY breaking scales?

$$f_a < m_{hidden} \Rightarrow$$
$$\mu \ll m(soft)$$

Higgs mass m(h)~mu
tells us where to look for axion!

$$m_a \sim 6.2\mu\text{eV}\left(\frac{10^{12}\ \text{GeV}}{f_a}\right)$$

Why μ term small?

Since μ is SUSY preserving, in principle, it can pick any value from weak scale to the Planck scale.

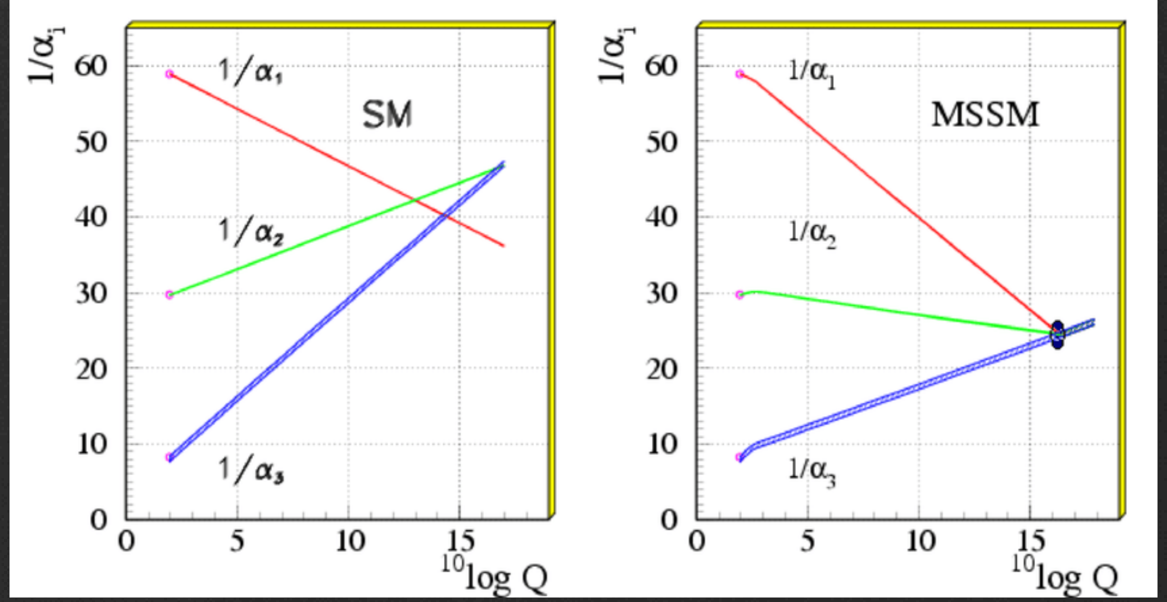
- NMSSM?
- Giudice-Masiero: restricted by some symmetries, doesn't show up in the tree level, generated via hidden sector during SUSY breaking:
  - $\mu \sim m_{soft}$
- Kim-Nilles: SUSY version of DFSZ axion solution to strong CP. μ is restricted by PQ symmetry and is only generated via PQ symmetry breaking:
  - $\mu \sim f_a^2/m_{Planck}$
  - $f_a < m_{hidden} \implies \mu < m_{soft}$

Statistical significance

- To construct the significance, likelihood method is used.
  - Likelihood function is built as the product of Poissonian terms for each bin in the kinematics distribution.
  - Ratio of likelihood for two competing hypothesis is used as the test statistics $\lambda(\mu)$. μ is signal strength in the null hypothesis. $\mu = 0$ for discovery sensitivity. $\mu = 1$ for exclusion sensitivity.
    - $$\lambda(0) = \prod_{i \in \text{bins, channels}} \frac{\frac{e^{-b_i}}{(s_i+b_i)!} b_i^{(s_i+b_i)}}{\frac{e^{-(s_i+b_i)}}{(s_i+b_i)!} (s_i+b_i)^{(s_i+b_i)}}, \quad \text{(Discovery)}$$
    - $$\lambda(1) = \prod_{i \in \text{bins, channels}} \frac{\frac{e^{-(s_i+b_i)}}{b_i!} (s_i+b_i)^{b_i}}{\frac{e^{-b_i}}{b_i!} b_i^{b_i}}. \quad \text{(Exclusion)}$$
- Statistics significance and confidence level are then extracted from these test statistics following Wilks' theorem with certain assumptions.
- Signal discovery is set to correspond to 5σ. Signal exclusion is set to 95% CLs

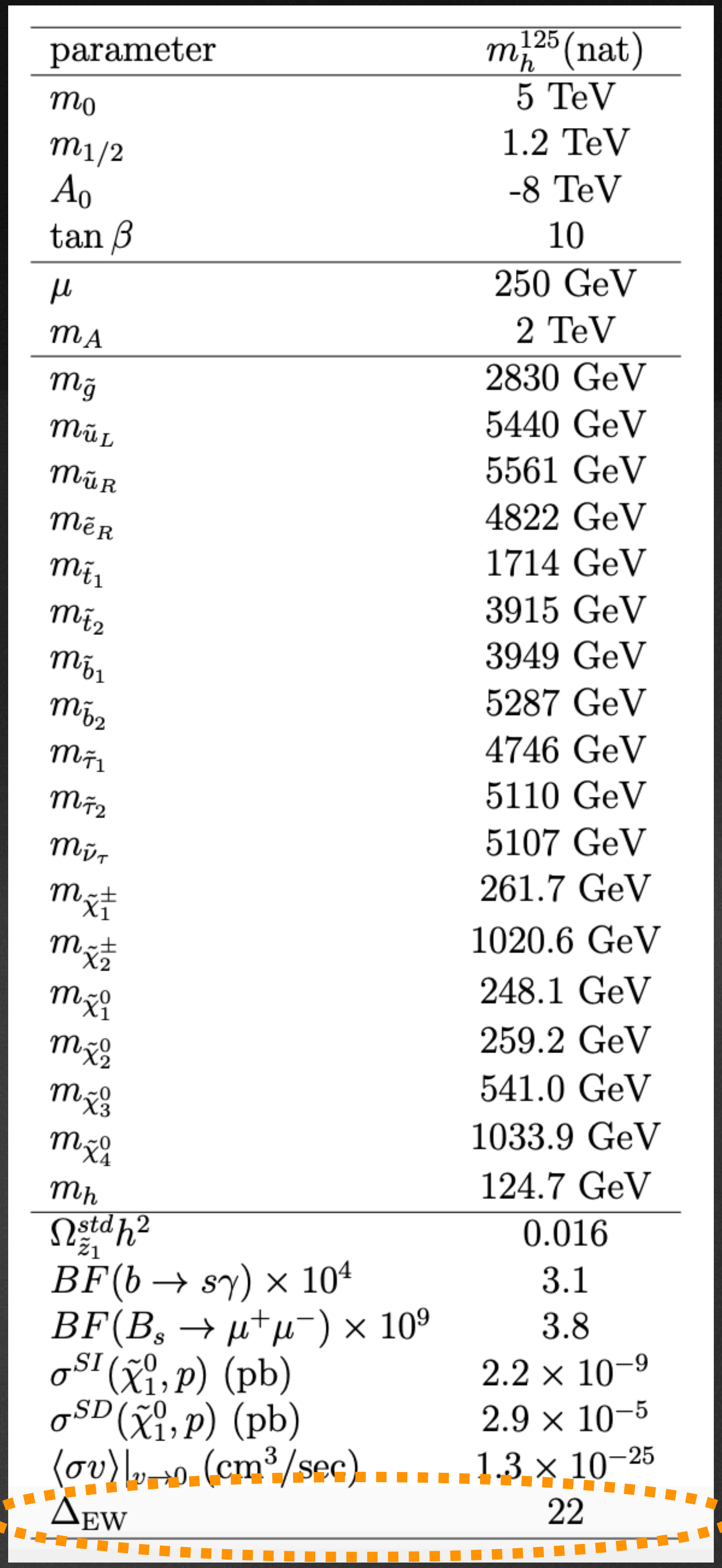
Minimal Supersymmetric Standard Model (MSSM)

- Minimal possible extension of the SM:
  - Each SM gauge boson together with their fermionic superpartner — gaugino.
  - Each SM fermion together with their scalar superpartner — sfermion.
  - *Two* Higgs doublets H_u and H_d together with their fermion superpartner — higgsino. Two are required because a lone higgsino leaves the gauge anomaly uncanceled.
- Theoretical indications:
  - Simplest possible.
  - Gauge couplings unification:



  - Higgs boson we observed $m_h = 125$ GeV. Unitarity bound only says $m_h < 1$ TeV, but MSSM says $m_h < 135$ GeV. MSSM Tree level relation $m_h \leq m_Z \cos 2\beta$ can only be broken by radiative correction.

Input Parameters and Spectrum for Natural SUSY Search



parameter	m_h^{125}(nat)
m_0	5 TeV
$m_{1/2}$	1.2 TeV
A_0	-8 TeV
$\tan\beta$	10
μ	250 GeV
m_A	2 TeV
$m_{\tilde{g}}$	2830 GeV
$m_{\tilde{u}_L}$	5440 GeV
$m_{\tilde{u}_R}$	5561 GeV
$m_{\tilde{e}_R}$	4822 GeV
$m_{\tilde{t}_1}$	1714 GeV
$m_{\tilde{t}_2}$	3915 GeV
$m_{\tilde{b}_1}$	3949 GeV
$m_{\tilde{b}_2}$	5287 GeV
$m_{\tilde{\tau}_1}$	4746 GeV
$m_{\tilde{\tau}_2}$	5110 GeV
$m_{\tilde{\nu}_\tau}$	5107 GeV
$m_{\tilde{\chi}_1^\pm}$	261.7 GeV
$m_{\tilde{\chi}_2^\pm}$	1020.6 GeV
$m_{\tilde{\chi}_1^0}$	248.1 GeV
$m_{\tilde{\chi}_2^0}$	259.2 GeV
$m_{\tilde{\chi}_3^0}$	541.0 GeV
$m_{\tilde{\chi}_4^0}$	1033.9 GeV
m_h	124.7 GeV
$\Omega_{\tilde{z}_1}^{std}h^2$	0.016
$BF(b \to s\gamma) \times 10^4$	3.1
$BF(B_s \to \mu^+\mu^-) \times 10^9$	3.8
$\sigma^{SI}(\tilde{\chi}_1^0, p)$ (pb)	2.2×10^{-9}
$\sigma^{SD}(\tilde{\chi}_1^0, p)$ (pb)	2.9×10^{-5}
$\langle\sigma v\rangle\|_{v\to 0}$ (cm^3/sec)	1.3×10^{-25}
$\Delta_{\rm EW}$	22

Low fine tuned!

Inputs for NUHM2 model with $m_t = 173.2$ GeV using Isajet 7.88

For the subsequent phenomenological SUSY study, NUHM2 is very convenient (mSUGRA but allows m_{H_u} and m_{H_d} to be non-universal, which two are then traded for m_A and μ for weak scale study). The parameters of NUHM2 are thus specified by:

$m_0, m_{1/2}, A_0, \tan\beta, \mu, m_A$