

The Galileo Galilei Institute for Theoretical Physics
Arcetri, Florence

Exploring the energy frontier with muon beams

Jun 30, 2025 - Aug 01, 2025

In this workshop we will explore the opportunities unleashed by progress in muon-based experiments, with particular focus on a multi-TeV muon collider. We will discuss both Standard Model precision physics and the search for new phenomena at the highest possible accelerator energies.

Muon beams up to multi-TeV energies hold the potential to revolutionize the exploration of the high-energy frontier. At the same time, they require the development of new methods and tools in particle theory as well as in collider experiments and accelerator physics. Our workshop will bring together experts, and early career scientists from these communities and will provide the setting to weave together the strategy to get to the next new kind of particle collider. In addition the workshop will serve as a platform to develop possible synergies between all the communities potentially interested in muon beams, and in the technologies that are necessary to develop them.

A muon collider requires an intense proton beam that produces similarly intense hadron, muon, and neutrino beams; we will discuss how those beams can enable exploration of the lepton and neutrino sector, as well as dark matter and dark sectors and other investigations at the intensity frontier. During the workshop we will organize several pedagogical activities aimed at increasing the awareness and competence in the high energy physics theoretical community on the exciting possibilities enabled by progress expected in muon beams and collider technologies. We will also organize small groups focused on further developing key tools needed for muon collider R&D.

Topics:

- Week-1 Training Week: Introduction To Muon Beams And Applications
- Week-2 Focus Week: Precision Physics (SM)
- Week-3 Focus Week: New Physics (BSM)
- Synergy Week: Physics With Muon Beams
- Public Conference: "Physics At The Highest Energies With Colliders"

with the support of
SIM NS FOUNDATION

Training Week (Jun 30, 2025 - Jul 04, 2025)
Conference (Jul 28, 2025 - Aug 01, 2025)
Deadline for applications: Feb14, 2025

SUSY beyond the TeV scale

Giovanni Villadoro



The Abdus Salam
International Centre
for Theoretical Physics

based on:

Arvanitaki, Craig, Dimopoulos and GV – ‘12
 Pardo Vega and GV – ‘15
 Chen, Redigolo, GV – *work in progress*

Supersymmetry

$$|\text{boson}\rangle \quad \leftrightarrow \quad |\text{fermion}\rangle$$

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$$\begin{array}{ccc} \text{Poincar\'e} & \rightarrow & \text{SUSY} \\ \mathcal{P} & & \mathcal{S} \end{array} \quad \left\{ \begin{array}{l} [\mathcal{P}, \mathcal{P}] = \mathcal{P} \\ [\mathcal{P}, \mathcal{S}] = \mathcal{S} \\ \{\mathcal{S}, \mathcal{S}\} = \mathcal{P} \end{array} \right.$$

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Important Feature of Quantum Gravity
→ Supergravity / String Theory

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Important Feature of Quantum Gravity
→ Supergravity / String Theory

$$\mathcal{P}|0\rangle = 0 \quad \mathcal{S}|0\rangle \neq 0$$

SUSY breaking scale?

Supersymmetry

Historical motivations for low-energy SUSY:

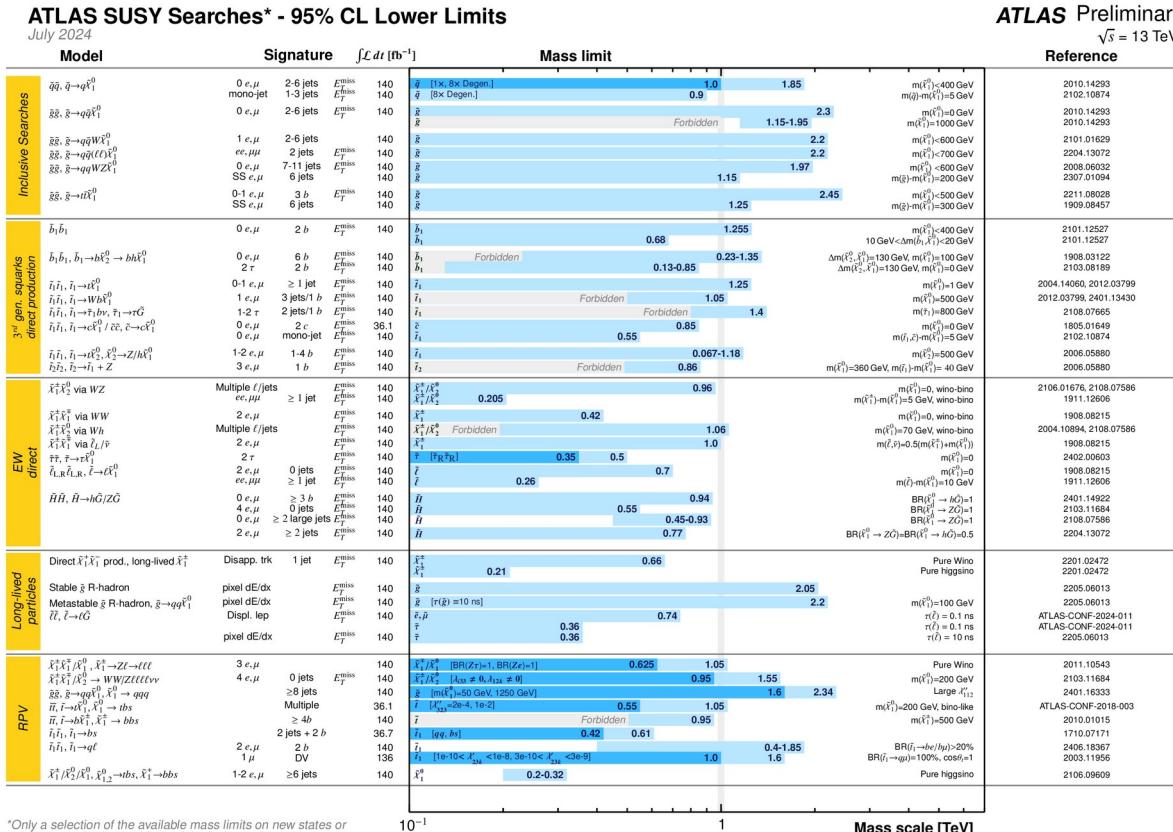
- Hierarchy Problem
- WIMP Miracle
- Grand Unification

1. Hierarchy Problem

$$\delta m_Z^2 \sim m_{\text{SUSY}}^2$$

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1. Hierarchy Problem

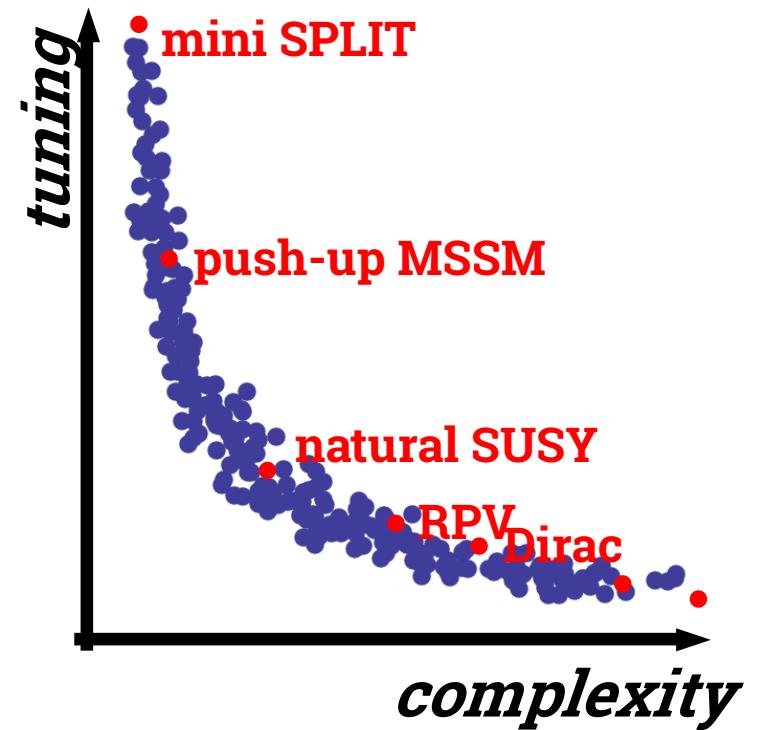
$$\delta m_Z^2 \sim m_{\text{SUSY}}^2 \sim 10^2 m_Z^2 \left(\frac{m_{\text{SUSY}}}{\text{TeV}} \right)^2$$

ATLAS SUSY Searches* - 95% CL Lower Limits
July 2024

Model	Signature	$\int \mathcal{L} dt [\text{fb}^{-1}]$	Mass limit	ATLAS Preliminary $\sqrt{s} = 13 \text{ TeV}$	Reference
Inclusive Searches	$q\bar{q} \rightarrow q\tilde{\chi}_1^0$ mono-jet	0 e, μ 1-3 jets	E_{miss} 140	$\tilde{\chi}_1^0$ [1x, 8x Degen.] $\tilde{\chi}_1^0$ [8x Degen.]	1.0 0.9
	$q\bar{q}, \tilde{g} \rightarrow q\tilde{\chi}_1^0$	0 e, μ 2-6 jets	E_{miss} E_T	\tilde{g} \tilde{g}	1.85 2.3
	$g\bar{g}, \tilde{g} \rightarrow q\tilde{W}\tilde{L}_1^0$	1 e, μ $ee, \mu\mu$	2-6 jets	\tilde{g} \tilde{g}	1.15-1.95 2.2 2.2
	$g\bar{g}, \tilde{g} \rightarrow q\tilde{q} W Z \tilde{L}_1^0$	0 e, μ SS e, μ	7-11 jets	\tilde{g} \tilde{g}	1.97 1.15
	$g\bar{g}, \tilde{g} \rightarrow t\tilde{t}\tilde{\chi}_1^0$	0-1 e, μ SS e, μ	3 jets	\tilde{g} \tilde{g}	2.45 1.25
	$t\bar{t}, b\bar{b} \rightarrow q\tilde{\chi}_1^0$	0 e, μ	2 jets	\tilde{b}_1 \tilde{b}_1	1.25
	$t\bar{t}, b\bar{b} \rightarrow b\tilde{b}\tilde{\chi}_1^0$	0 e, μ 2 τ	6 jets	\tilde{b}_1 \tilde{b}_1	0.68 0.13-0.85
	$t\bar{t}, \tilde{t}_1 \rightarrow t\tilde{\chi}_1^0$	0-1 e, μ	≥ 1 jet	\tilde{t}_1	2.3-1.35
	$t\bar{t}, \tilde{t}_1 \rightarrow W\tilde{L}_1^0$	1 e, μ	3 jets/1 b	\tilde{t}_1	1.25
	$t\bar{t}, \tilde{t}_1 \rightarrow t\tilde{b}, \tilde{b} \rightarrow t\tilde{G}$	1-2 τ	2 jets/1 b	\tilde{t}_1	1.05
3 rd gen. squarks direct production	$\tilde{t}_1 \tilde{t}_1 \rightarrow t\tilde{\chi}_1^0 / \tilde{c}\tilde{c}, \tilde{c} \rightarrow c\tilde{\chi}_1^0$	0 e, μ	2 c	\tilde{t}_1	1.4
	$\tilde{t}_1 \tilde{t}_1 \rightarrow t\tilde{\chi}_1^0 / \tilde{c}\tilde{c}, \tilde{c} \rightarrow c\tilde{\chi}_1^0$	0 e, μ	mono-jet	\tilde{t}_1	0.85
	$\tilde{t}_1 \tilde{t}_1 \rightarrow t\tilde{\chi}_1^0, \tilde{g}_2^0 \rightarrow Z/h\tilde{\chi}_1^0$	1-2 e, μ	1-4 jets	\tilde{t}_1	0.067-1.18
	$\tilde{t}_1 \tilde{t}_1 \rightarrow t\tilde{\chi}_1^0, \tilde{g}_2^0 \rightarrow Z/h\tilde{\chi}_1^0$	3 e, μ	1 b	\tilde{t}_2	0.86
	$\tilde{t}_1 \tilde{t}_1 \rightarrow t\tilde{\chi}_1^0 + Z$				
	$\tilde{\chi}_1^0 \tilde{\chi}_2^0$ via WZ	Multiple ℓ/ℓ jets	E_{miss} E_T	$\tilde{\chi}_1^0 / \tilde{\chi}_2^0$	0.96
	$\tilde{\chi}_1^0 \tilde{\chi}_2^0$ via WW	2 e, μ	E_{miss}	$\tilde{\chi}_1^0 / \tilde{\chi}_2^0$	0.205
	$\tilde{\chi}_1^0 \tilde{\chi}_2^0$ via Wh	Multiple ℓ/ℓ jets	E_{miss}	$\tilde{\chi}_1^0 / \tilde{\chi}_2^0$	0.42
	$\tilde{\chi}_1^0 \tilde{\chi}_2^0$ via $\tilde{t}_1 \tilde{t}_2$	2 e, μ	E_{miss}	$\tilde{\chi}_1^0 / \tilde{\chi}_2^0$	1.06
	$t\bar{t}, \tilde{t}_1 \tilde{t}_2 \rightarrow t\tilde{\chi}_1^0 / \tilde{\chi}_2^0$	2 τ	0 jets	\tilde{t}_1 \tilde{t}_2	Forbidden
EW direct	$t\bar{t}, \tilde{t}_1 \tilde{t}_2 \rightarrow t\tilde{\chi}_1^0 / \tilde{\chi}_2^0$	2 e, μ	≥ 1 jet	\tilde{t}_1 \tilde{t}_2	0.35-0.5
	$H\bar{H}, H \rightarrow h\tilde{G}/Z\tilde{G}$	0 e, μ	≥ 3 b	\tilde{H}	0.26
	$H\bar{H}, H \rightarrow h\tilde{G}/Z\tilde{G}$	0 e, μ	0 jets	\tilde{H}	0.94
	$H\bar{H}, H \rightarrow h\tilde{G}/Z\tilde{G}$	0 e, μ	≥ 2 large jets	\tilde{H}	0.45-0.93
	$H\bar{H}, H \rightarrow h\tilde{G}/Z\tilde{G}$	2 e, μ	≥ 2 jets	\tilde{H}	0.77
	Direct $\tilde{t}_1 \tilde{t}_1$ prod., long-lived $\tilde{\chi}_1^0$	Disapp. trk	1 jet	\tilde{t}_1^+	0.66
	Stable \tilde{g} R-Hadron	pixel dE/dx	0 jets	\tilde{t}_1^+	0.21
	Metastable \tilde{g} R-hadron, $\tilde{g} \rightarrow q\tilde{\chi}_1^0$	pixel dE/dx	E_{miss}	\tilde{g}	2.05
	$\tilde{t}_1, \tilde{t}_2 \rightarrow t\tilde{\chi}_1^0$	Displ. lep	E_{miss}	\tilde{t}_1, \tilde{t}_2	2.2
	$\tilde{t}_1, \tilde{t}_2 \rightarrow t\tilde{\chi}_1^0$	pixel dE/dx	E_{miss}	\tilde{t}_1, \tilde{t}_2	0.74
Long-lived particles	$\tilde{\chi}_1^0 \tilde{\chi}_2^0 / \tilde{\chi}_1^0 \tilde{\chi}_2^0 \rightarrow Z\ell\ell$	3 e, μ	0 jets	\tilde{t}_1^+	0.625
	$\tilde{\chi}_1^0 \tilde{\chi}_2^0 / \tilde{\chi}_1^0 \tilde{\chi}_2^0 \rightarrow Z\ell\ell$	4 e, μ	≥ 2 jets	\tilde{t}_1^+	1.05
	$\tilde{\chi}_1^0 \tilde{\chi}_2^0 / \tilde{\chi}_1^0 \tilde{\chi}_2^0 \rightarrow qq$	3 e, μ	Multiple	\tilde{t}_1^+	0.95
	$\tilde{\chi}_1^0 \tilde{\chi}_2^0 / \tilde{\chi}_1^0 \tilde{\chi}_2^0 \rightarrow tb\bar{s}$	36.1	\tilde{t}_1^+	1.6	
	$\tilde{\chi}_1^0 \tilde{\chi}_2^0 / \tilde{\chi}_1^0 \tilde{\chi}_2^0 \rightarrow bb\bar{s}$	36.7	\tilde{t}_1^+	2.34	
	$\tilde{\chi}_1^0 \tilde{\chi}_2^0 / \tilde{\chi}_1^0 \tilde{\chi}_2^0 \rightarrow bs\bar{s}$	36.7	\tilde{t}_1^+	0.55	
	$\tilde{\chi}_1^0 \tilde{\chi}_2^0 / \tilde{\chi}_1^0 \tilde{\chi}_2^0 \rightarrow t\tilde{t}$	2 e, μ	2 jets	\tilde{t}_1^+	0.95
	$\tilde{\chi}_1^0 \tilde{\chi}_2^0 / \tilde{\chi}_1^0 \tilde{\chi}_2^0 \rightarrow b\tilde{b}$	2 e, μ	2 jets	\tilde{t}_1^+	0.42
	$\tilde{\chi}_1^0 \tilde{\chi}_2^0 / \tilde{\chi}_1^0 \tilde{\chi}_2^0 \rightarrow bb\bar{s}s$	1-2 e, μ	2 jets	\tilde{t}_1^+	0.61
	$\tilde{\chi}_1^0 \tilde{\chi}_2^0 / \tilde{\chi}_1^0 \tilde{\chi}_2^0 \rightarrow bb\bar{s}s$	1-2 e, μ	≥ 6 jets	\tilde{t}_1^+	0.4-1.85
RPV	$\tilde{\chi}_1^0 \tilde{\chi}_2^0 / \tilde{\chi}_1^0 \tilde{\chi}_2^0 \rightarrow Z\ell\ell$	1-2 e, μ	0 jets	\tilde{t}_1^+	0.2-0.32
	$\tilde{\chi}_1^0 \tilde{\chi}_2^0 / \tilde{\chi}_1^0 \tilde{\chi}_2^0 \rightarrow Z\ell\ell$	1-2 e, μ	≥ 6 jets	\tilde{t}_1^+	0.2-0.32

Mass scale [TeV]

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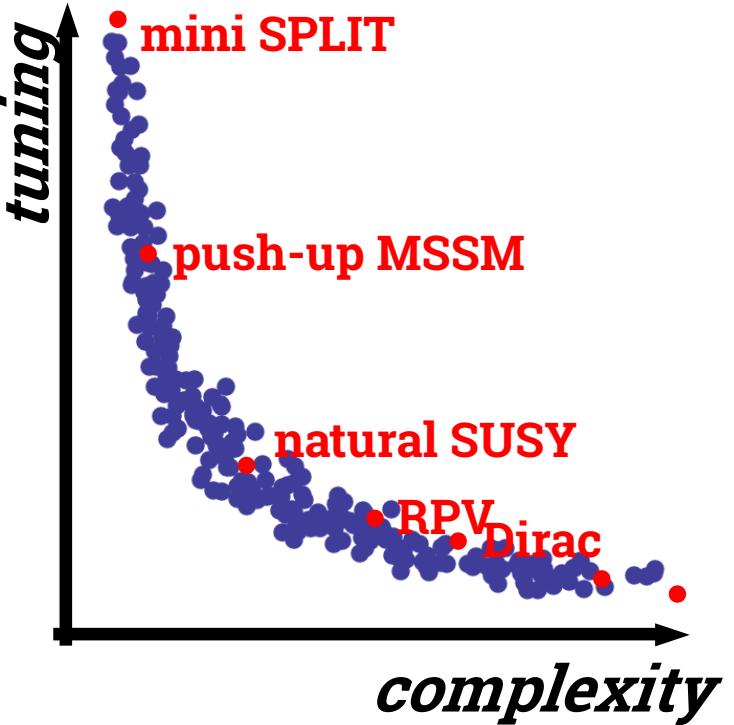
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ATLAS Preliminary
 $\sqrt{s} = 13 \text{ TeV}$

Reference

Model	Signature	$\int \mathcal{L} dt [\text{fb}^{-1}]$	Mass limit	
Inclusive Searches	$\tilde{q}\tilde{q} \rightarrow q\tilde{\chi}_1^0$ mono-jet	0 e, μ 1-3 jets	E_{miss} 140	$\tilde{q} \rightarrow [1 \times, 8 \times \text{Degen.}]$ $\tilde{q} \rightarrow [8x \text{ Degen.}]$
	$\tilde{g}\tilde{g}, \tilde{g} \rightarrow q\tilde{\chi}_1^0$	0 e, μ 2-6 jets	E_{miss} 140	\tilde{g} \tilde{g}
	$\tilde{g}\tilde{g}, \tilde{g} \rightarrow q\tilde{q} W\tilde{\chi}_1^0$	1 e, μ $ee, \mu\mu$ 2 jets	E_{miss} 140	\tilde{g} \tilde{g}
	$\tilde{g}\tilde{g}, \tilde{g} \rightarrow q\tilde{q} Z\tilde{\chi}_1^0$	0 e, μ SS, e, μ 7-11 jets	E_{miss} 140	\tilde{g} \tilde{g}
	$\tilde{g}\tilde{g}, \tilde{g} \rightarrow t\tilde{\chi}_1^0$	0-1 e, μ SS, e, μ 3 jets	E_{miss} 140	\tilde{g} \tilde{g}
	$\tilde{g}\tilde{g}, \tilde{g} \rightarrow t\tilde{\chi}_1^0$	0-1 e, μ SS, e, μ 6 jets	E_{miss} 140	\tilde{g} \tilde{g}
	$\tilde{b}_1\tilde{b}_1$	0 e, μ 2 jets	E_{miss} 140	\tilde{b}_1 \tilde{b}_1
	$\tilde{b}_1\tilde{b}_1, \tilde{b}_1 \rightarrow b\tilde{\chi}_1^0$	0 e, μ 2 jets	E_{miss} 140	\tilde{b}_1 \tilde{b}_1
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1 \rightarrow t\tilde{\chi}_1^0$	0-1 e, μ ≥ 1 jets	E_{miss} 140	\tilde{t}_1 \tilde{t}_1
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1 \rightarrow W\tilde{\chi}_1^0$	1 e, μ 1-2 τ 3 jets	E_{miss} 140	\tilde{t}_1 \tilde{t}_1
3 rd gen. squarks direct production	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1 \rightarrow t\tilde{b}, \tilde{b} \rightarrow t\tau G$	1 e, μ 1-2 τ 2 jets	E_{miss} 140	\tilde{t}_1 \tilde{t}_1
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1 \rightarrow t\tilde{c}, \tilde{c} \rightarrow t\tilde{c}_1^0$	0 e, μ mono-jet	E_{miss} 140	\tilde{t}_1 \tilde{t}_1
	$\tilde{t}_1\tilde{t}_1 \rightarrow t\tilde{b}_1^0, \tilde{b}_1^0 \rightarrow Z/h\tilde{\chi}_1^0$	1-2 e, μ 3 e, μ	E_{miss} 140	\tilde{t}_1 \tilde{t}_1
	$\tilde{t}_1\tilde{t}_1 \rightarrow t\tilde{b}_1^0, \tilde{b}_1^0 \rightarrow Z/h\tilde{\chi}_1^0$	1-4 jets	E_{miss} 140	\tilde{t}_1 \tilde{t}_1
	$\tilde{t}_1\tilde{t}_1 \rightarrow t\tilde{b}_1^0 + Z$	1-6 jets	E_{miss} 140	\tilde{t}_1 \tilde{t}_1
	$\tilde{\chi}_1^0 \tilde{\chi}_2^0$ via WZ	Multiple ℓ/jets	E_{miss} E_{ℓ}	$\tilde{\chi}_1^0 / \tilde{\chi}_2^0$ $\tilde{\chi}_1^0 / \tilde{\chi}_2^0$
	$\tilde{\chi}_1^0 \tilde{\chi}_1^0$ via WW	2 e, μ	E_{miss} E_{ℓ}	$\tilde{\chi}_1^0$ $\tilde{\chi}_1^0$
	$\tilde{\chi}_1^0 \tilde{\chi}_2^0$ via Wh	Multiple ℓ/jets	E_{miss} E_{ℓ}	$\tilde{\chi}_1^0 / \tilde{\chi}_2^0$ $\tilde{\chi}_1^0 / \tilde{\chi}_2^0$
	$\tilde{\chi}_1^0 \tilde{\chi}_1^0$ via $\tilde{\ell}_L \tilde{\nu}_L$	2 e, μ	E_{miss} E_{ℓ}	$\tilde{\chi}_1^0 / \tilde{\chi}_1^0$ $\tilde{\chi}_1^0 / \tilde{\chi}_1^0$
	$\tilde{\tau}, \tilde{\tau} \rightarrow \tau\tilde{\chi}_1^0$	2 τ	E_{miss} E_{ℓ}	$\tilde{\tau} / [\tau \tilde{\chi}_1^0]$ $\tilde{\tau} / [\tau \tilde{\chi}_1^0]$
EW direct	$\tilde{H}\tilde{H}, \tilde{H} \rightarrow h\tilde{\chi}_1^0/Z\tilde{\chi}_1^0$	0 e, μ 0 jets	E_{miss} 140	\tilde{H} \tilde{H}
	$\tilde{H}\tilde{H}, \tilde{H} \rightarrow h\tilde{\chi}_1^0/Z\tilde{\chi}_1^0$	0 e, μ ≥ 1 jets	E_{miss} 140	\tilde{H} \tilde{H}
	$\tilde{H}\tilde{H}, \tilde{H} \rightarrow h\tilde{\chi}_1^0/Z\tilde{\chi}_1^0$	0 e, μ ≥ 2 large jets	E_{miss} 140	\tilde{H} \tilde{H}
	$\tilde{H}\tilde{H}, \tilde{H} \rightarrow h\tilde{\chi}_1^0/Z\tilde{\chi}_1^0$	2 e, μ ≥ 2 jets	E_{miss} 140	\tilde{H} \tilde{H}
	Direct $\tilde{\chi}_1^0 \tilde{\chi}_1^0$ prod., long-lived $\tilde{\chi}_1^0$	Disapp. trk	1 jet	$\tilde{\chi}_1^0$
Long-lived particles	Stable \tilde{g} R-Hadron	pixel dE/dx	0 jets	$\tilde{\chi}_1^0$
	Metastable \tilde{g} R-hadron, $\tilde{g} \rightarrow q\tilde{\chi}_1^0$	pixel dE/dx	≥ 8 jets	$\tilde{\chi}_1^0$
	$\tilde{t}, \tilde{t} \rightarrow t\tilde{\chi}_1^0$	Displ. lep	0 jets	$\tilde{t}, \tilde{\mu}$
	$\tilde{t}, \tilde{t} \rightarrow t\tilde{\chi}_1^0$	pixel dE/dx	0 jets	$\tilde{t}, \tilde{\tau}$
RPV	$\tilde{\chi}_1^0 \tilde{\chi}_2^0 / \tilde{\chi}_1^0 \tilde{\chi}_2^0 \rightarrow Z\ell\ell$	3 e, μ	E_{miss} E_{ℓ}	$\tilde{\chi}_1^0 / \tilde{\chi}_2^0$ $\tilde{\chi}_1^0 / \tilde{\chi}_2^0$
	$\tilde{\chi}_1^0 \tilde{\chi}_2^0 / \tilde{\chi}_1^0 \tilde{\chi}_2^0 \rightarrow WW/Z\ell\ell\ell\ell\nu\nu$	4 e, μ	E_{miss} E_{ℓ}	$\tilde{\chi}_1^0 / \tilde{\chi}_2^0$ $\tilde{\chi}_1^0 / \tilde{\chi}_2^0$
	$\tilde{g}\tilde{g}, \tilde{g} \rightarrow q\tilde{q} \tilde{\chi}_1^0 \tilde{\chi}_1^0 \rightarrow qq$	≥ 8 jets	E_{miss} 140	\tilde{g} \tilde{g}
	$\tilde{t}_1, \tilde{t}_1 \rightarrow t\tilde{\chi}_1^0, \tilde{\chi}_1^0 \rightarrow tb$	Multiple	E_{miss} 36.1	\tilde{t}_1 \tilde{t}_1
	$\tilde{t}_1, \tilde{t}_1 \rightarrow t\tilde{\chi}_1^0, \tilde{\chi}_1^0 \rightarrow bbs$	≥ 4b	E_{miss} 36.7	\tilde{t}_1 \tilde{t}_1
	$\tilde{t}_1, \tilde{t}_1 \rightarrow tb$	2 jets + 2 b	E_{miss} 140	\tilde{t}_1 \tilde{t}_1
	$\tilde{t}_1, \tilde{t}_1 \rightarrow t\tilde{t}$	2 e, μ 2 jets	E_{miss} 140	\tilde{t}_1 \tilde{t}_1
	$\tilde{t}_1^0 \tilde{t}_2^0 / \tilde{t}_1^0, \tilde{t}_2^0 \rightarrow bbs, \tilde{\chi}_1^+ \rightarrow bbs$	1-2 e, μ ≥ 6 jets	E_{miss} 140	\tilde{t}_1^0 \tilde{t}_1^0

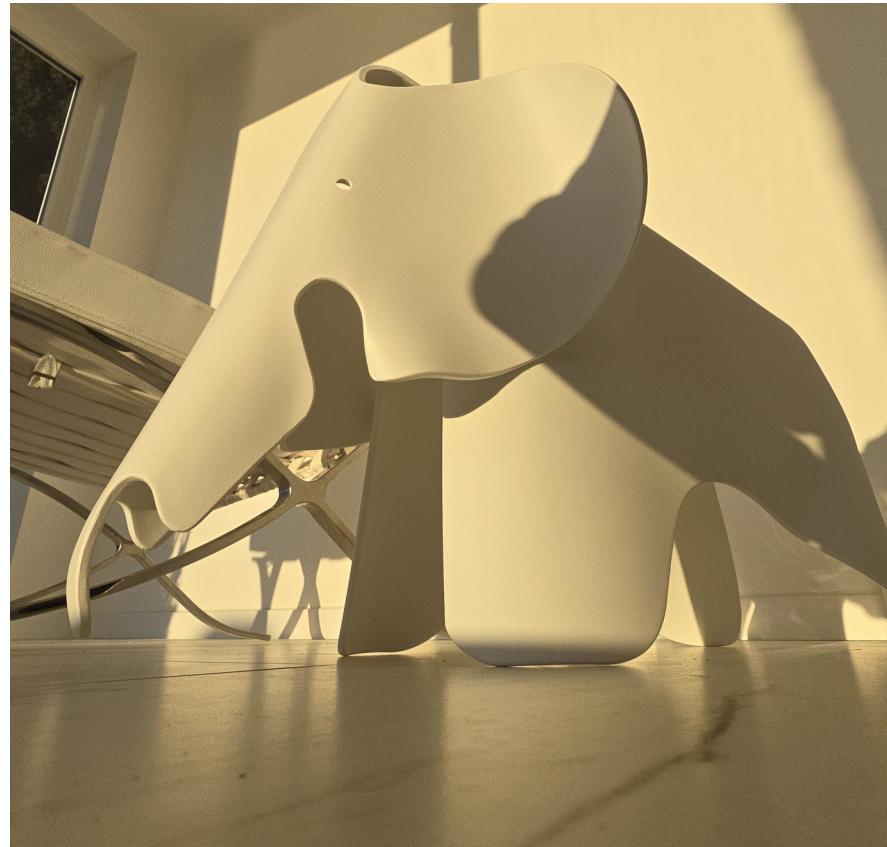
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1. Hierarchy Problem

$$\delta m_Z^2 \sim m_{\text{SUSY}}^2 \sim 10^2 m_Z^2 \left(\frac{m_{\text{SUSY}}}{\text{TeV}} \right)^2$$

$$\delta \Lambda_{cc} \sim m_{\text{SUSY}}^4 \sim 10^{62} \Lambda_{cc} \left(\frac{m_{\text{SUSY}}}{\text{TeV}} \right)^4$$

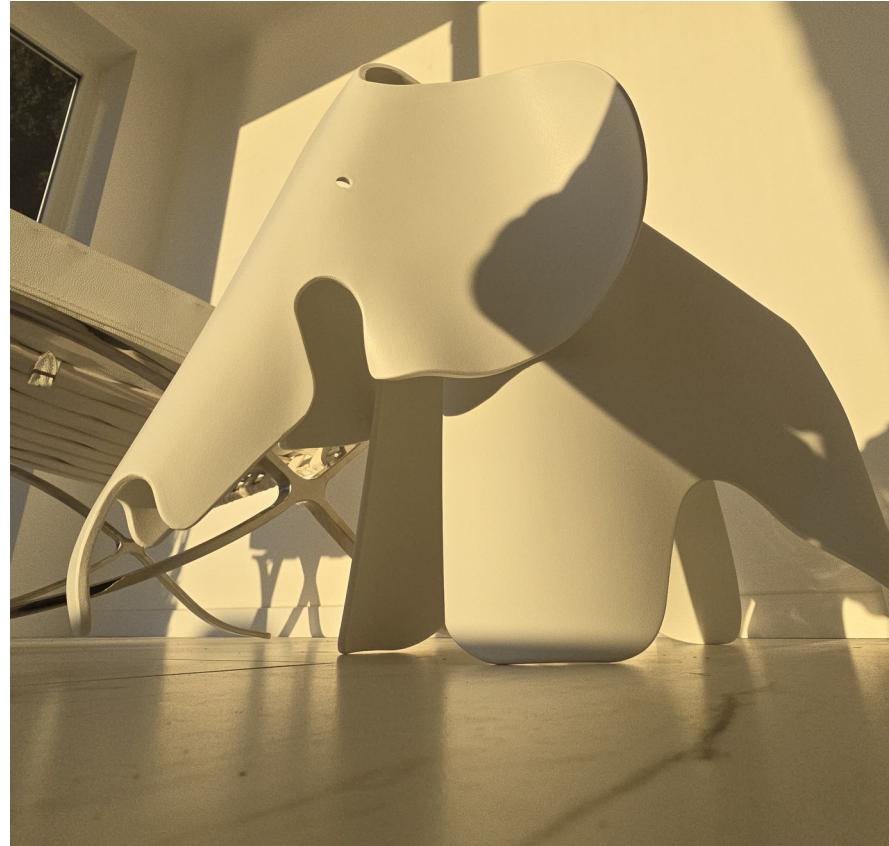


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$$\delta \Lambda_{cc} \sim m_{\text{SUSY}}^4 \sim 10^{62} \Lambda_{cc} \left(\frac{m_{\text{SUSY}}}{\text{TeV}} \right)^4$$

no known alternatives to
SUSY



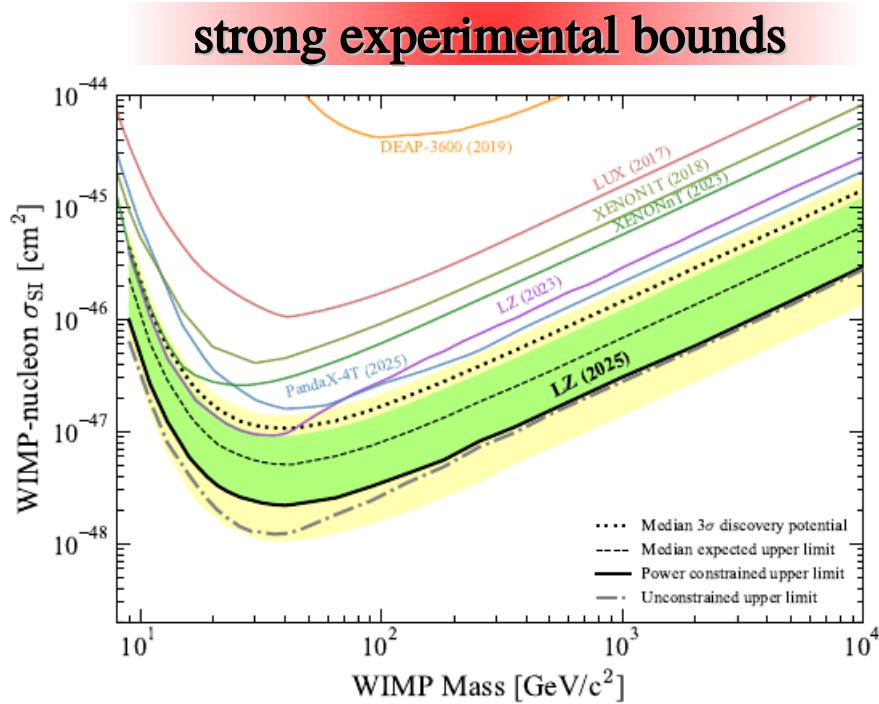
2. WIMP Miracle

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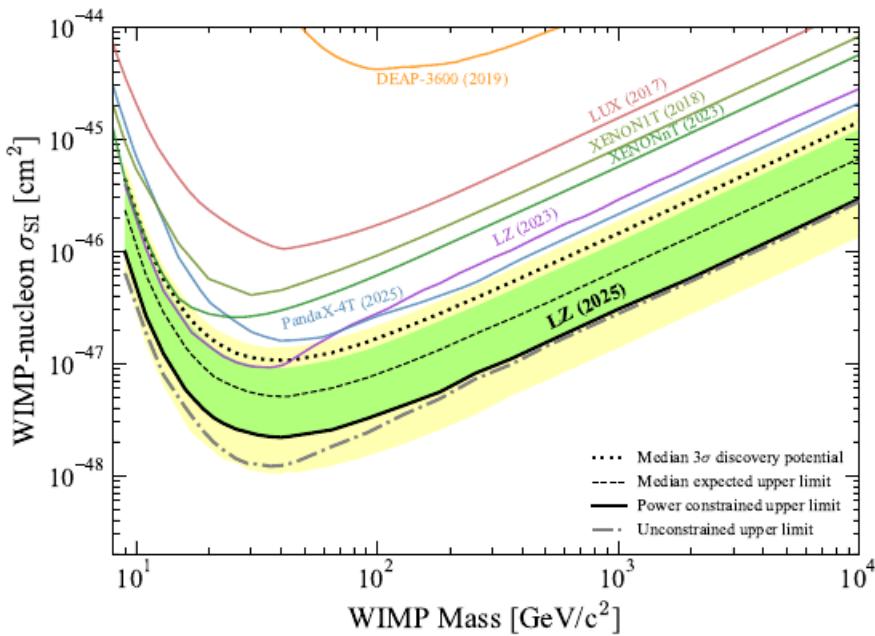


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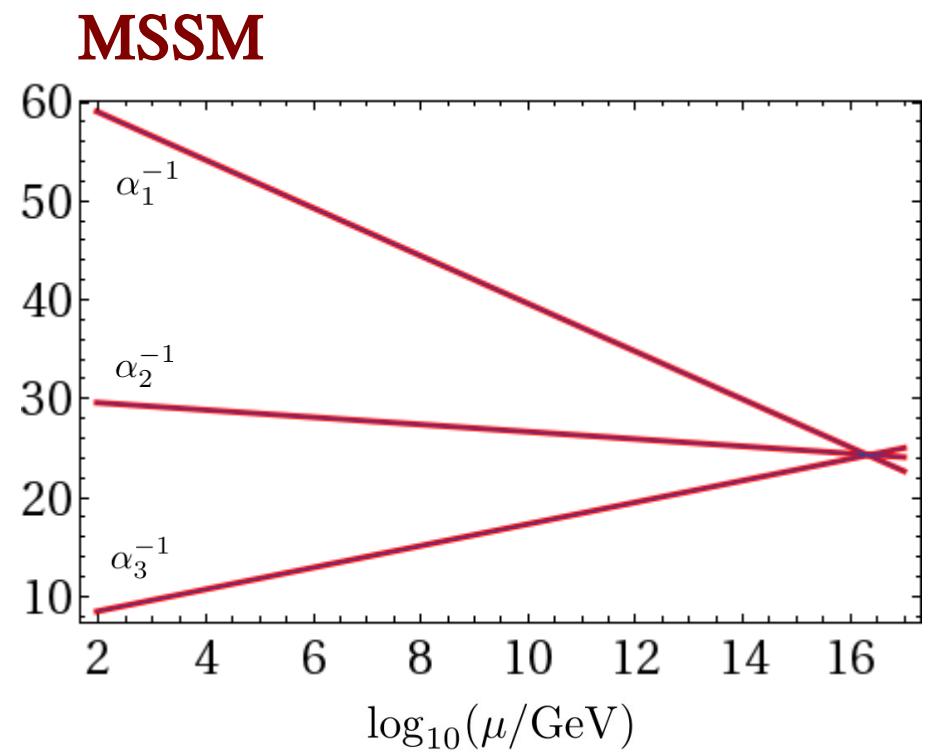
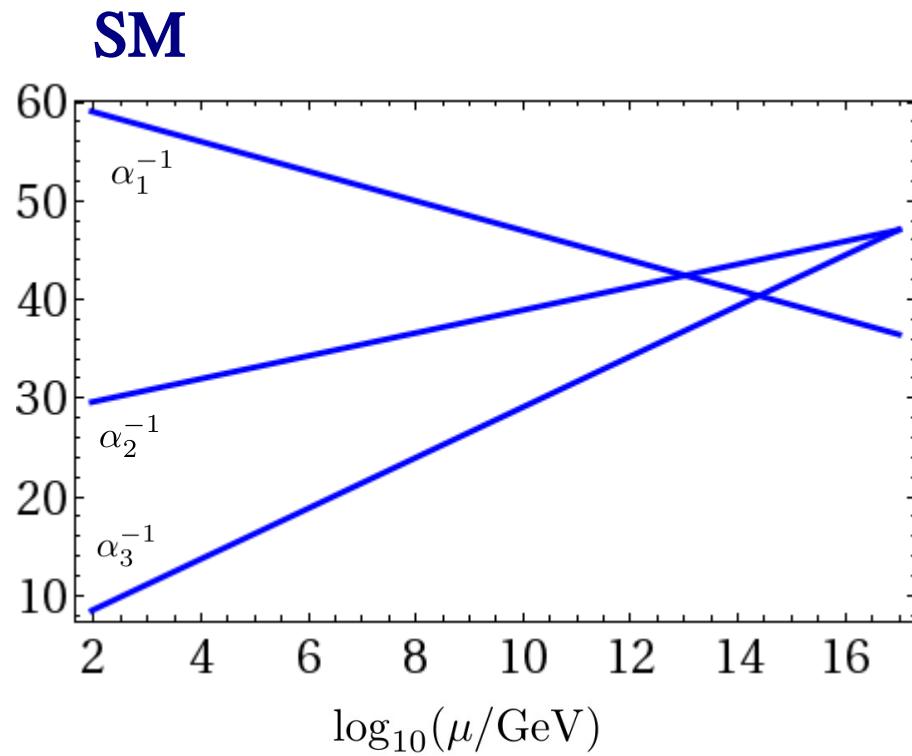
strong experimental bounds



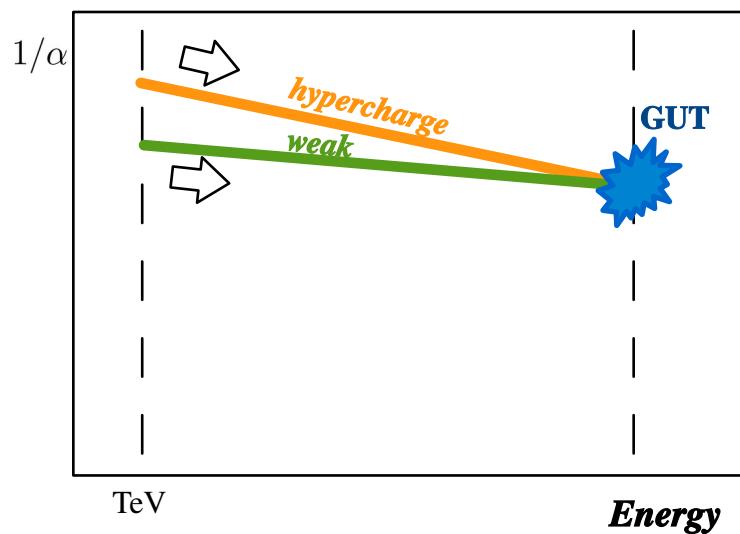
many other equally plausible candidates:

QCD axion, ALPs, Dark Sectors, etc...

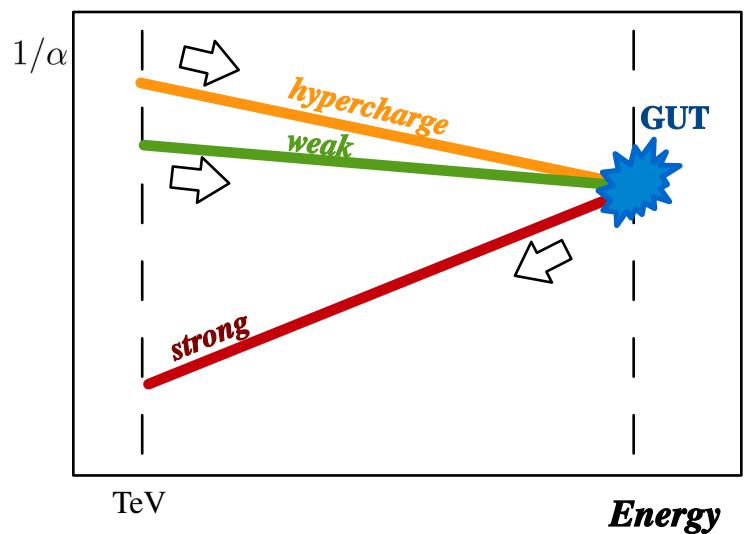
3. GUT



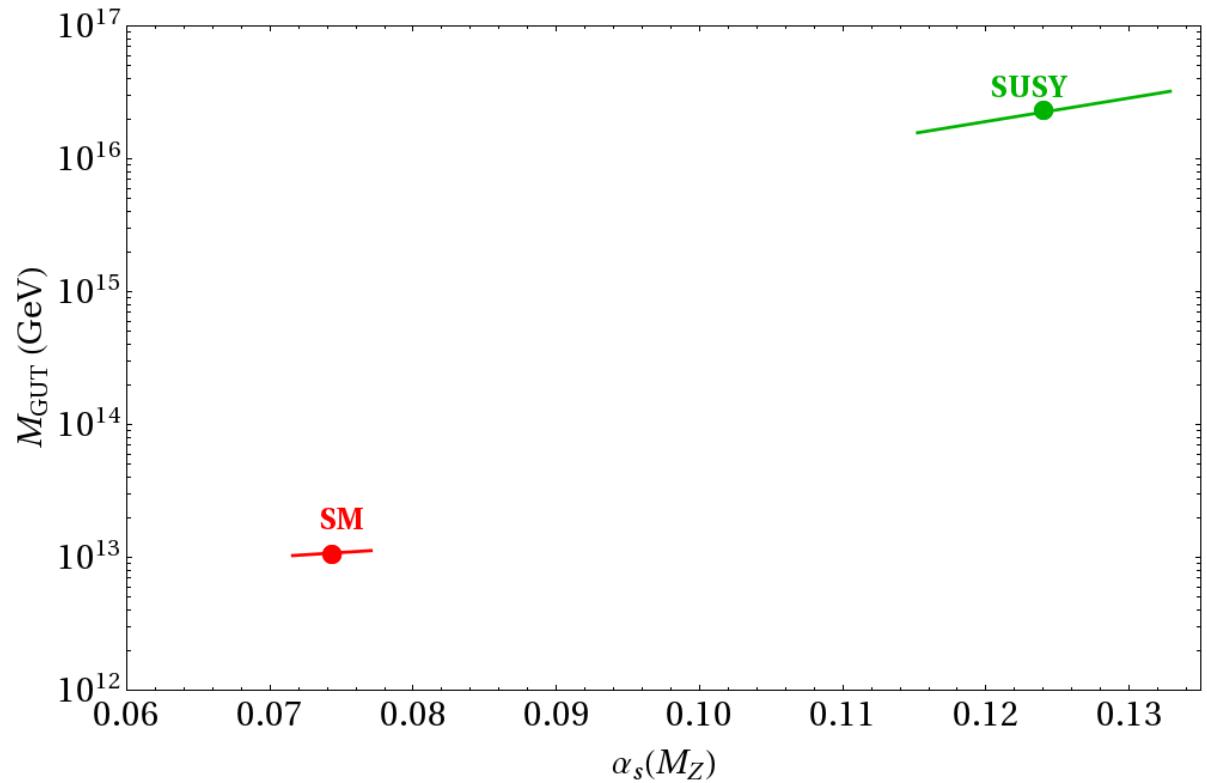
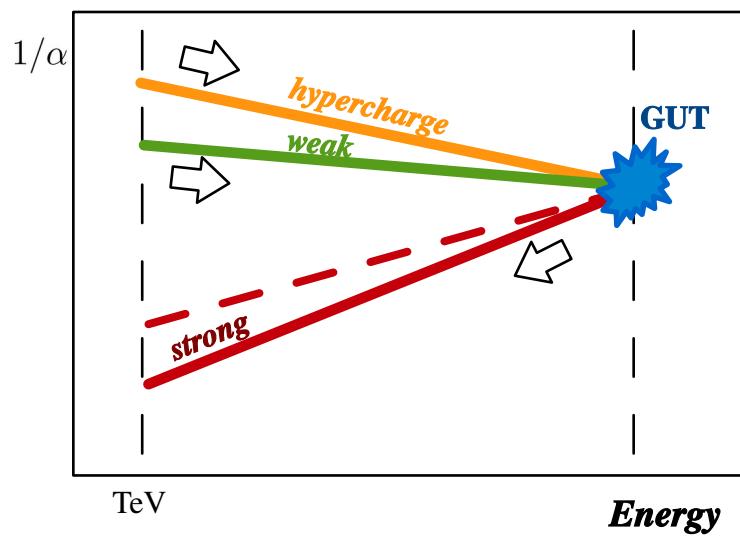
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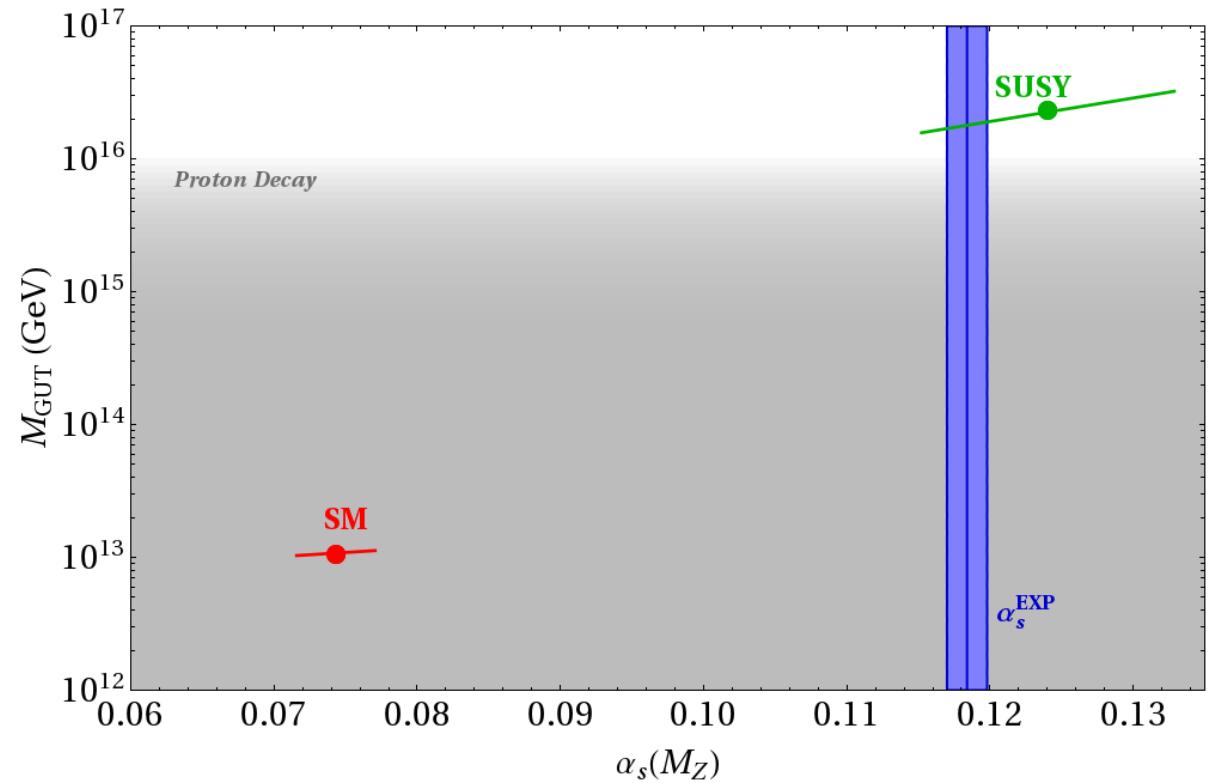
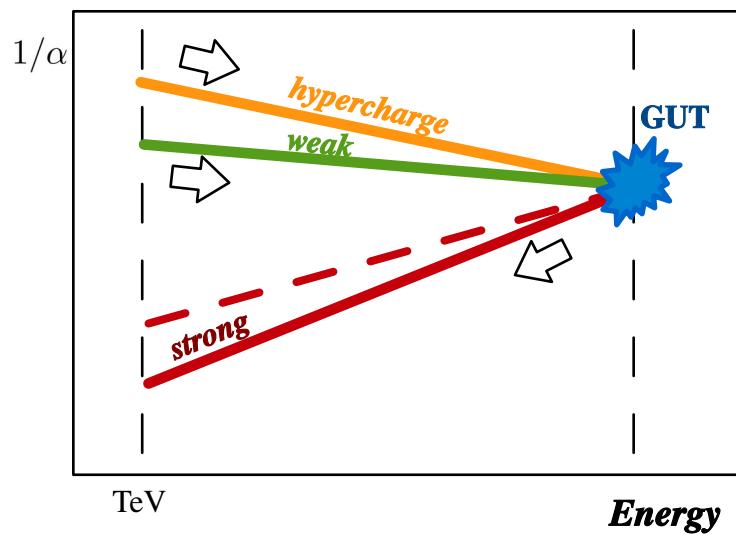
3. GUT



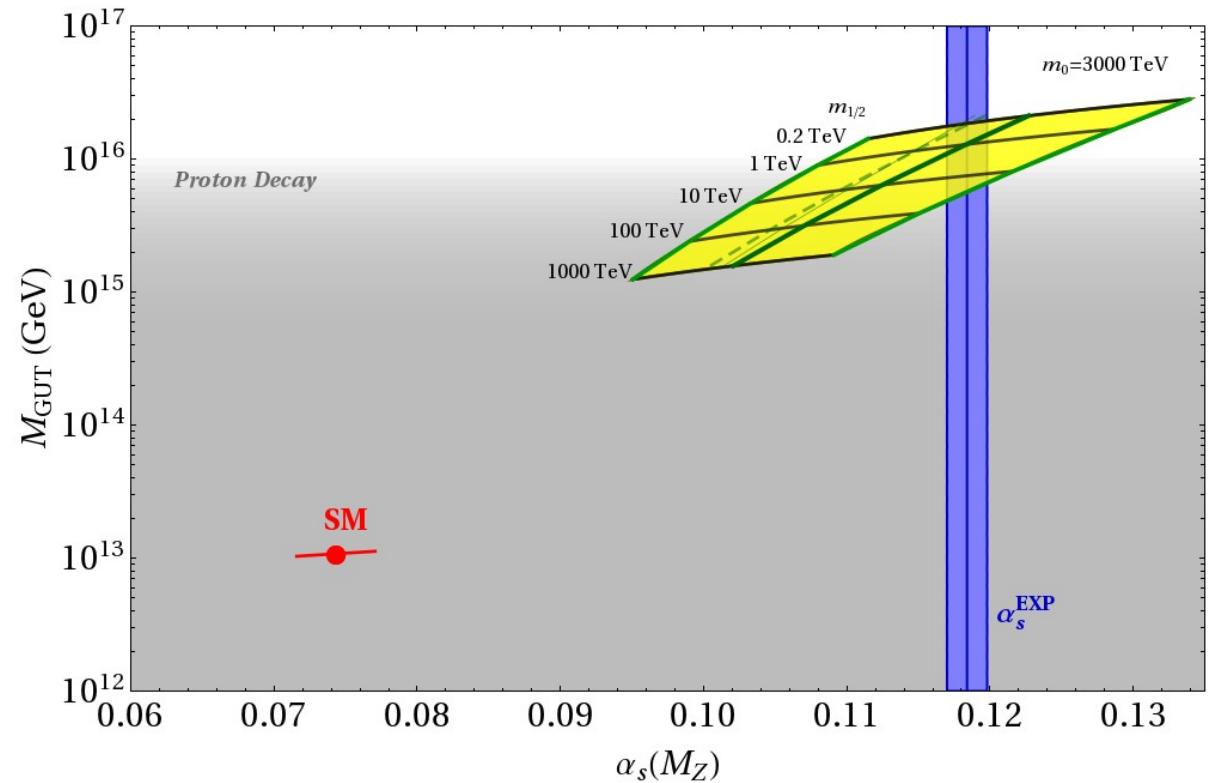
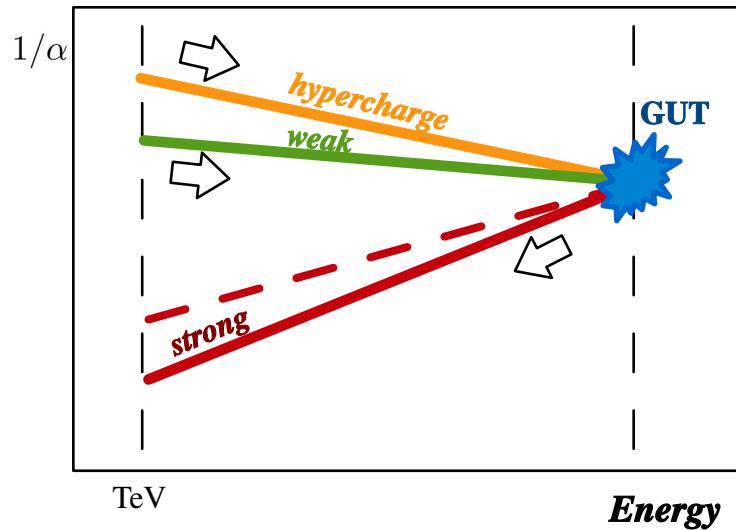
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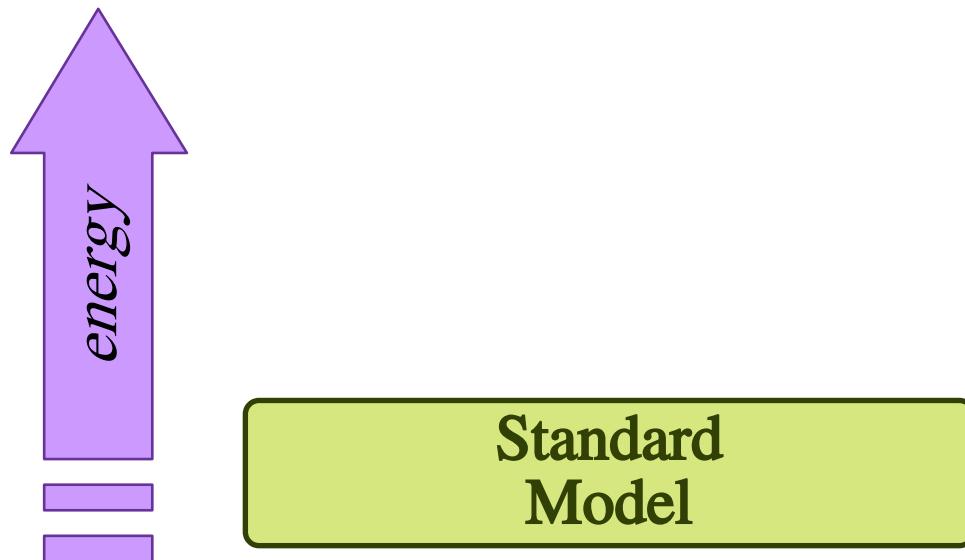


SUSY: A New Angle

- assume SUSY
- take seriously GUT
- use exp. to determine SUSY scale

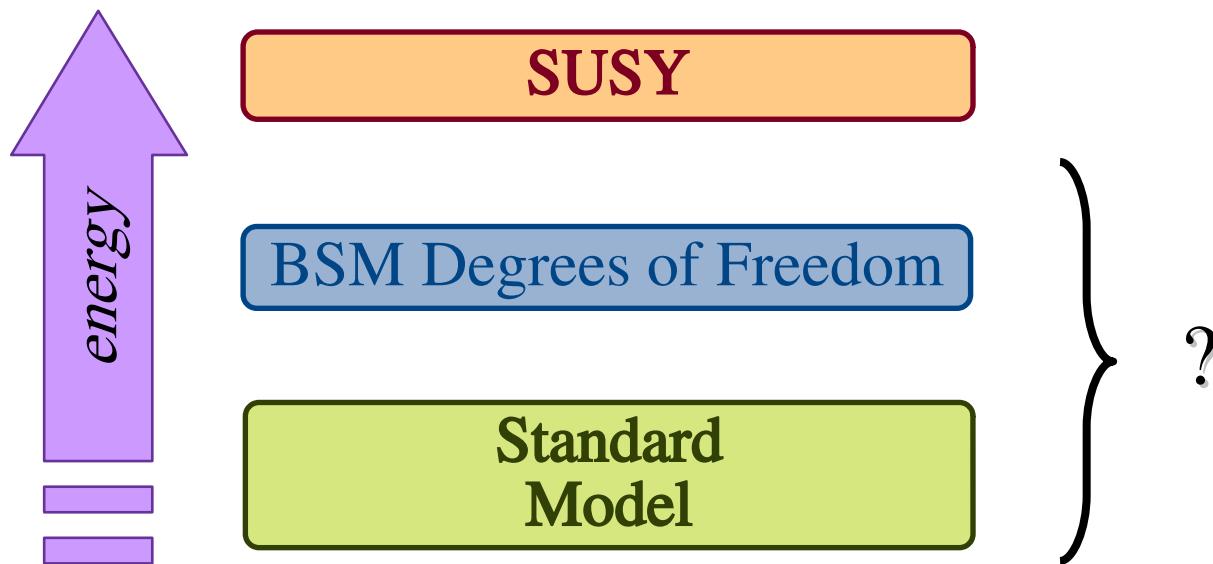
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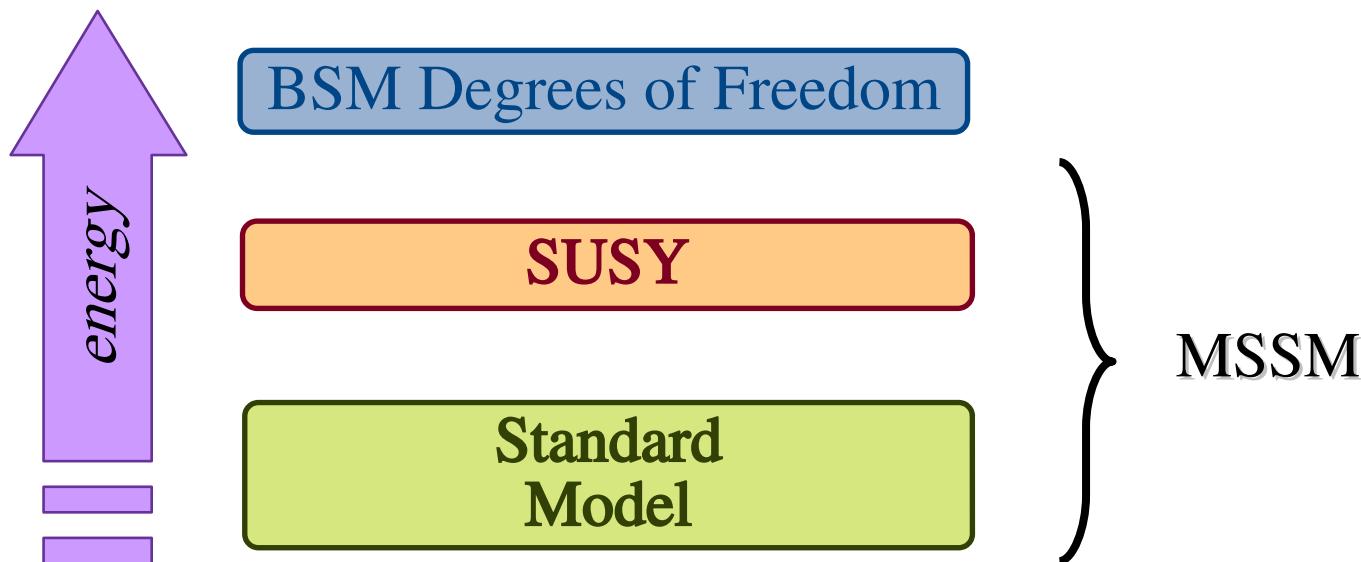
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$$125^2 \sim 90^2 + 90^2$$

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only *log*-dependence on new physics scale

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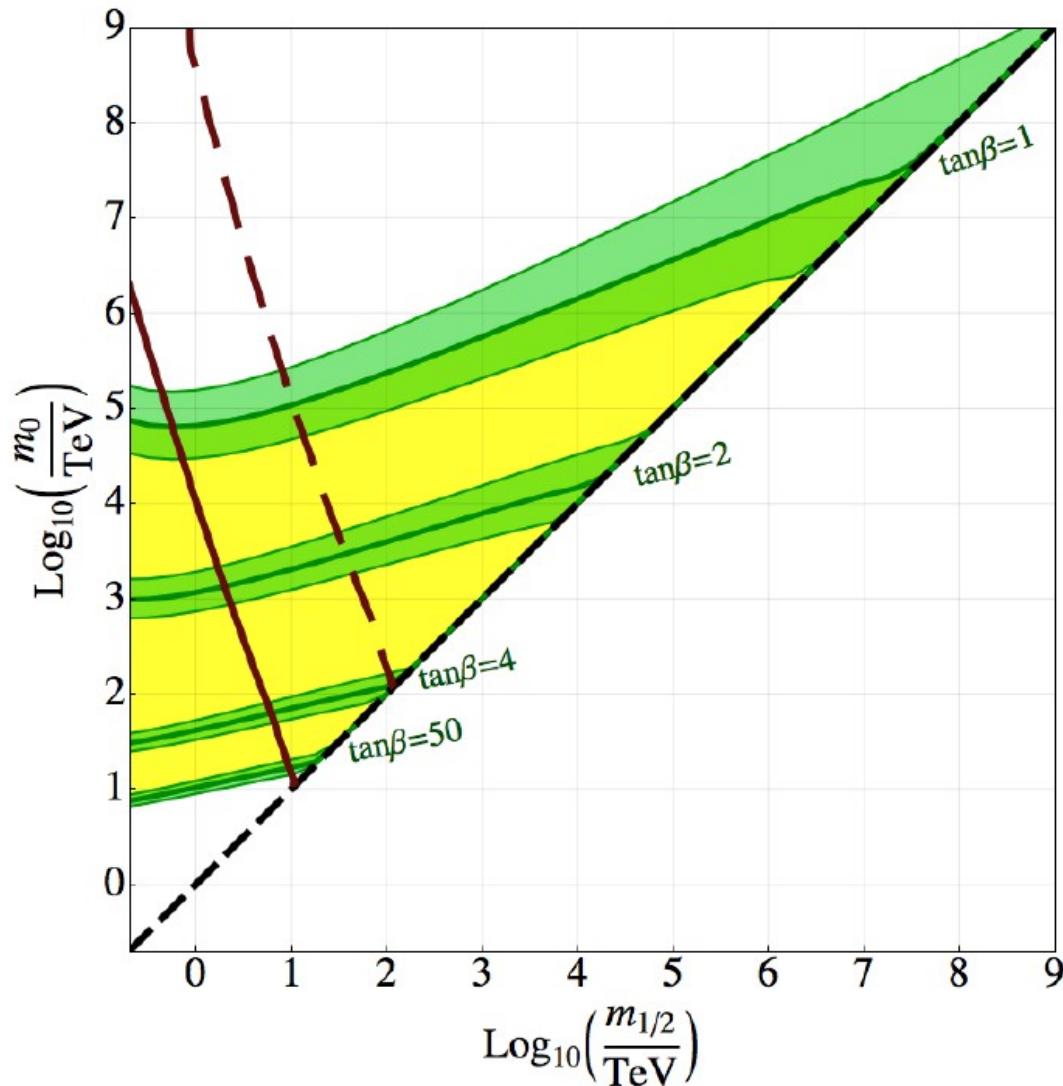
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only *log*-dependence on new physics scale

⇒ *high precision to get reliable constraints*

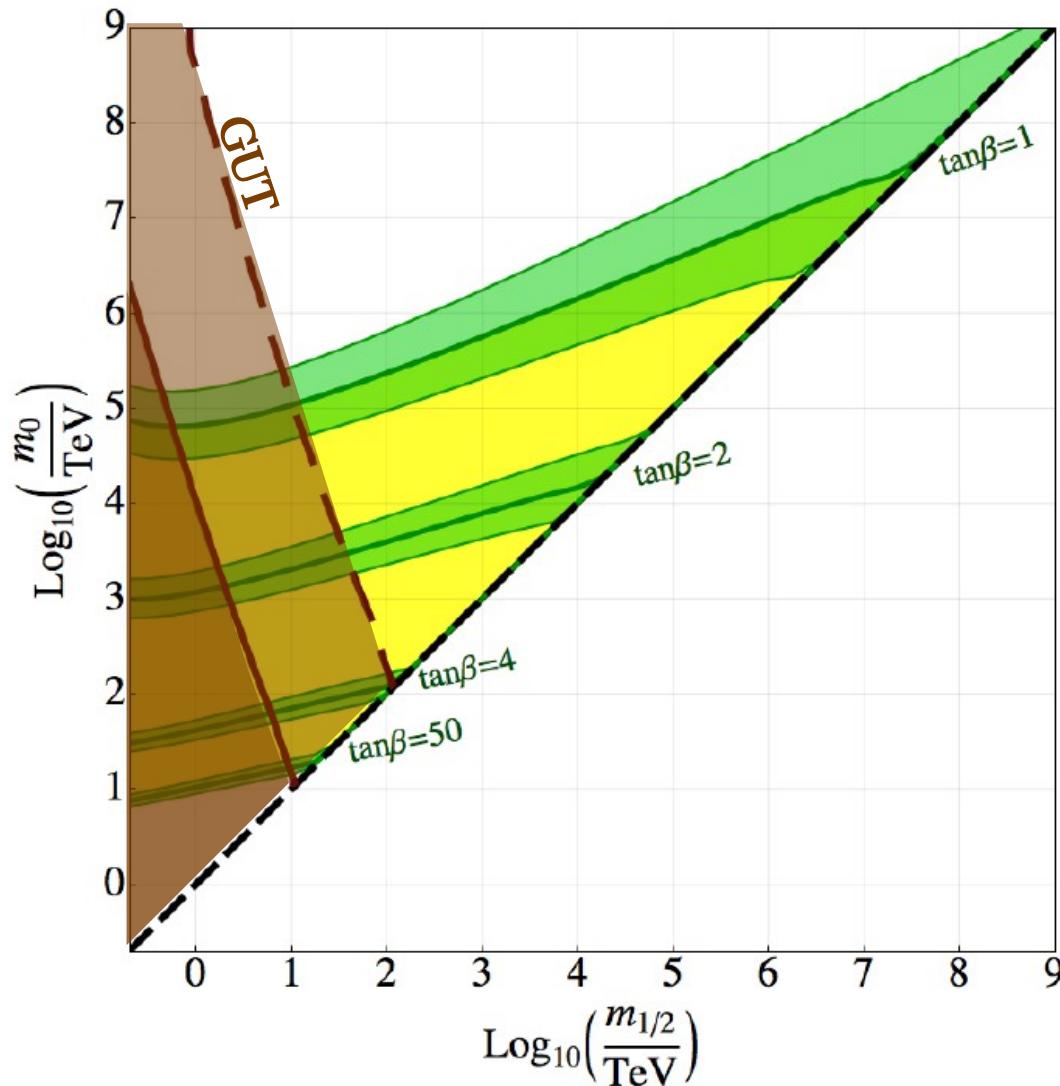
Mini - Split

Arvanitaki et al. '12
Arkani-Hamed et al. '12



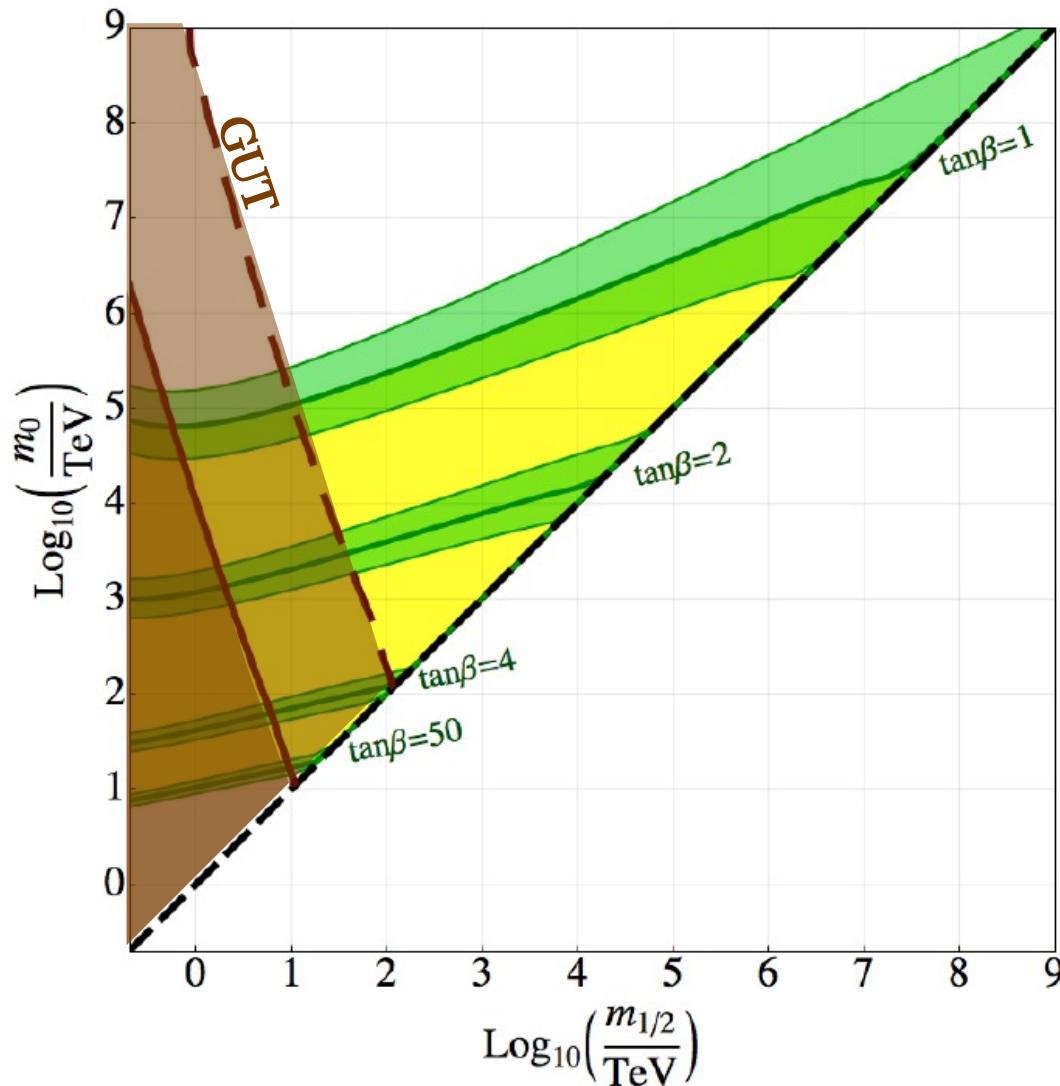
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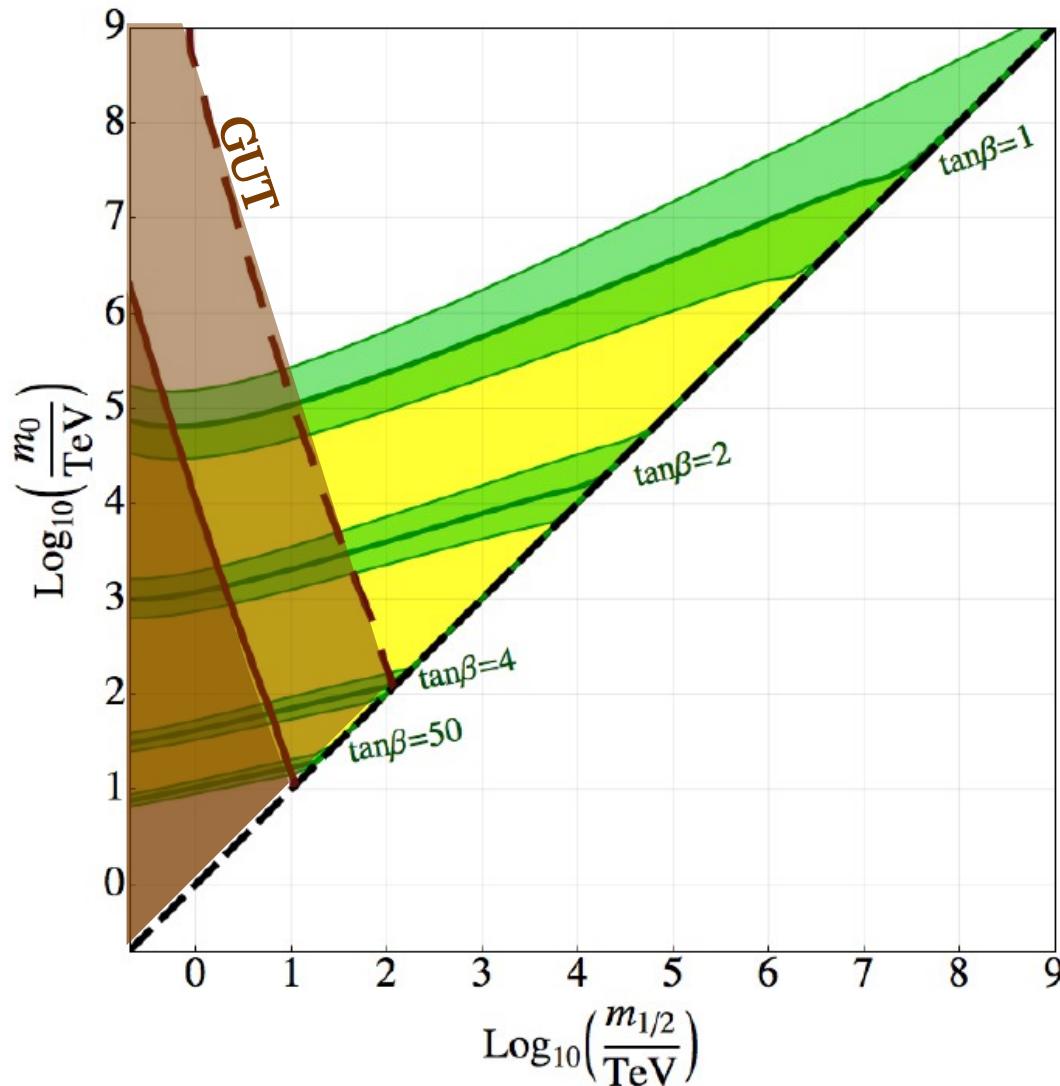


Small $\tan\beta$ and EWSB

$$\det \begin{pmatrix} |\mu|^2 + m_{H_u}^2 & -B_\mu \\ -B_\mu^* & |\mu|^2 + m_{H_d}^2 \end{pmatrix} \approx 0$$

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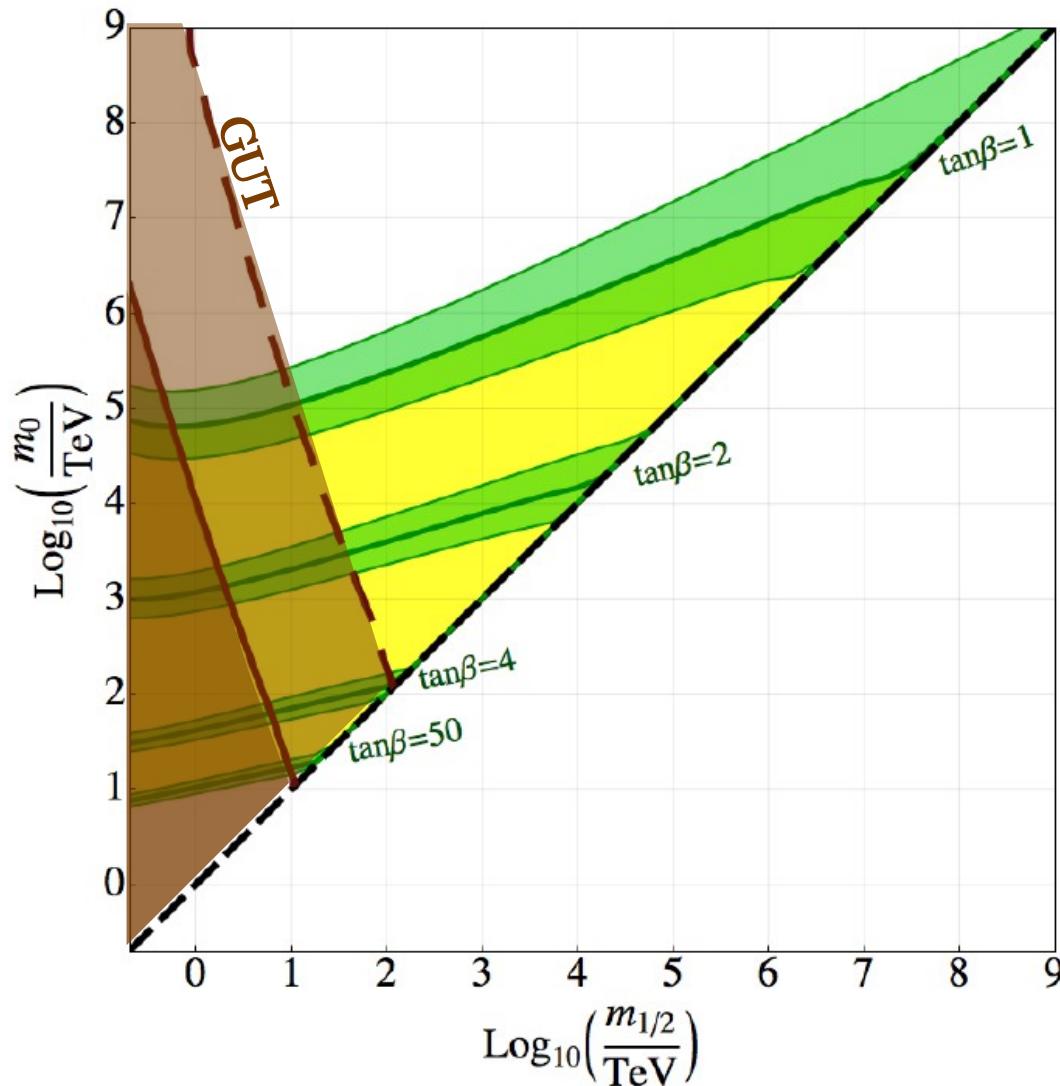
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↓

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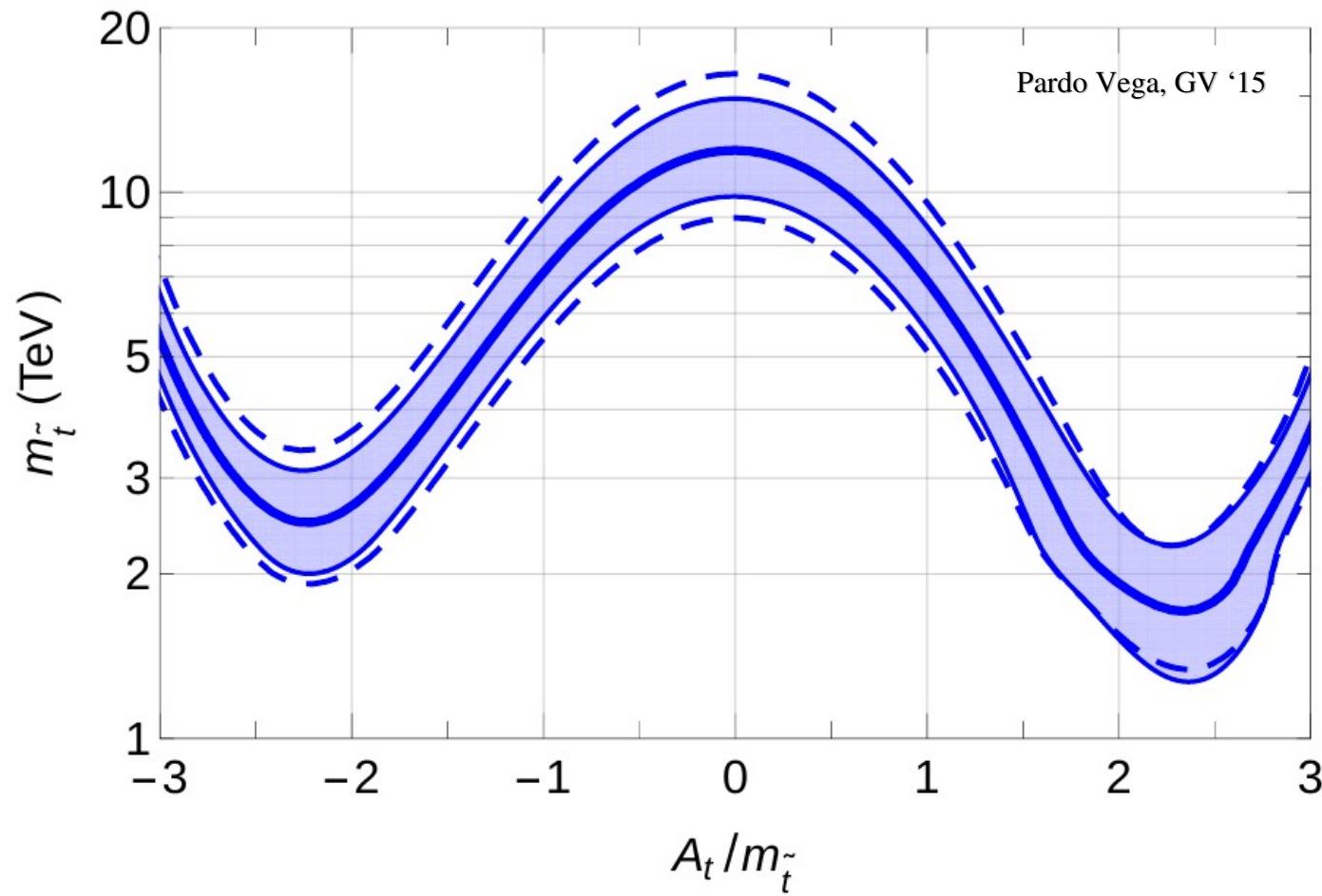


$$\tan\beta \approx \frac{m_{H_d}}{m_{H_u}}$$

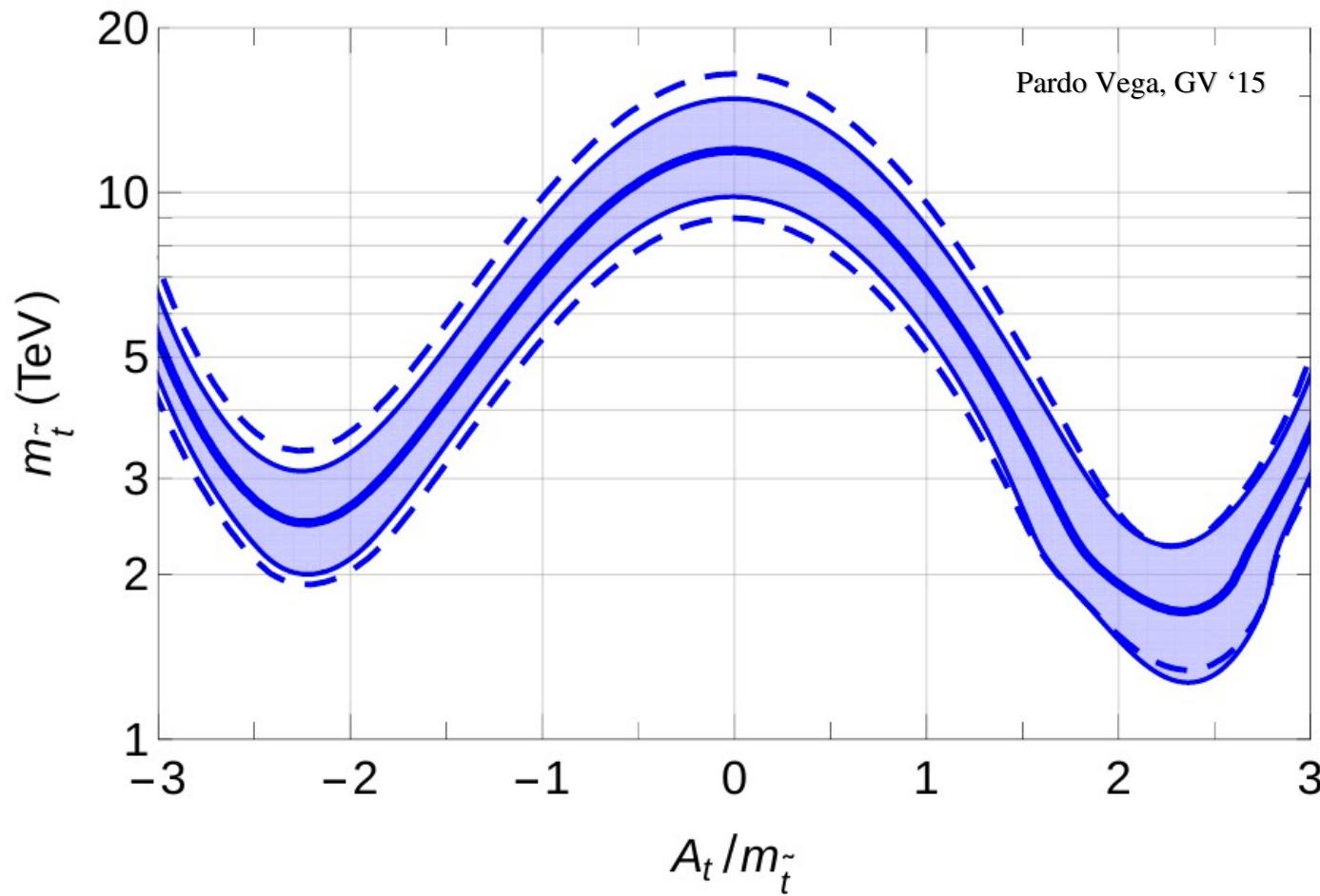
but relation: $m_{H_u}^2 \simeq m_{H_d}^2$

broken by Yukawa

MSSM Higgs @ large $\tan\beta$



MSSM Higgs @ large $\tan\beta$



"Hell is truth seen too late."

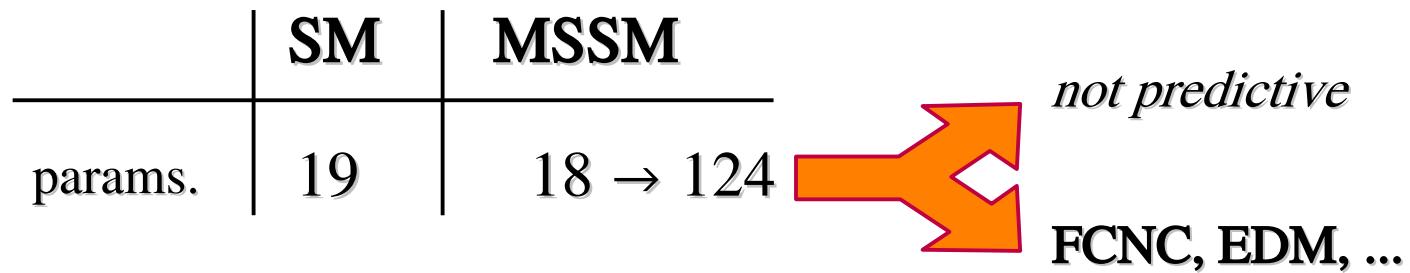
– Thomas Hobbes, Leviathan



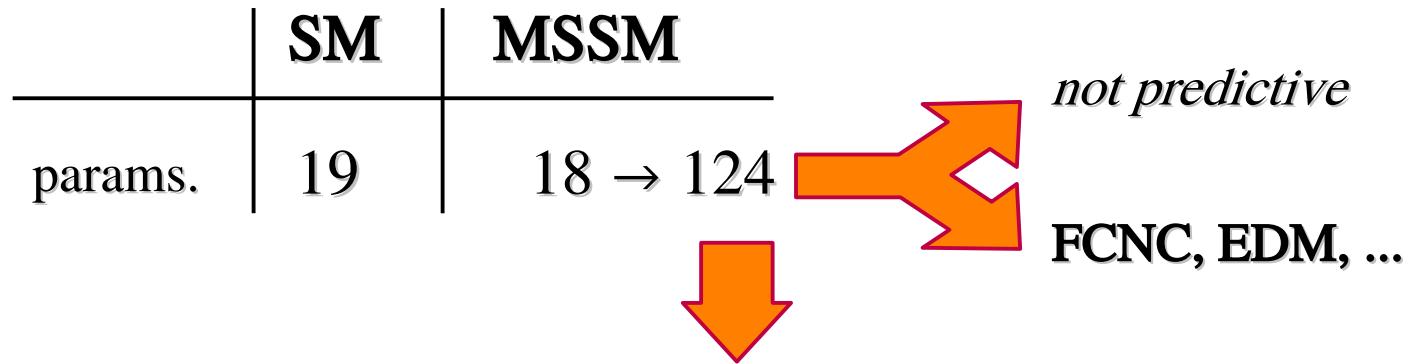
MSSM freedom

	SM	MSSM
params.	19	18

MSSM freedom



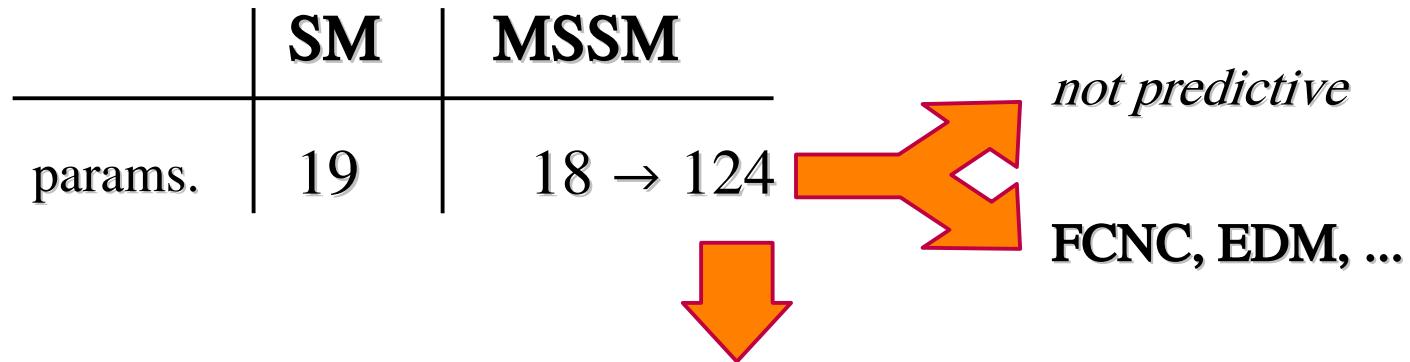
MSSM freedom



Depend on Mediation Mechanism:

Gravity / Anomaly / (Generalized) Gauge / Gaugino / Moduli / ...

MSSM freedom



Depend on Mediation Mechanism:

Gravity / Anomaly / (Generalized) Gauge / Gaugino / Moduli / ...

Minimal Gauge Mediation

most simple + predictive + most compatible

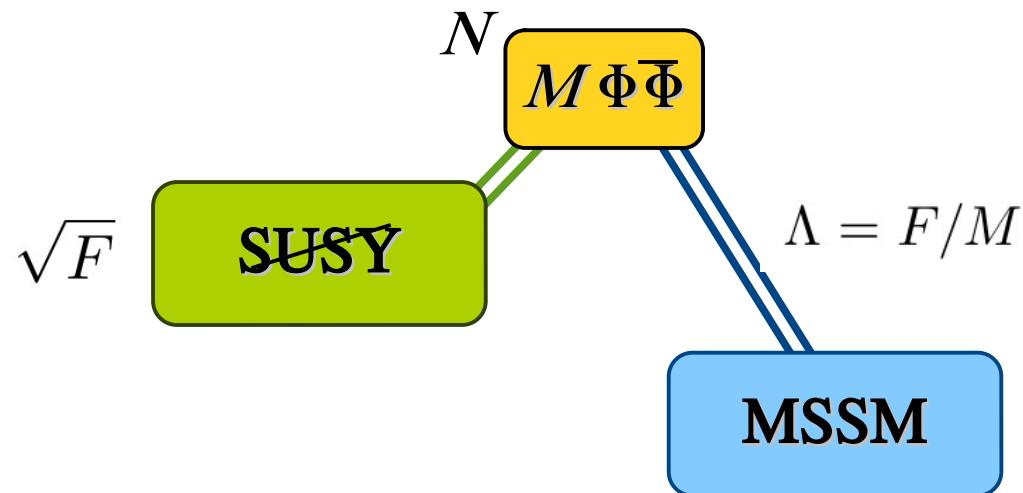
Minimal Gauge Mediation

\sqrt{F}

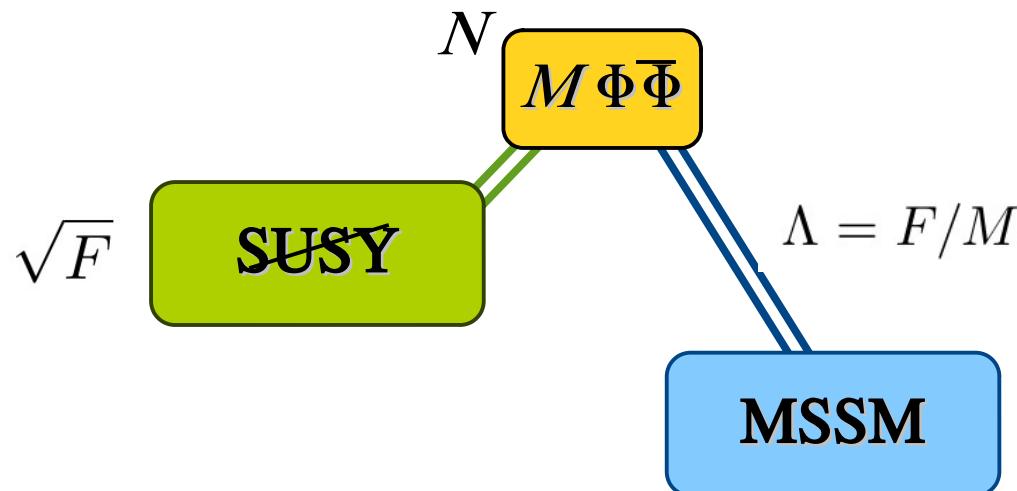
~~SUSY~~

MSSM

Minimal Gauge Mediation

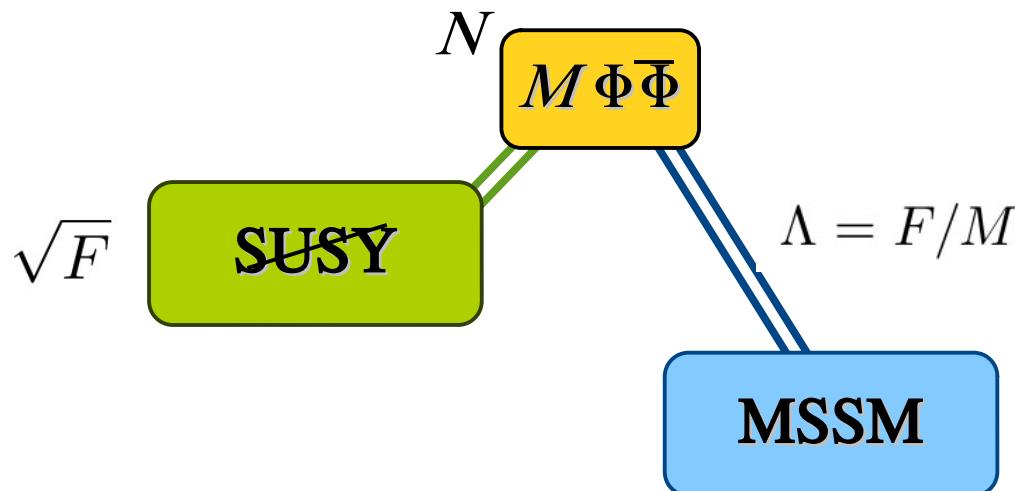


Minimal Gauge Mediation



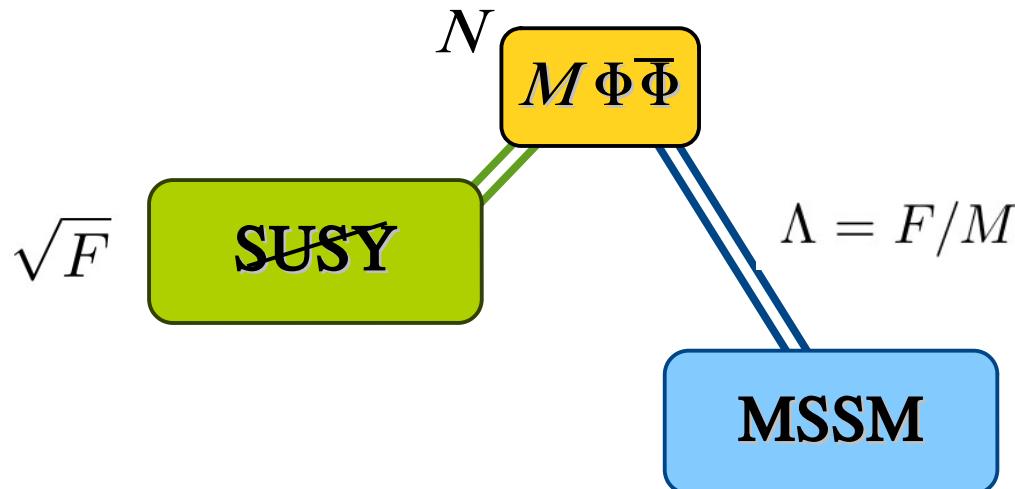
spectrum:
$$\left\{ \begin{array}{l} M_j = N \frac{\alpha_j}{4\pi} \Lambda \\ m_i = 2\sqrt{N} C_{ij} \frac{\alpha_j}{4\pi} \Lambda \\ A_i = B_\mu = 0 \end{array} \right.$$

Minimal Gauge Mediation



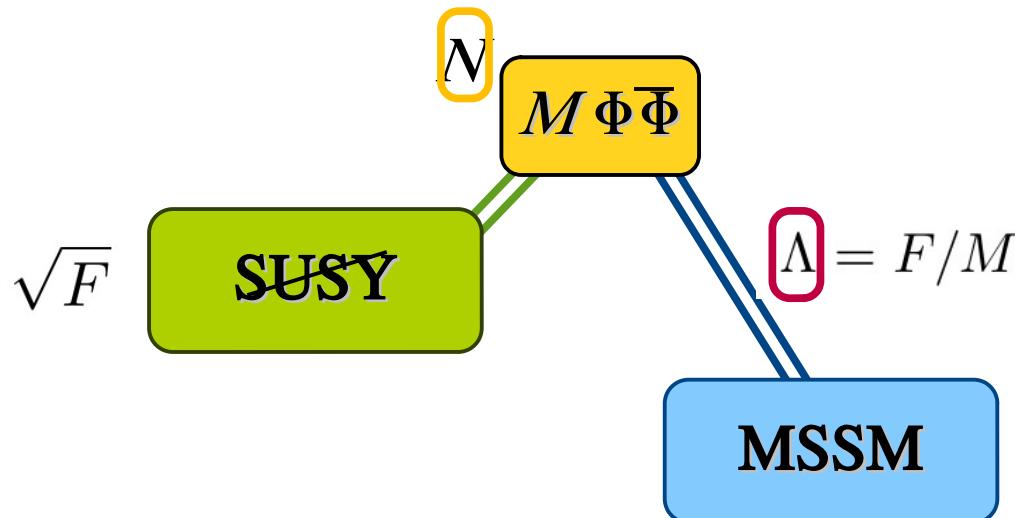
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Minimal Gauge Mediation



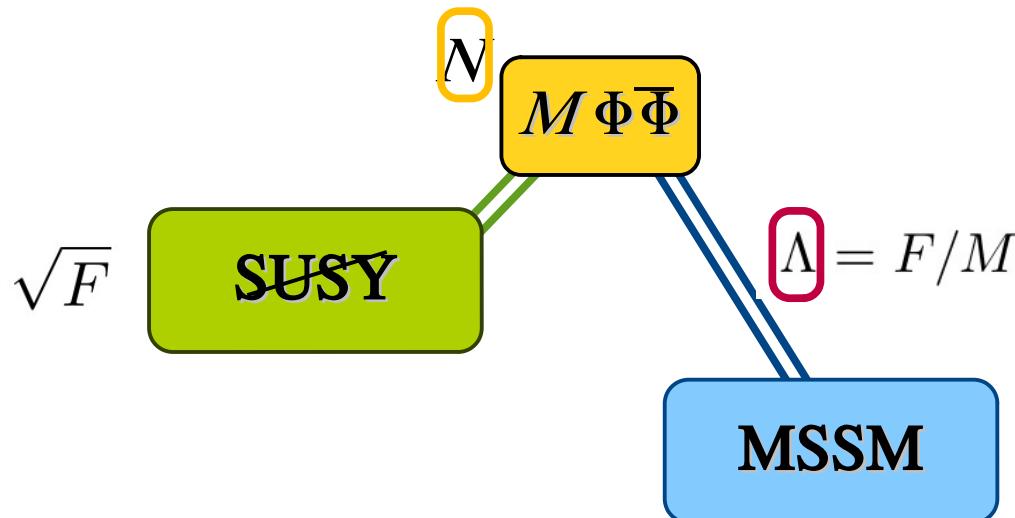
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Minimal Gauge Mediation



spectrum:
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$$\quad \begin{array}{l} \xrightarrow{\hspace{2cm}} \text{NO CPV phases} \end{array}$$

Minimal Gauge Mediation



spectrum:
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 → flavor blind (MFV) spectrum:
NO dangerous FCNC

→ NO CPV phases

parameters = # parameters of SM
+ weak dependence on N and $\log(M)$

No naturalness \rightarrow no μ problem:

$\Lambda = F/M$ 

 μ No EWSB

$m_o, M_{1/2}$ 

No naturalness \rightarrow no μ problem:

$\Lambda = F/M$ 

$m_o, M_{1/2}$  m_z

EWSB $\sim m_o$

 μ

No naturalness \rightarrow no μ problem:

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$m_o, M_{1/2}$   μ EWSB $\ll m_o$ $|\mu|^2 \simeq -m_{H_u}^2 + \dots$

m_Z 

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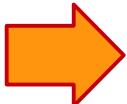
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$m_o, M_{1/2}$   μ EWSB $\ll m_o$ $|\mu|^2 \simeq -m_{H_u}^2 + \dots$

m_Z 

$B_\mu, A = 0$ at the scale M

generated radiatively

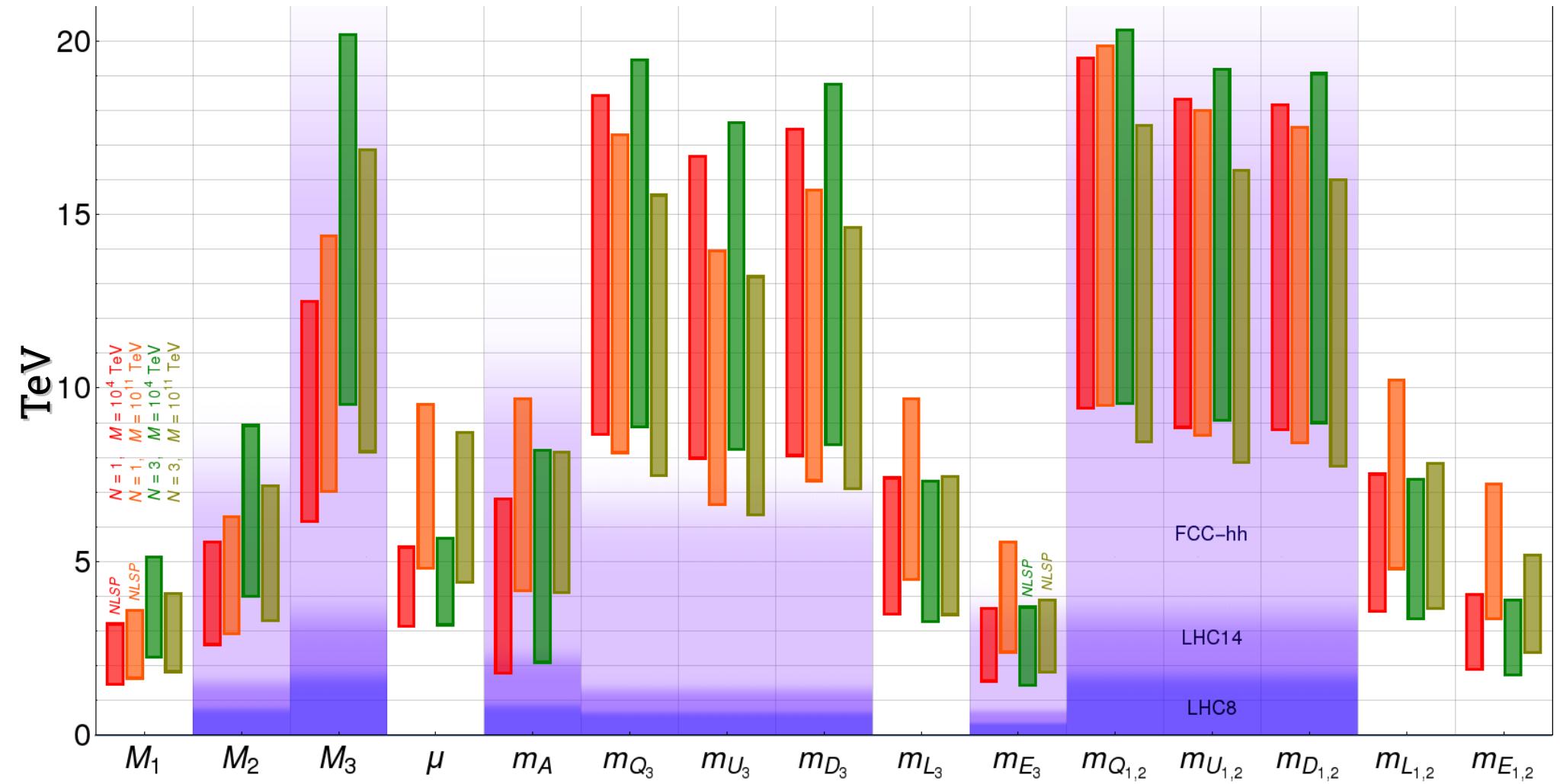
 $A_t \lesssim m_0$ *no maximal mixing*

 $B_\mu \ll m_0^2$ $\tan(\beta) \sim 30\text{-}60$

 *no CP phases \rightarrow no EDMs*

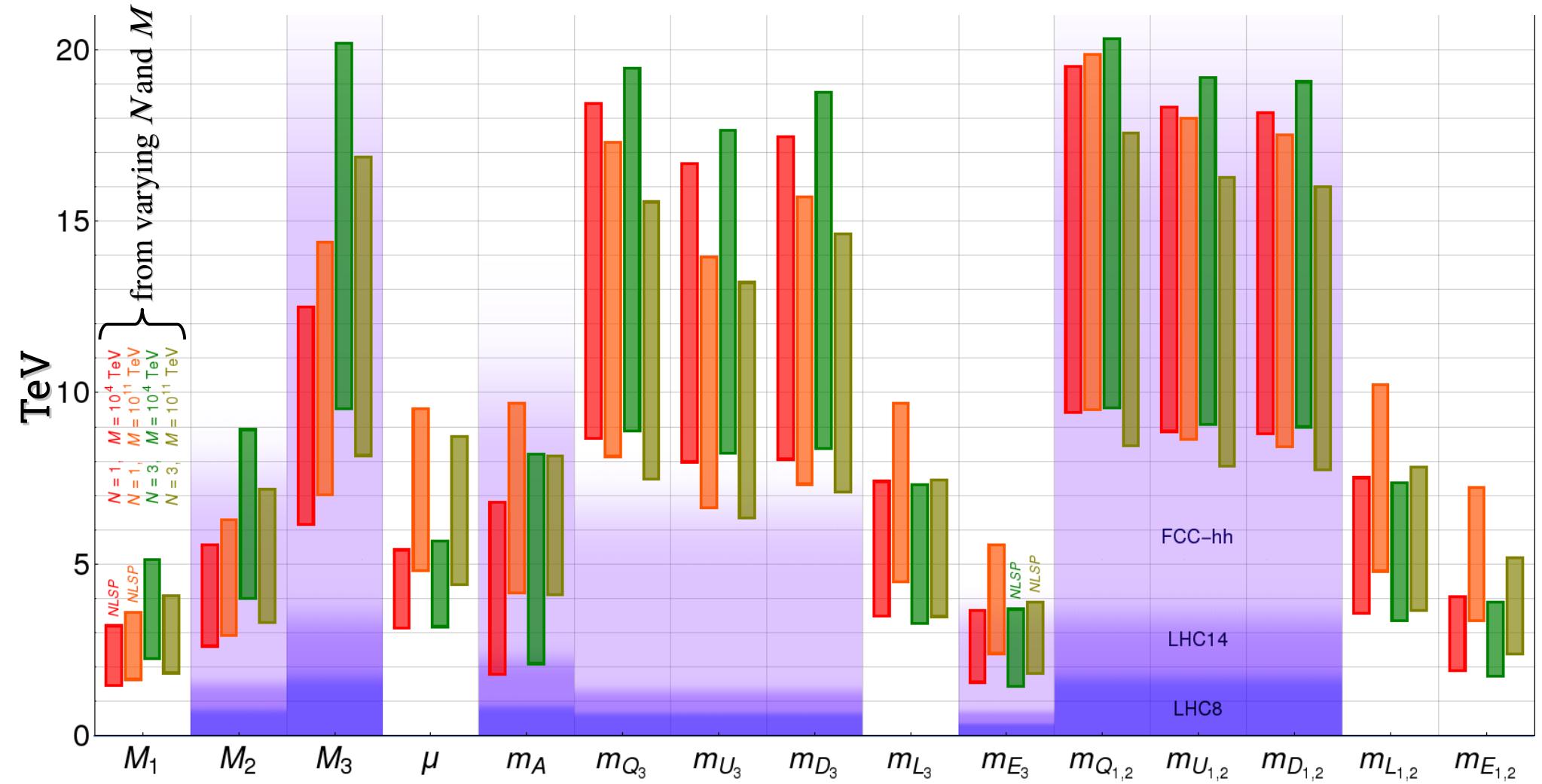
Predicting the MGM spectrum

Pardo Vega, GV '15



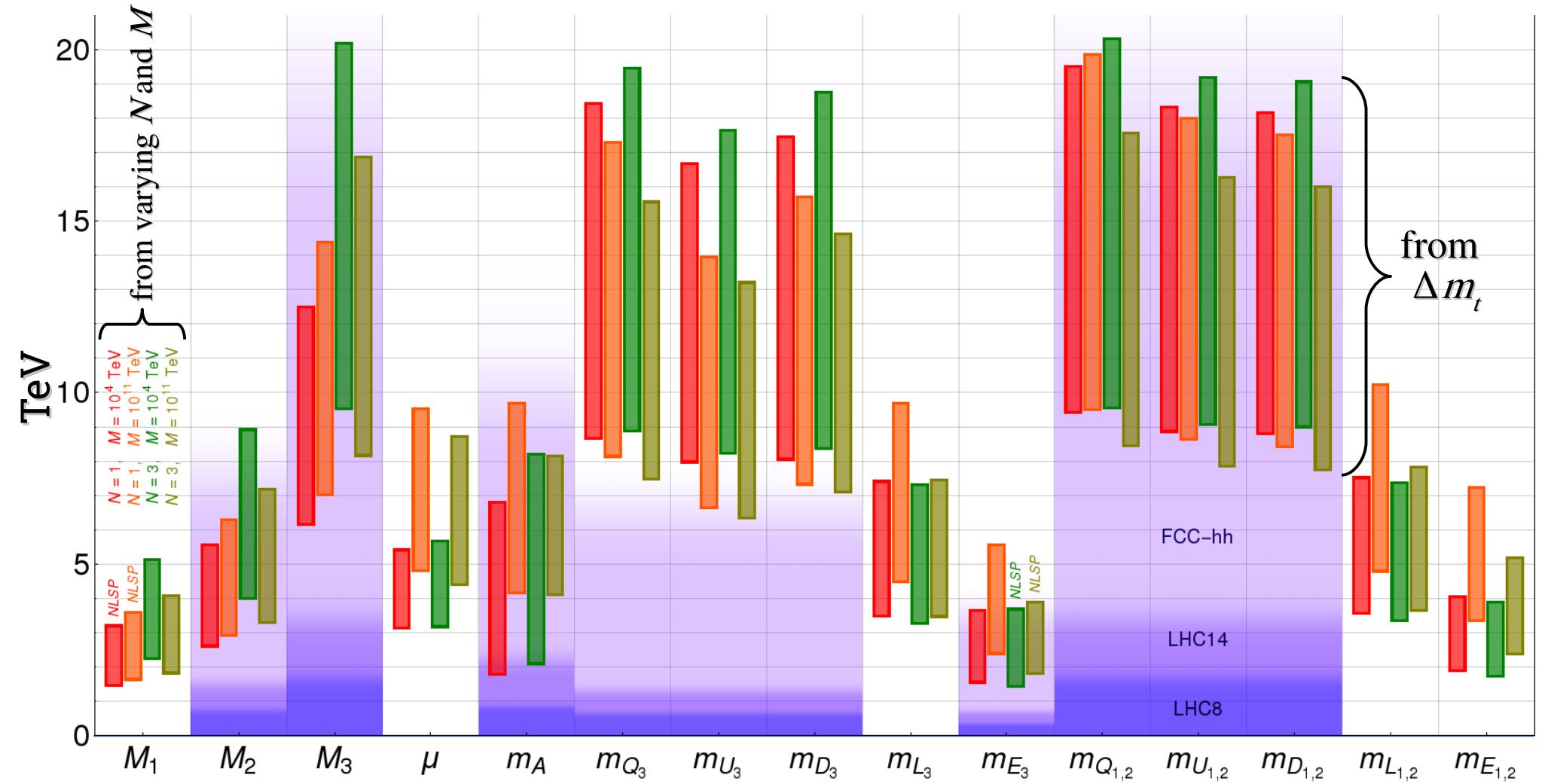
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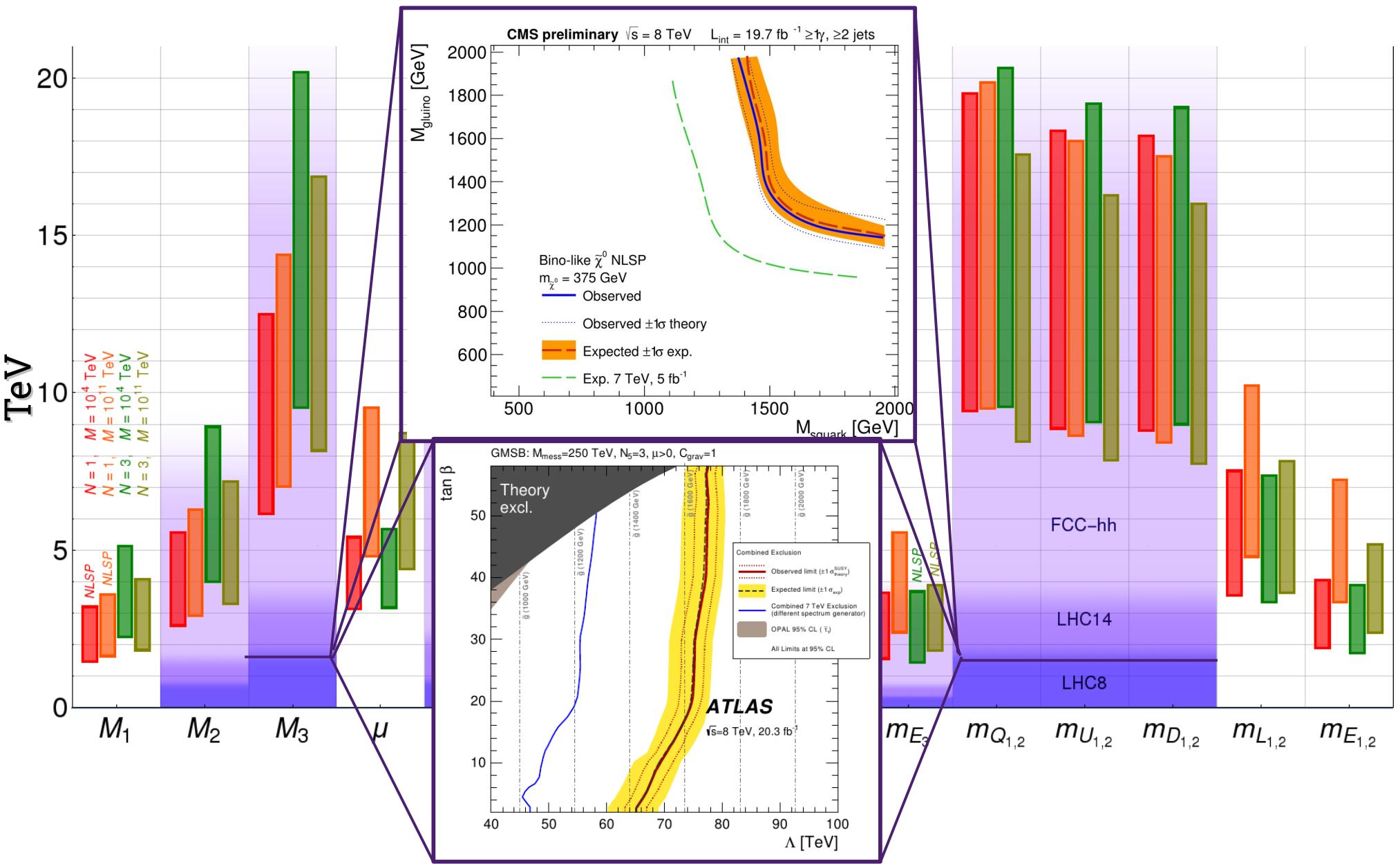
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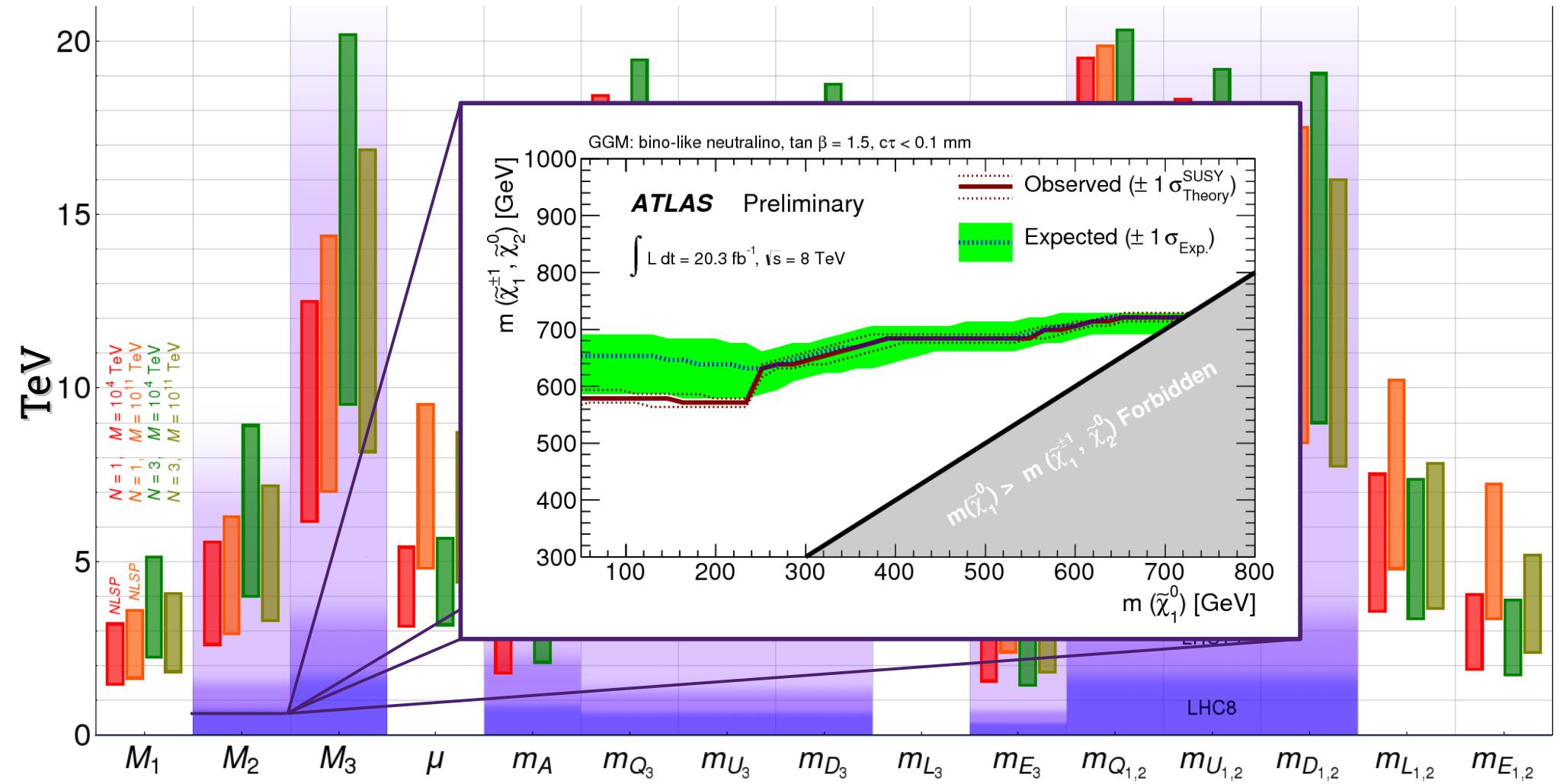
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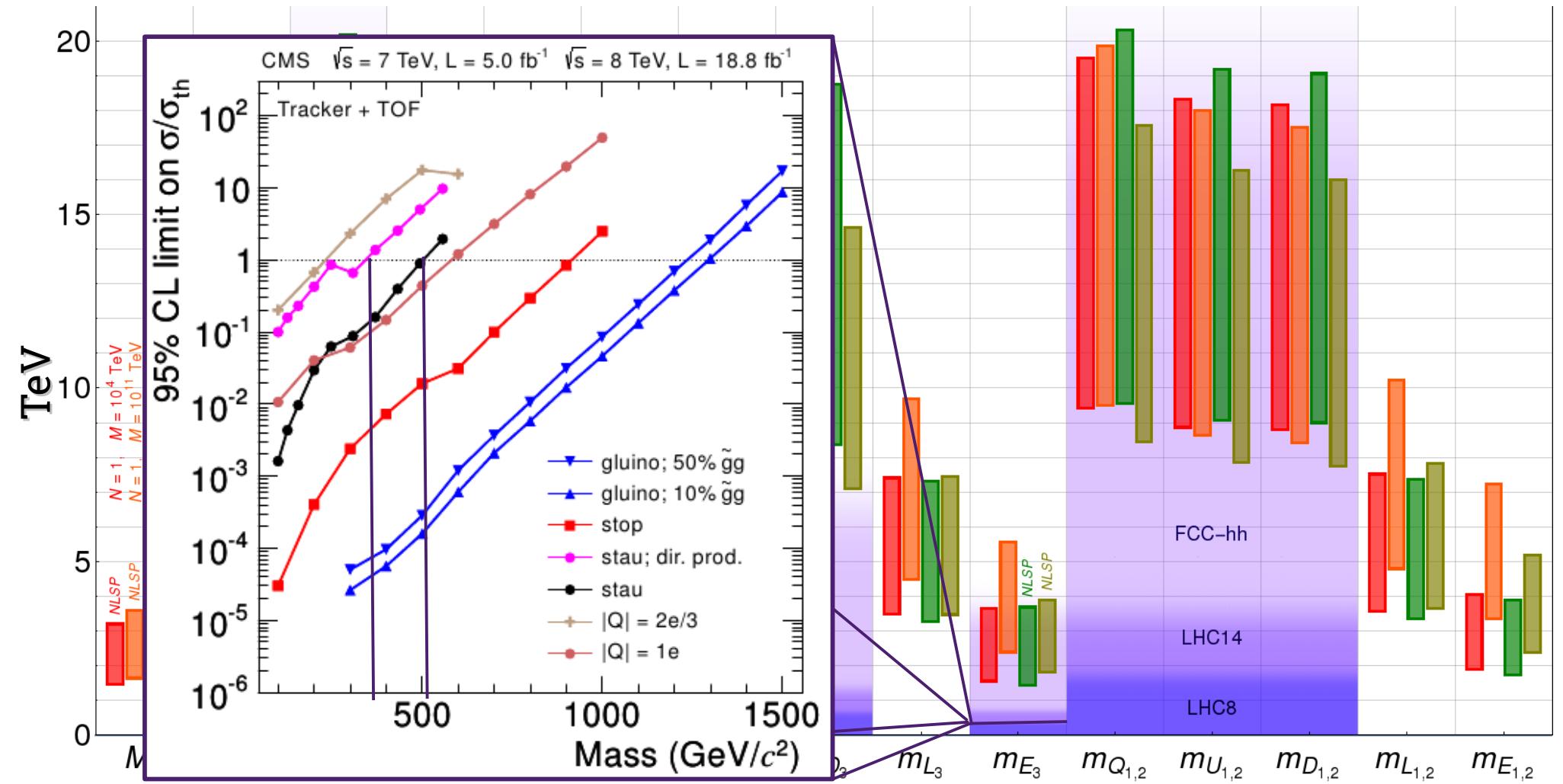
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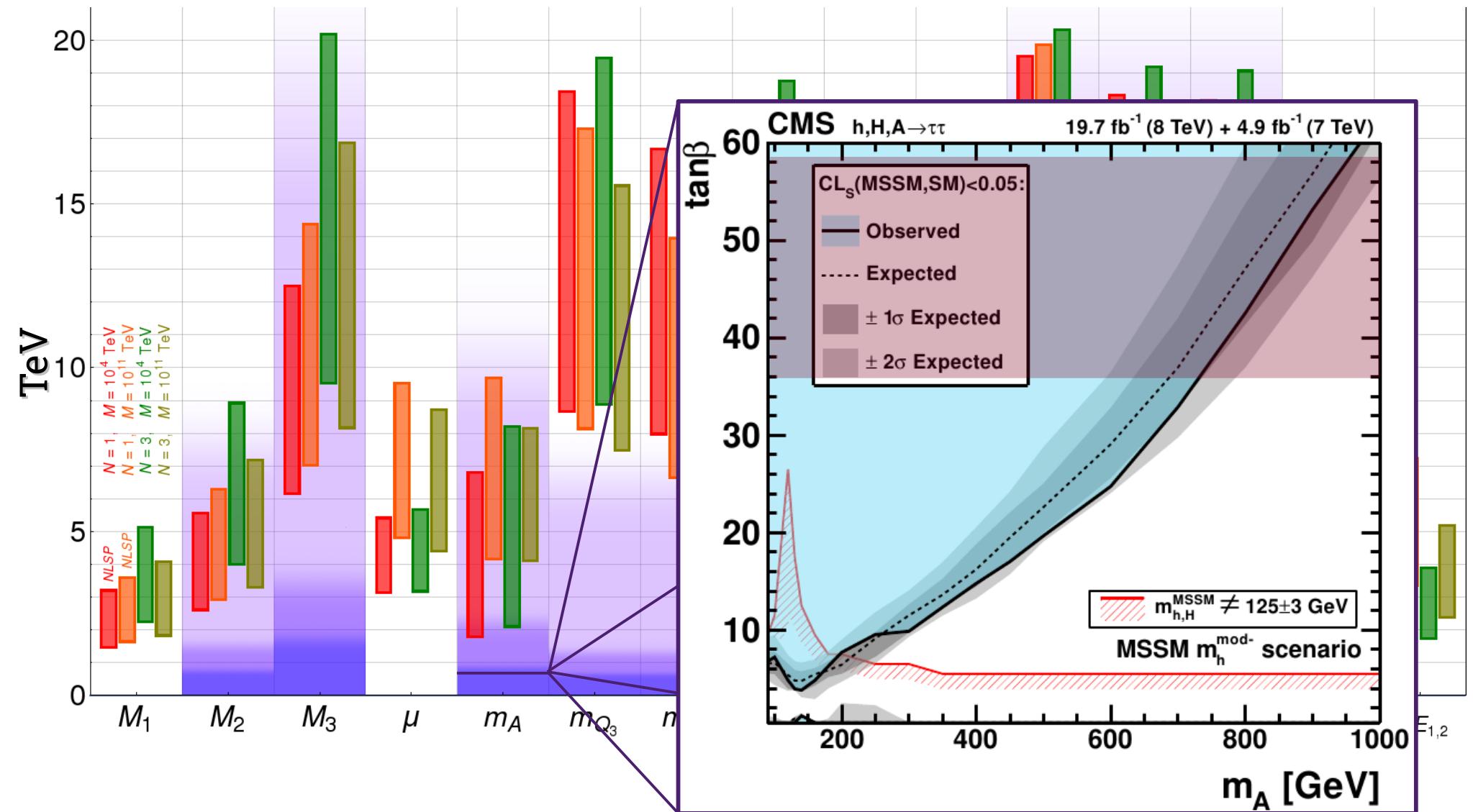
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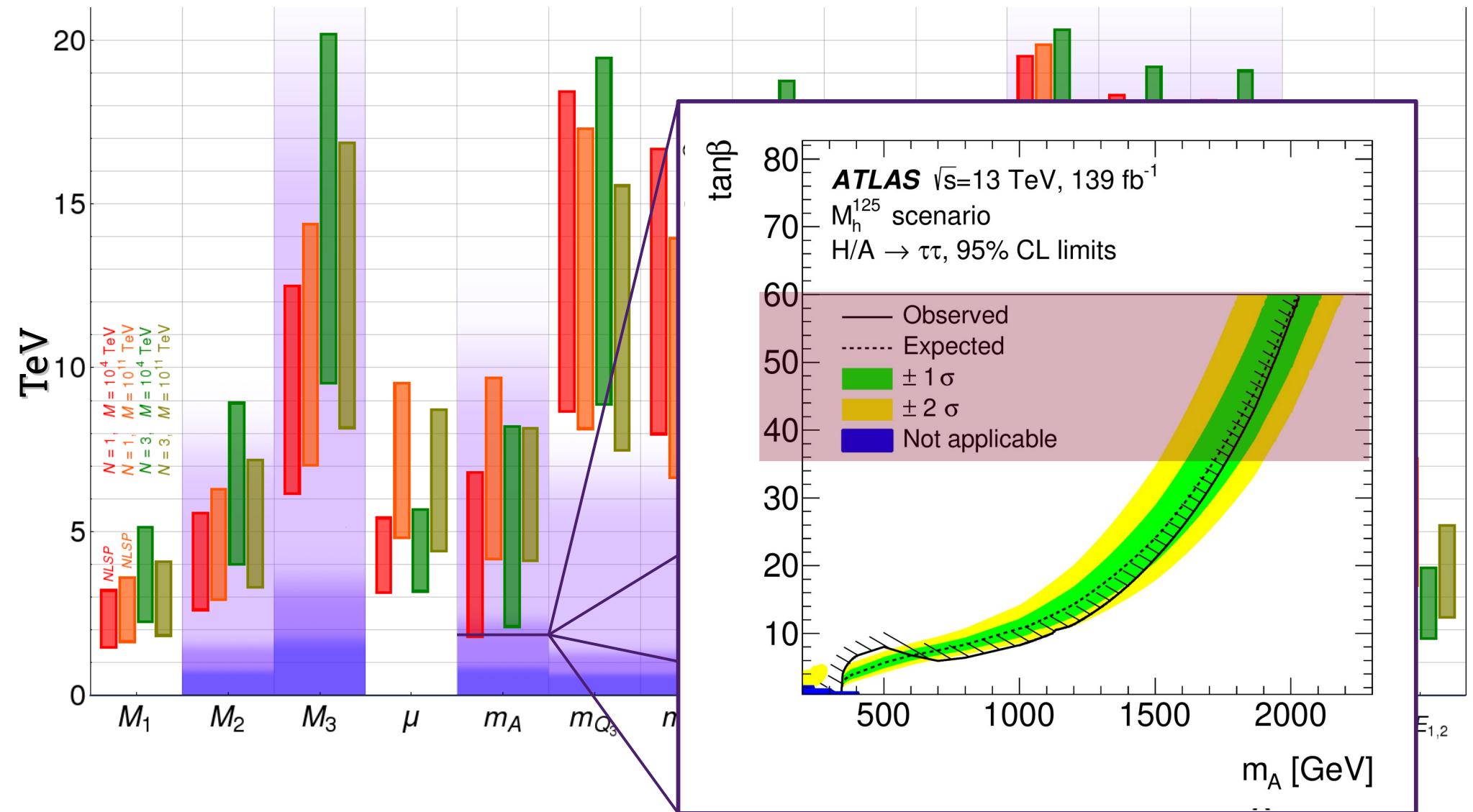
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MGM Summary

fully compatible with: $\left\{ \begin{array}{l} \text{No obs. flavor violation} \\ \text{No obs. EDM*} \\ \text{No obs. Proton decay} \\ \text{No obs. WIMP} \\ \text{No obs. SUSY @ LHC} \end{array} \right.$

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MGM as benchmark for Future Collider – “*work in progress*”

- Muon Collider (and FCC) reach / parameters
- Constraints from cosmology and SUSY breaking sectors



more in general

O(10) TeV SUSY still well motivated
and plausible scenario for BSM

Thank You!

Backup

Estimate of the Uncertainties:

