First FCC-ee mini-workshop on Precision Observables and Radiative Corrections

Predicting SUSY from SM precision physics

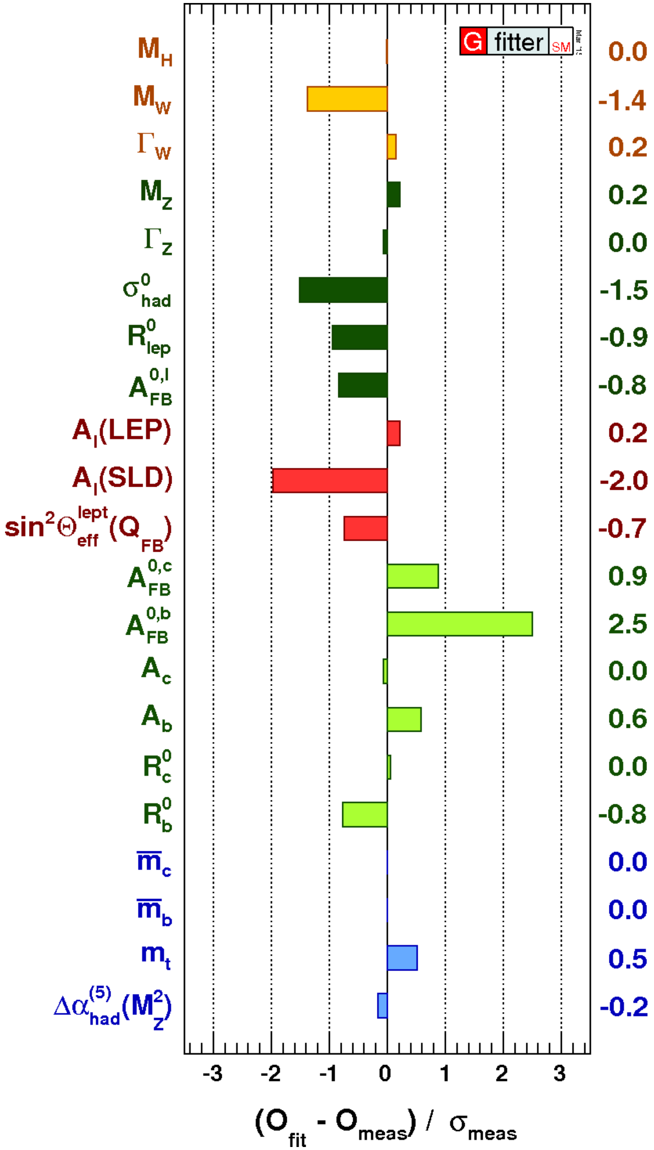
Giovanni Villadoro

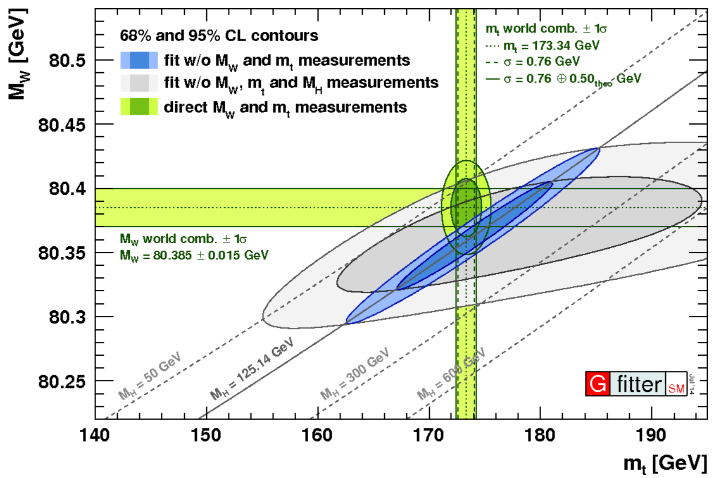
The Abdus Salam International Centre for Theoretical Physics (ICTP)

based on: Javier Pardo Vega and GV arXiv:1504.05200

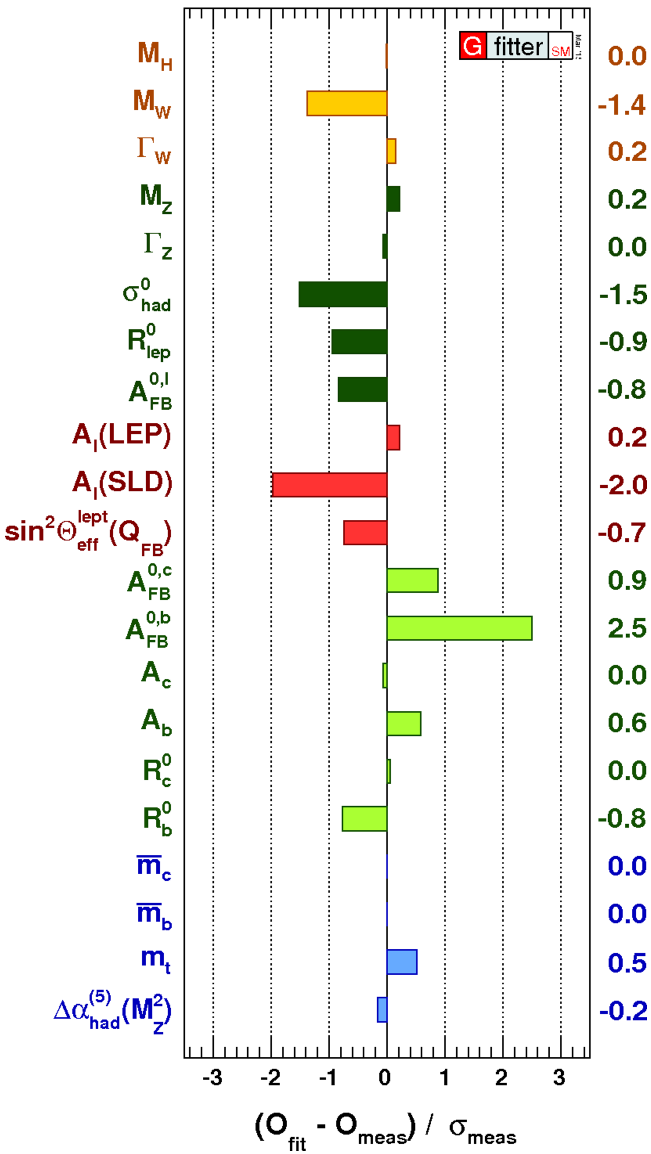
SusyHD

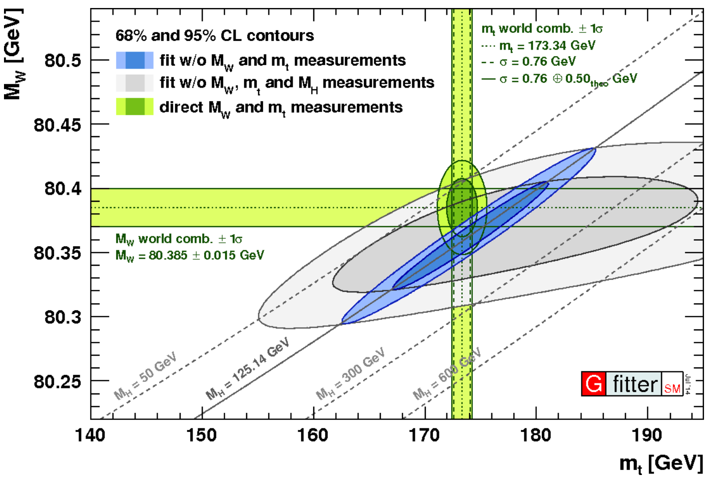
Probing NP with Precision Physics

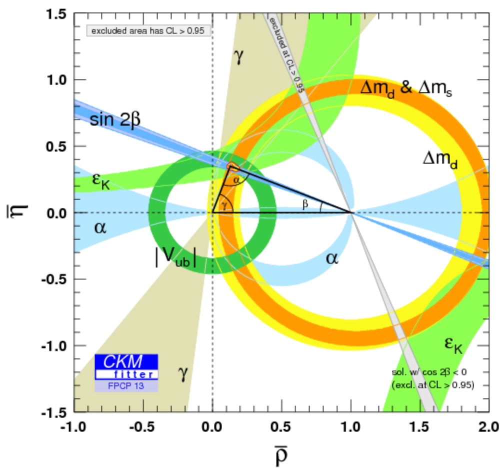




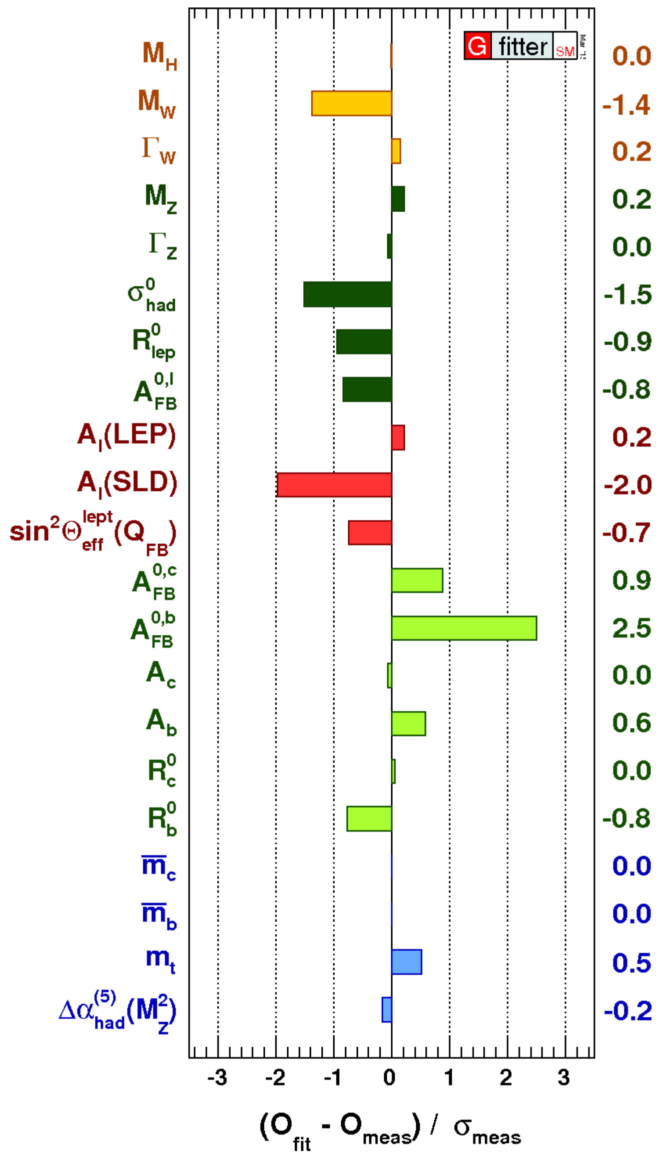
Probing NP with Precision Physics

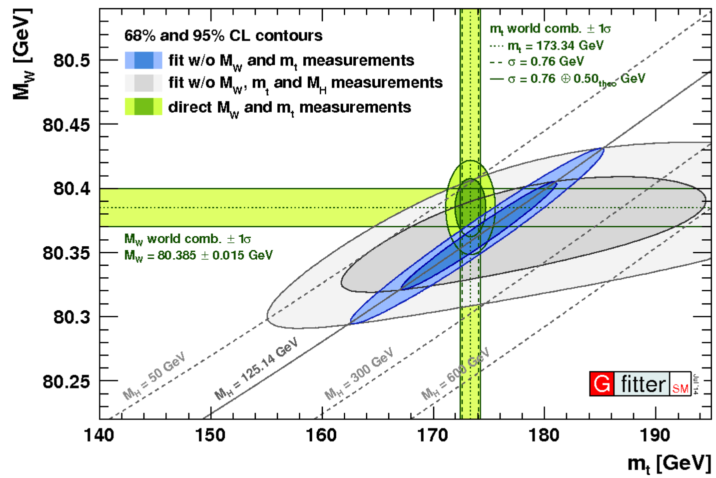


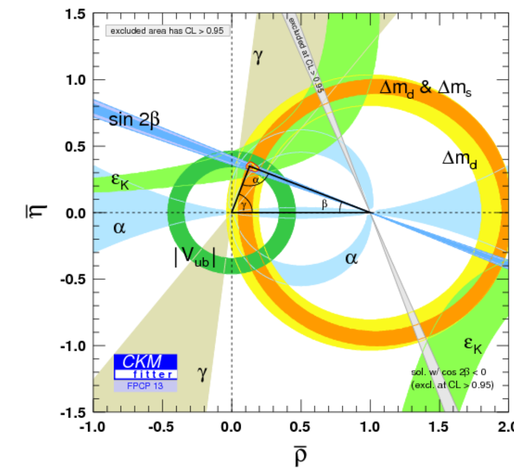


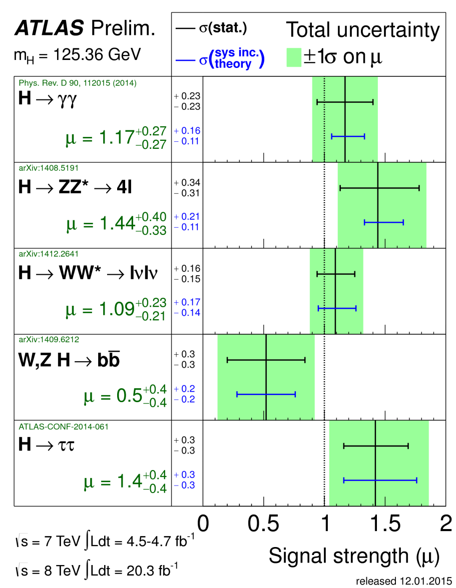


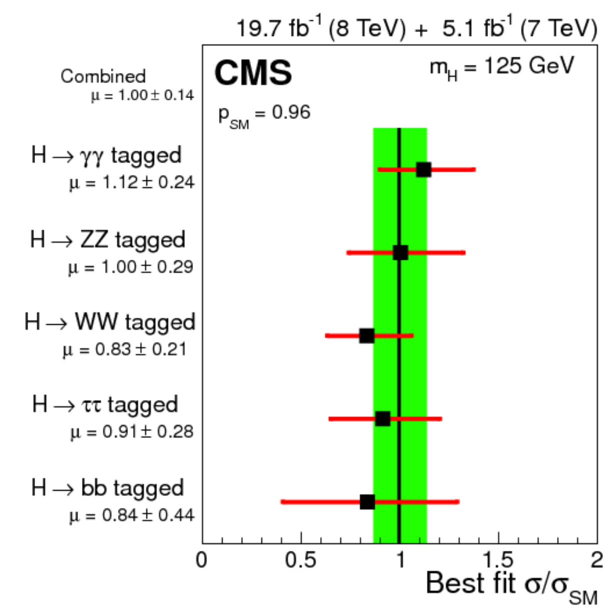
Probing NP with Precision Physics











The case of SUSY

Poincaré $\rightarrow$ SUSY

$\mathcal{P}$ $\qquad$ $\mathcal{S}$

$$\begin{cases} [\mathcal{P},\mathcal{P}] = \mathcal{P} \\ [\mathcal{P},\mathcal{S}] = \mathcal{S} \\ \{\mathcal{S},\mathcal{S}\} = \mathcal{P} \end{cases}$$

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Remarkable features in QFT:

CFT , Dualities , Finiteness , L.P. , etc...

Poincaré → SUSY

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Remarkable features in QFT:

CFT , Dualities , Finiteness , L.P. , etc...

...and in QG:

Supergravity , String Theory

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

SUSY breaking scale?

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

SUSY breaking scale?

$$\delta m_h^2 \sim m_{\rm SUSY}^2$$

ATLAS SUSY Searches* - 95% CL Lower Limits

Status: Feb 2015

ATLAS Preliminary

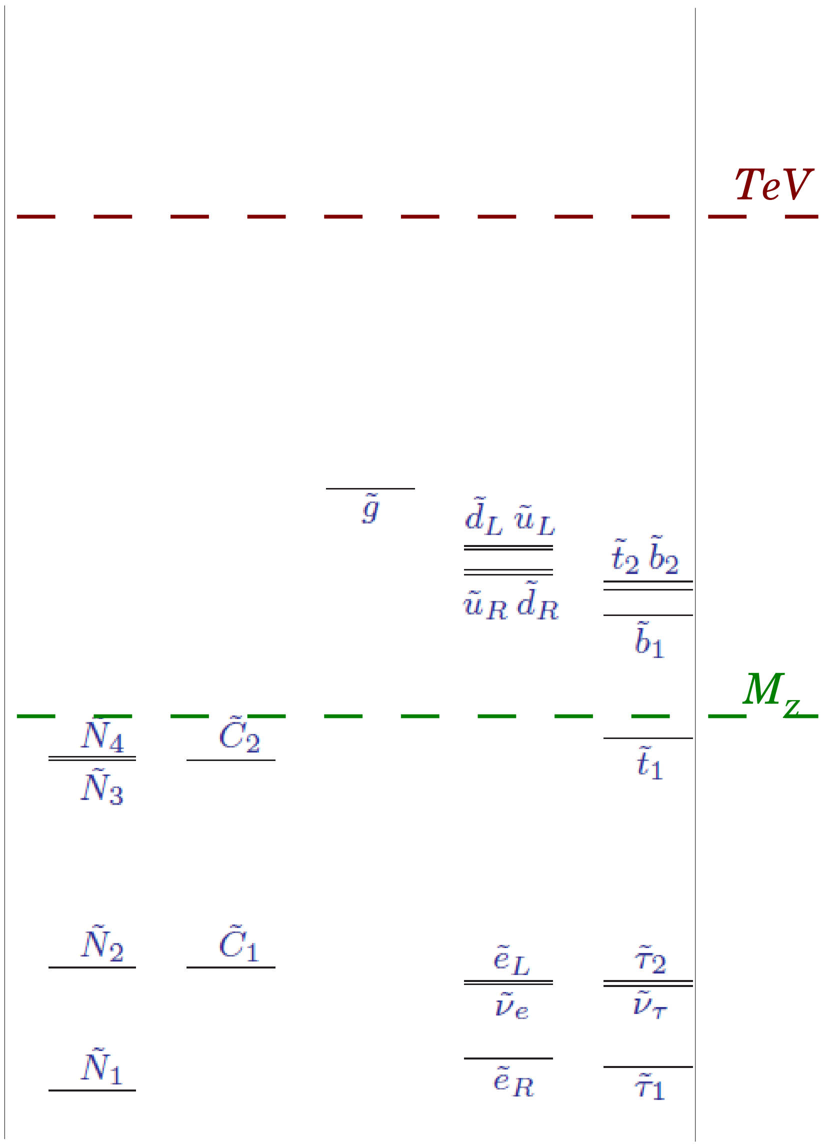
$\sqrt{s}$ = 7, 8 TeV

	Model	e, μ, τ, γ	Jets	E_T^{miss}	$\int \mathcal{L}\, dt[fb^{-1}]$	Mass limit		Reference
Inclusive Searches	MSUGRA/CMSSM	0	2-6 jets	Yes	20.3	$\tilde{q}, \tilde{g}$ 1.7 TeV	$m(\tilde{q})=m(\tilde{g})$	1405.7875
	$\tilde{q}\tilde{q}, \tilde{q}\to q\tilde{\chi}^0_1$	0	2-6 jets	Yes	20.3	$\tilde{q}$ 850 GeV	$m(\tilde{\chi}^0_1)$=0 GeV, m(1st gen. $\tilde{q}$)=m(2nd gen. $\tilde{q}$)	1405.7875
	$\tilde{q}\tilde{q}\gamma, \tilde{q}\to q\tilde{\chi}^0_1$ (compressed)	1 γ	0-1 jet	Yes	20.3	$\tilde{q}$ 250 GeV	$m(\tilde{q})-m(\tilde{\chi}^0_1)$ = m(c)	1411.1559
	$\tilde{g}\tilde{g}, \tilde{g}\to q\bar{q}\tilde{\chi}^0_1$	0	2-6 jets	Yes	20.3	$\tilde{g}$ 1.33 TeV	$m(\tilde{\chi}^0_1)$=0 GeV	1405.7875
	$\tilde{g}\tilde{g}, \tilde{g}\to qq\tilde{\chi}^\pm_1\to qqW^\pm\tilde{\chi}^0_1$	1 e,μ	3-6 jets	Yes	20	$\tilde{g}$ 1.2 TeV	$m(\tilde{\chi}^0_1)$<300 GeV, $m(\tilde{\chi}^\pm)=0.5(m(\tilde{\chi}^0_1)+m(\tilde{g}))$	1501.03555
	$\tilde{g}\tilde{g}, \tilde{g}\to qq(\ell\ell/\ell\nu/\nu\nu)\tilde{\chi}^0_1$	2 e,μ	0-3 jets	-	20	$\tilde{g}$ 1.32 TeV	$m(\tilde{\chi}^0_1)$=0 GeV	1501.03555
	GMSB ($\tilde{\ell}$ NLSP)	1-2 τ + 0-1 ℓ	0-2 jets	Yes	20.3	$\tilde{g}$ 1.6 TeV	$\tan\beta$ >20	1407.0603
	GGM (bino NLSP)	2 γ	-	Yes	20.3	$\tilde{g}$ 1.28 TeV	$m(\tilde{\chi}^0_1)$>50 GeV	ATLAS-CONF-2014-001
	GGM (wino NLSP)	1 $e,\mu+\gamma$	-	Yes	4.8	$\tilde{g}$ 619 GeV	$m(\tilde{\chi}^0_1)$>50 GeV	ATLAS-CONF-2012-144
	GGM (higgsino-bino NLSP)	γ	1 b	Yes	4.8	$\tilde{g}$ 900 GeV	$m(\tilde{\chi}^0_1)$>220 GeV	1211.1167
	GGM (higgsino NLSP)	2 e,μ (Z)	0-3 jets	Yes	5.8	$\tilde{g}$ 690 GeV	m(NLSP)>200 GeV	ATLAS-CONF-2012-152
	Gravitino LSP	0	mono-jet	Yes	20.3	$F^{1/2}$ scale 865 GeV	$m(\tilde{G})>1.8\times10^{-4}$ eV, $m(\tilde{g})=m(\tilde{q})$=1.5 TeV	1502.01518
3^{rd} gen. $\tilde{g}$ med.	$\tilde{g}\to b\bar{b}\tilde{\chi}^0_1$	0	3 b	Yes	20.1	$\tilde{g}$ 1.25 TeV	$m(\tilde{\chi}^0_1)$<400 GeV	1407.0600
	$\tilde{g}\to t\bar{t}\tilde{\chi}^0_1$	0	7-10 jets	Yes	20.3	$\tilde{g}$ 1.1 TeV	$m(\tilde{\chi}^0_1)$ <350 GeV	1308.1841
	$\tilde{g}\to t\bar{t}\tilde{\chi}^0_1$	0-1 e,μ	3 b	Yes	20.1	$\tilde{g}$ 1.34 TeV	$m(\tilde{\chi}^0_1)$<400 GeV	1407.0600
	$\tilde{g}\to b\bar{t}\tilde{\chi}^+_1$	0-1 e,μ	3 b	Yes	20.1	$\tilde{g}$ 1.3 TeV	$m(\tilde{\chi}^0_1)$<300 GeV	1407.0600
3^{rd} gen. squarks direct production	$\tilde{b}_1\tilde{b}_1, \tilde{b}_1\to b\tilde{\chi}^0_1$	0	2 b	Yes	20.1	$\tilde{b}_1$ 100-620 GeV	$m(\tilde{\chi}^0_1)$<90 GeV	1308.2631
	$\tilde{b}_1\tilde{b}_1, \tilde{b}_1\to t\tilde{\chi}^\pm_1$	2 e,μ (SS)	0-3 b	Yes	20.3	$\tilde{b}_1$ 275-440 GeV	$m(\tilde{\chi}^\pm_1)$=2 $m(\tilde{\chi}^0_1)$	1404.2500
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1\to b\tilde{\chi}^\pm_1$	1-2 e,μ	1-2 b	Yes	4.7	$\tilde{t}_1$ 110-167 GeV; 230-460 GeV	$m(\tilde{\chi}^\pm_1)$ = 2$m(\tilde{\chi}^0_1)$, $m(\tilde{\chi}^0_1)$=55 GeV	1209.2102, 1407.0583
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1\to Wb\tilde{\chi}^0_1$ or $t\tilde{\chi}^0_1$	2 e,μ	0-2 jets	Yes	20.3	$\tilde{t}_1$ 90-191 GeV; 215-530 GeV	$m(\tilde{\chi}^0_1)$=1 GeV	1403.4853, 1412.4742
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1\to t\tilde{\chi}^0_1$	0-1 e,μ	1-2 b	Yes	20	$\tilde{t}_1$ 210-640 GeV	$m(\tilde{\chi}^0_1)$=1 GeV	1407.0583,1406.1122
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1\to c\tilde{\chi}^0_1$	0	mono-jet/c-tag	Yes	20.3	$\tilde{t}_1$ 90-240 GeV	$m(\tilde{t}_1)-m(\tilde{\chi}^0_1)$<85 GeV	1407.0608
	$\tilde{t}_1\tilde{t}_1$ (natural GMSB)	2 e,μ (Z)	1 b	Yes	20.3	$\tilde{t}_1$ 150-580 GeV	$m(\tilde{\chi}^0_1)$>150 GeV	1403.5222
	$\tilde{t}_2\tilde{t}_2, \tilde{t}_2\to\tilde{t}_1+Z$	3 e,μ (Z)	1 b	Yes	20.3	$\tilde{t}_2$ 290-600 GeV	$m(\tilde{\chi}^0_1)$<200 GeV	1403.5222
EW direct	$\tilde{\ell}_{L,R}\tilde{\ell}_{L,R}, \tilde{\ell}\to\ell\tilde{\chi}^0_1$	2 e,μ	0	Yes	20.3	$\tilde{\ell}$ 90-325 GeV	$m(\tilde{\chi}^0_1)$=0 GeV	1403.5294
	$\tilde{\chi}^+_1\tilde{\chi}^-_1, \tilde{\chi}^+_1\to\tilde{\ell}\nu(\ell\tilde{\nu})$	2 e,μ	0	Yes	20.3	$\tilde{\chi}^\pm_1$ 140-465 GeV	$m(\tilde{\chi}^0_1)$=0 GeV, $m(\tilde{\ell},\tilde{\nu})=0.5(m(\tilde{\chi}^\pm_1)+m(\tilde{\chi}^0_1))$	1403.5294
	$\tilde{\chi}^+_1\tilde{\chi}^-_1, \tilde{\chi}^+_1\to\tilde{\tau}\nu(\tau\tilde{\nu})$	2 τ	-	Yes	20.3	$\tilde{\chi}^\pm_1$ 100-350 GeV	$m(\tilde{\chi}^0_1)$=0 GeV, $m(\tilde{\tau},\tilde{\nu})=0.5(m(\tilde{\chi}^\pm_1)+m(\tilde{\chi}^0_1))$	1407.0350
	$\tilde{\chi}^\pm_1\tilde{\chi}^0_2\to\tilde{\ell}_L\nu\tilde{\ell}_L\ell(\tilde{\nu}\nu), \ell\tilde{\nu}\tilde{\ell}_L\ell(\tilde{\nu}\nu)$	3 e,μ	0	Yes	20.3	$\tilde{\chi}^\pm_1, \tilde{\chi}^0_2$ 700 GeV	$m(\tilde{\chi}^\pm_1)=m(\tilde{\chi}^0_2)$, $m(\tilde{\chi}^0_1)$=0, $m(\tilde{\ell},\tilde{\nu})=0.5(m(\tilde{\chi}^\pm_1)+m(\tilde{\chi}^0_1))$	1402.7029
	$\tilde{\chi}^\pm_1\tilde{\chi}^0_2\to W\tilde{\chi}^0_1Z\tilde{\chi}^0_1$	2-3 e,μ	0-2 jets	Yes	20.3	$\tilde{\chi}^\pm_1, \tilde{\chi}^0_2$ 420 GeV	$m(\tilde{\chi}^\pm_1)=m(\tilde{\chi}^0_2)$, $m(\tilde{\chi}^0_1)$=0, sleptons decoupled	1403.5294, 1402.7029
	$\tilde{\chi}^\pm_1\tilde{\chi}^0_2\to W\tilde{\chi}^0_1h\tilde{\chi}^0_1, h\to b\bar{b}/WW/\tau\tau/\gamma\gamma$	e,μ,γ	0-2 b	Yes	20.3	$\tilde{\chi}^\pm_1, \tilde{\chi}^0_2$ 250 GeV	$m(\tilde{\chi}^\pm_1)=m(\tilde{\chi}^0_2)$, $m(\tilde{\chi}^0_1)$=0, sleptons decoupled	1501.07110
	$\tilde{\chi}^0_2\tilde{\chi}^0_3, \tilde{\chi}^0_{2,3}\to\tilde{\ell}_R\ell$	4 e,μ	0	Yes	20.3	$\tilde{\chi}^0_{2,3}$ 620 GeV	$m(\tilde{\chi}^0_2)=m(\tilde{\chi}^0_3)$, $m(\tilde{\chi}^0_1)$=0, $m(\tilde{\ell},\tilde{\nu})=0.5(m(\tilde{\chi}^0_2)+m(\tilde{\chi}^0_1))$	1405.5086
Long-lived particles	Direct $\tilde{\chi}^+_1\tilde{\chi}^-_1$ prod., long-lived $\tilde{\chi}^\pm_1$	Disapp. trk	1 jet	Yes	20.3	$\tilde{\chi}^\pm_1$ 270 GeV	$m(\tilde{\chi}^\pm_1)-m(\tilde{\chi}^0_1)$=160 MeV, $\tau(\tilde{\chi}^\pm_1)$=0.2 ns	1310.3675
	Stable, stopped $\tilde{g}$ R-hadron	0	1-5 jets	Yes	27.9	$\tilde{g}$ 832 GeV	$m(\tilde{\chi}^0_1)$=100 GeV, 10 $\mu s<\tau(\tilde{g})<$1000 s	1310.6584
	Stable $\tilde{g}$ R-hadron	trk	-	-	19.1	$\tilde{g}$ 1.27 TeV		1411.6795
	GMSB, stable $\tilde{\tau}, \tilde{\chi}^0_1\to\tilde{\tau}(\tilde{e},\tilde{\mu})+\tau(e,\mu)$	1-2 μ	-	-	19.1	$\tilde{\chi}^0_1$ 537 GeV	10<$\tan\beta$<50	1411.6795
	GMSB, $\tilde{\chi}^0_1\to\gamma\tilde{G}$, long-lived $\tilde{\chi}^0_1$	2 γ	-	Yes	20.3	$\tilde{\chi}^0_1$ 435 GeV	2<$\tau(\tilde{\chi}^0_1)$<3 ns, SPS8 model	1409.5542
	$\tilde{q}\tilde{q}, \tilde{\chi}^0_1\to qq\mu$ (RPV)	1 μ, displ. vtx	-	-	20.3	$\tilde{q}$ 1.0 TeV	1.5 <$c\tau$<156 mm, BR(μ)=1, $m(\tilde{\chi}^0_1)$=108 GeV	ATLAS-CONF-2013-092
RPV	LFV $pp\to\tilde{\nu}_\tau+X, \tilde{\nu}_\tau\to e+\mu$	2 e,μ	-	-	4.6	$\tilde{\nu}_\tau$ 1.61 TeV	λ'_{311}=0.10, λ_{132}=0.05	1212.1272
	LFV $pp\to\tilde{\nu}_\tau+X, \tilde{\nu}_\tau\to e(\mu)+\tau$	1 $e,\mu+\tau$	-	-	4.6	$\tilde{\nu}_\tau$ 1.1 TeV	λ'_{311}=0.10, $\lambda_{1(2)33}$=0.05	1212.1272
	Bilinear RPV CMSSM	2 e,μ (SS)	0-3 b	Yes	20.3	$\tilde{q}, \tilde{g}$ 1.35 TeV	$m(\tilde{q})=m(\tilde{g})$, $c\tau_{LSP}$<1 mm	1404.2500
	$\tilde{\chi}^+_1\tilde{\chi}^-_1, \tilde{\chi}^+_1\to W\tilde{\chi}^0_1, \tilde{\chi}^0_1\to ee\tilde{\nu}_\mu, e\mu\tilde{\nu}_e$	4 e,μ	-	Yes	20.3	$\tilde{\chi}^\pm_1$ 750 GeV	$m(\tilde{\chi}^0_1)$>0.2×$m(\tilde{\chi}^\pm_1)$, $\lambda_{121}\neq0$	1405.5086
	$\tilde{\chi}^+_1\tilde{\chi}^-_1, \tilde{\chi}^+_1\to W\tilde{\chi}^0_1, \tilde{\chi}^0_1\to\tau\tau\tilde{\nu}_e, e\tau\tilde{\nu}_\tau$	3 $e,\mu+\tau$	-	Yes	20.3	$\tilde{\chi}^\pm_1$ 450 GeV	$m(\tilde{\chi}^0_1)$>0.2×$m(\tilde{\chi}^\pm_1)$, $\lambda_{133}\neq0$	1405.5086
	$\tilde{g}\to qqq$	0	6-7 jets	-	20.3	$\tilde{g}$ 916 GeV	BR(t)=BR(b)=BR(c)=0%	ATLAS-CONF-2013-091
	$\tilde{g}\to\tilde{t}_1t, \tilde{t}_1\to bs$	2 e,μ (SS)	0-3 b	Yes	20.3	$\tilde{g}$ 850 GeV		1404.250
Other	Scalar charm, $\tilde{c}\to c\tilde{\chi}^0_1$	0	2 c	Yes	20.3	$\tilde{c}$ 490 GeV	$m(\tilde{\chi}^0_1)$<200 GeV	1501.01325

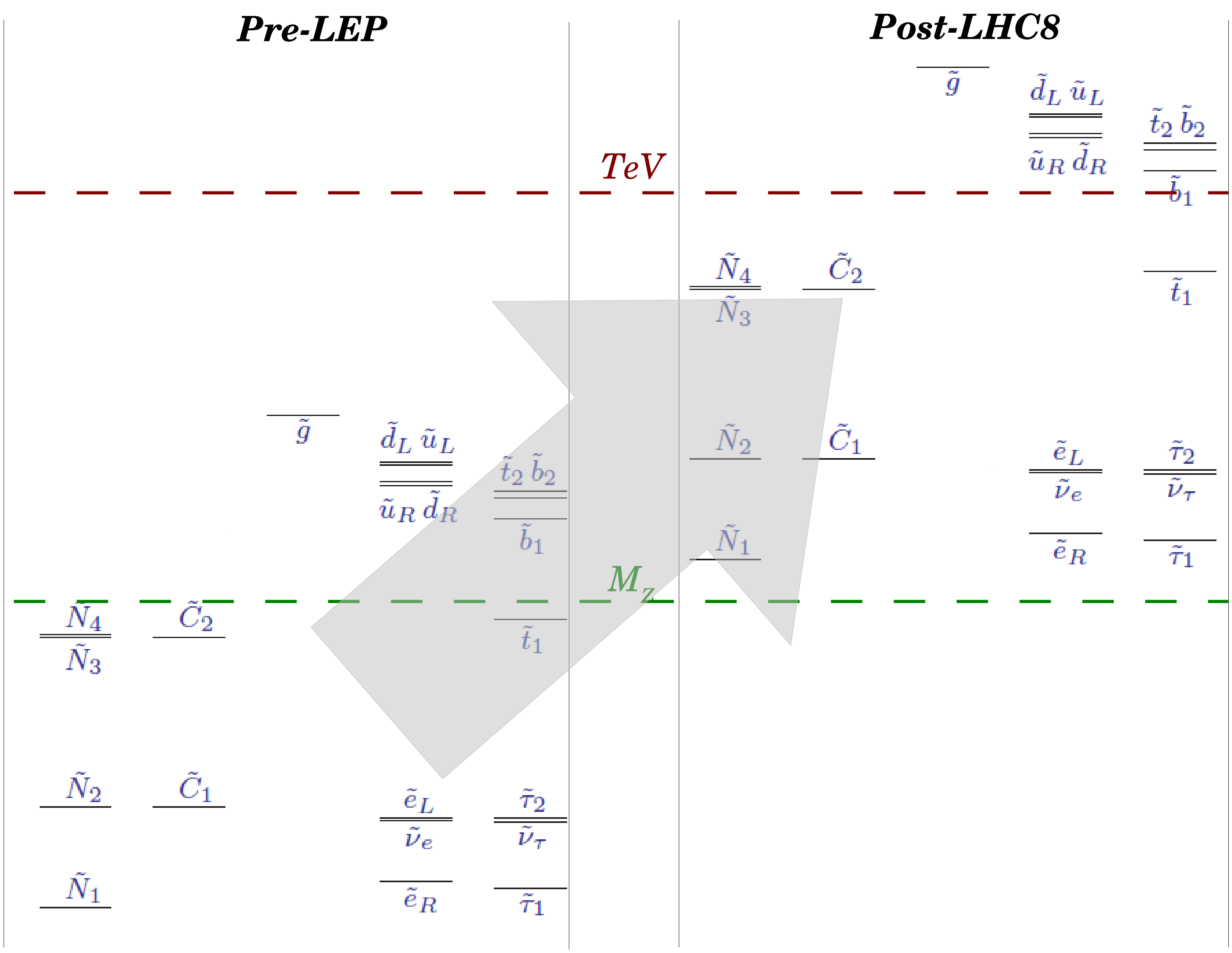
$\sqrt{s}$ = 7 TeV full data | $\sqrt{s}$ = 8 TeV partial data | $\sqrt{s}$ = 8 TeV full data

10^{-1} 1 Mass scale [TeV]

How Natural SUSY would look like



Reality


Pre-LEP
Post-LHC8
TeV
M_Z
$\tilde{g}$
$\tilde{d}_L\ \tilde{u}_L$
$\tilde{u}_R\ \tilde{d}_R$
$\tilde{t}_2\ \tilde{b}_2$
$\tilde{b}_1$
$\tilde{t}_1$
$\tilde{N}_4$
$\tilde{N}_3$
$\tilde{C}_2$
$\tilde{N}_2$
$\tilde{C}_1$
$\tilde{N}_1$
$\tilde{e}_L$
$\tilde{\nu}_e$
$\tilde{e}_R$
$\tilde{\tau}_2$
$\tilde{\nu}_\tau$
$\tilde{\tau}_1$

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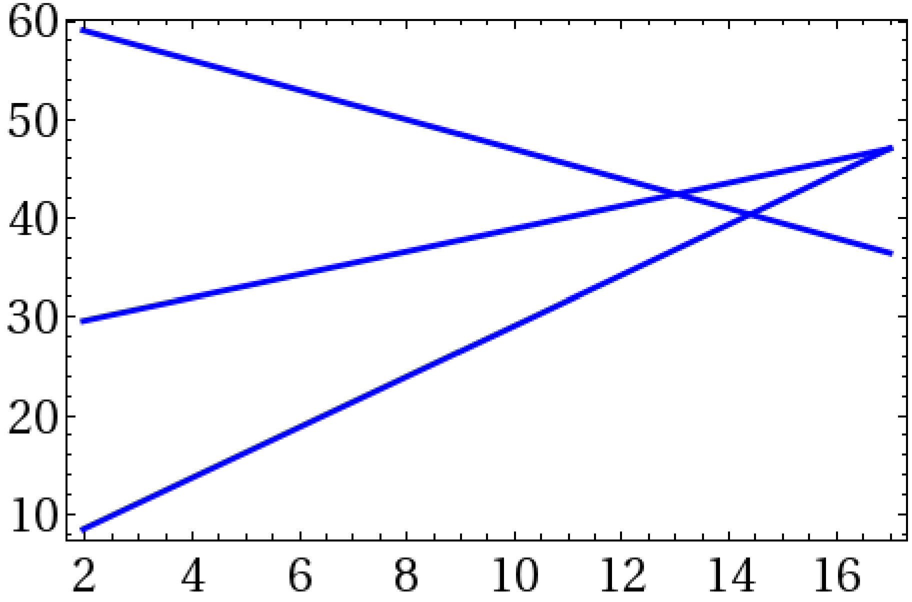
Bigger pressure to low scale SUSY!

Naturalness not a good criterion to predict SUSY?

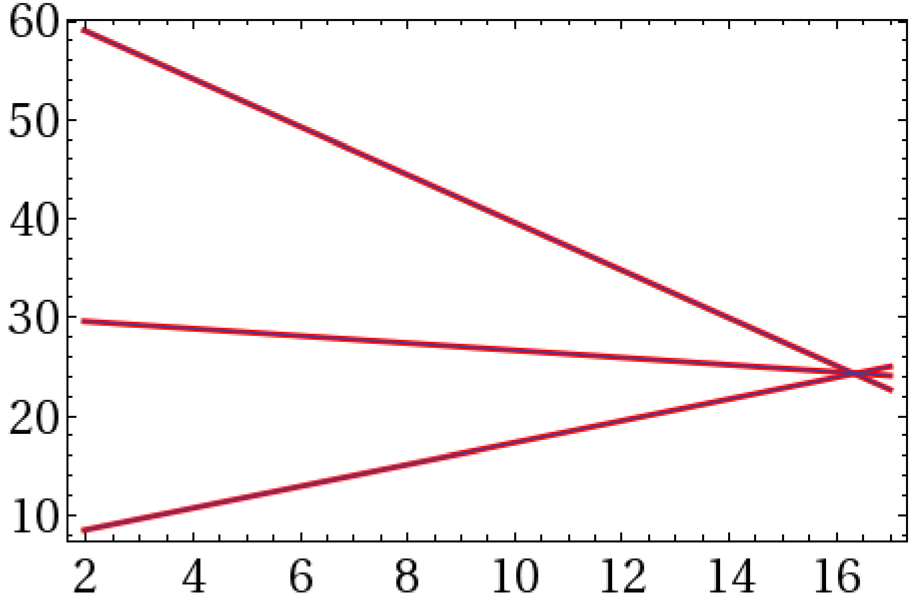
Weaker argument:

Gauge Coupling Unification

SM

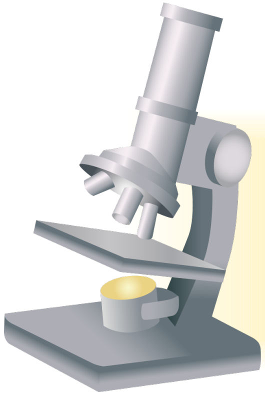


MSSM



$$m_{\mathrm{SUSY}} \lesssim \mathrm{few} \cdot 10\ \mathrm{TeV}$$

SUSY breaking scale?



Back to Experiments

Use Precision Data

In SUSY the Higgs mass is calculable:

ATLAS + CMS $m_h^{\text{exp}} = 125.09 \pm 0.24\ \text{GeV}$

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only *log*-dependence on new physics scale

⇒ high precision to get reliable constraints

Exploiting the Hierarchy Problem:

the EFT technique

SUSY

SM

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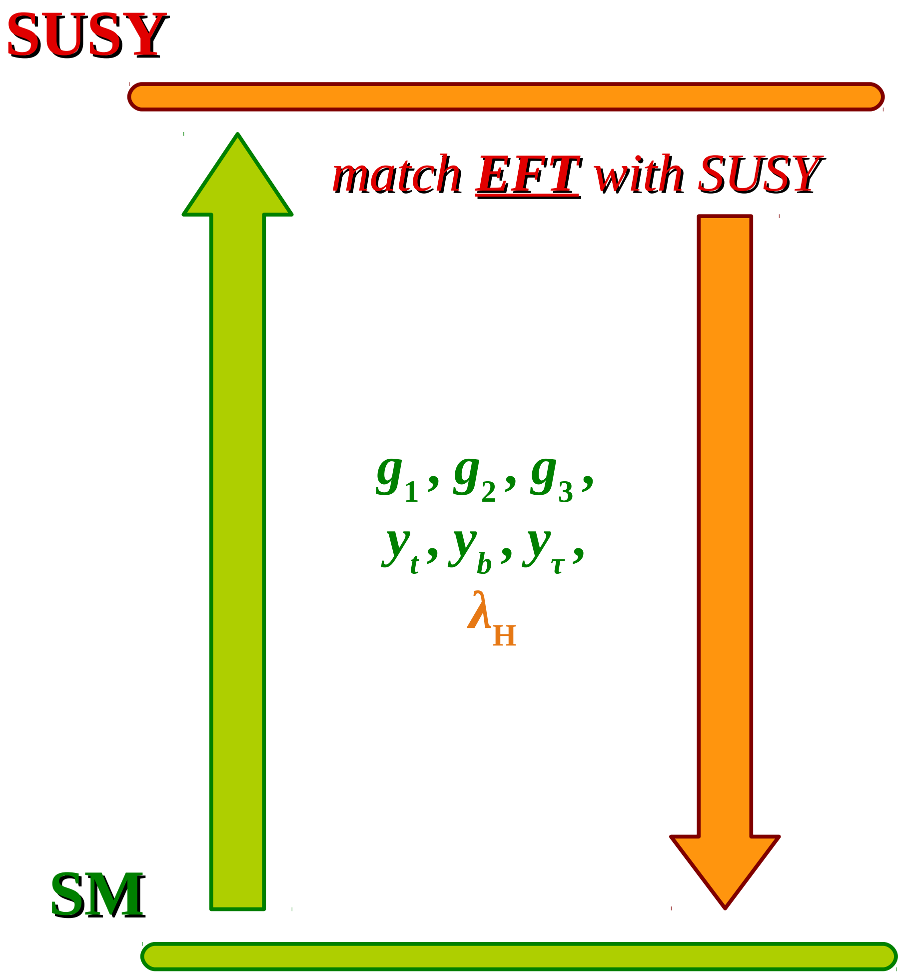
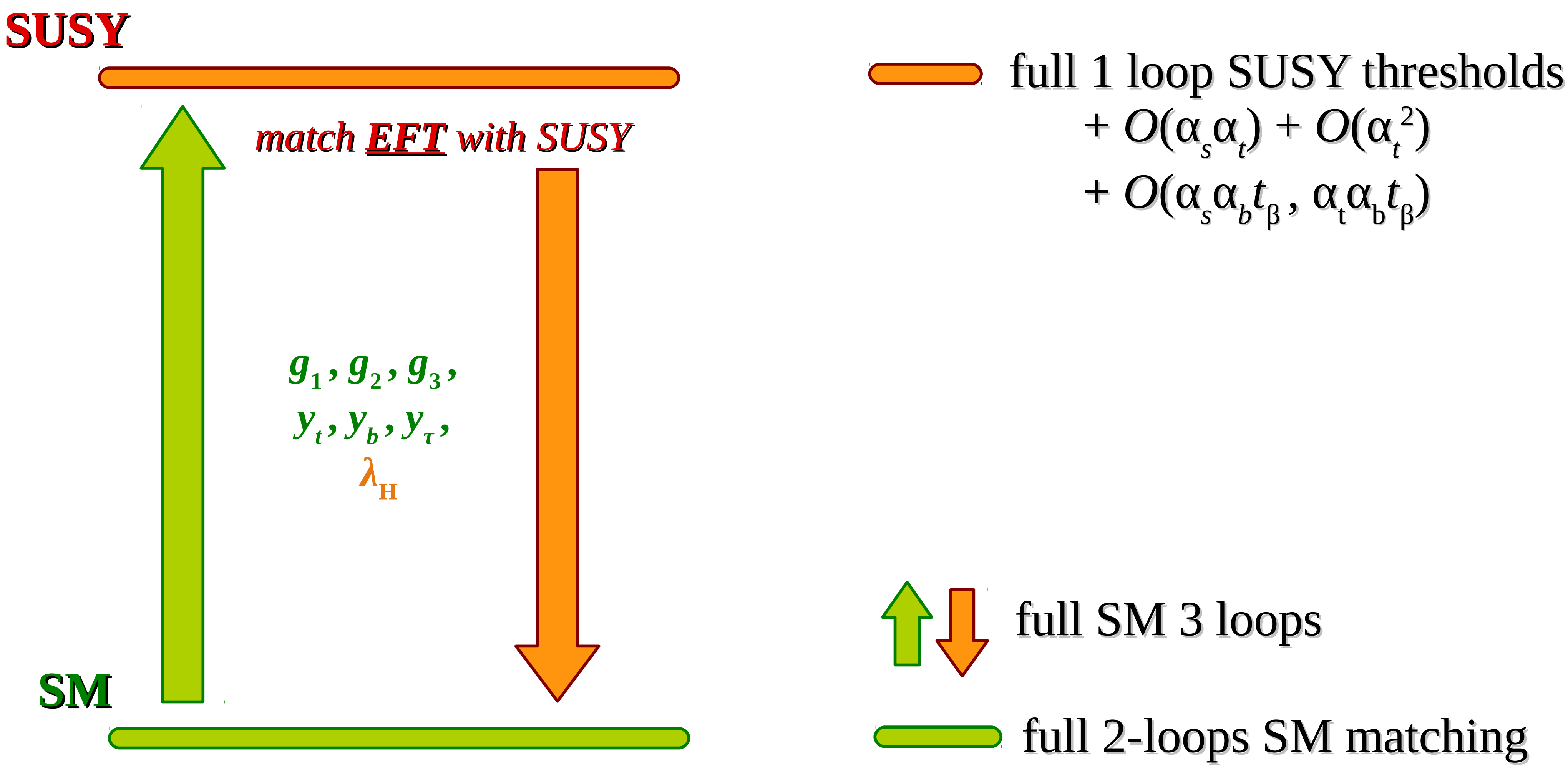
the EFT technique



Exploiting the Hierarchy Problem:

the EFT technique



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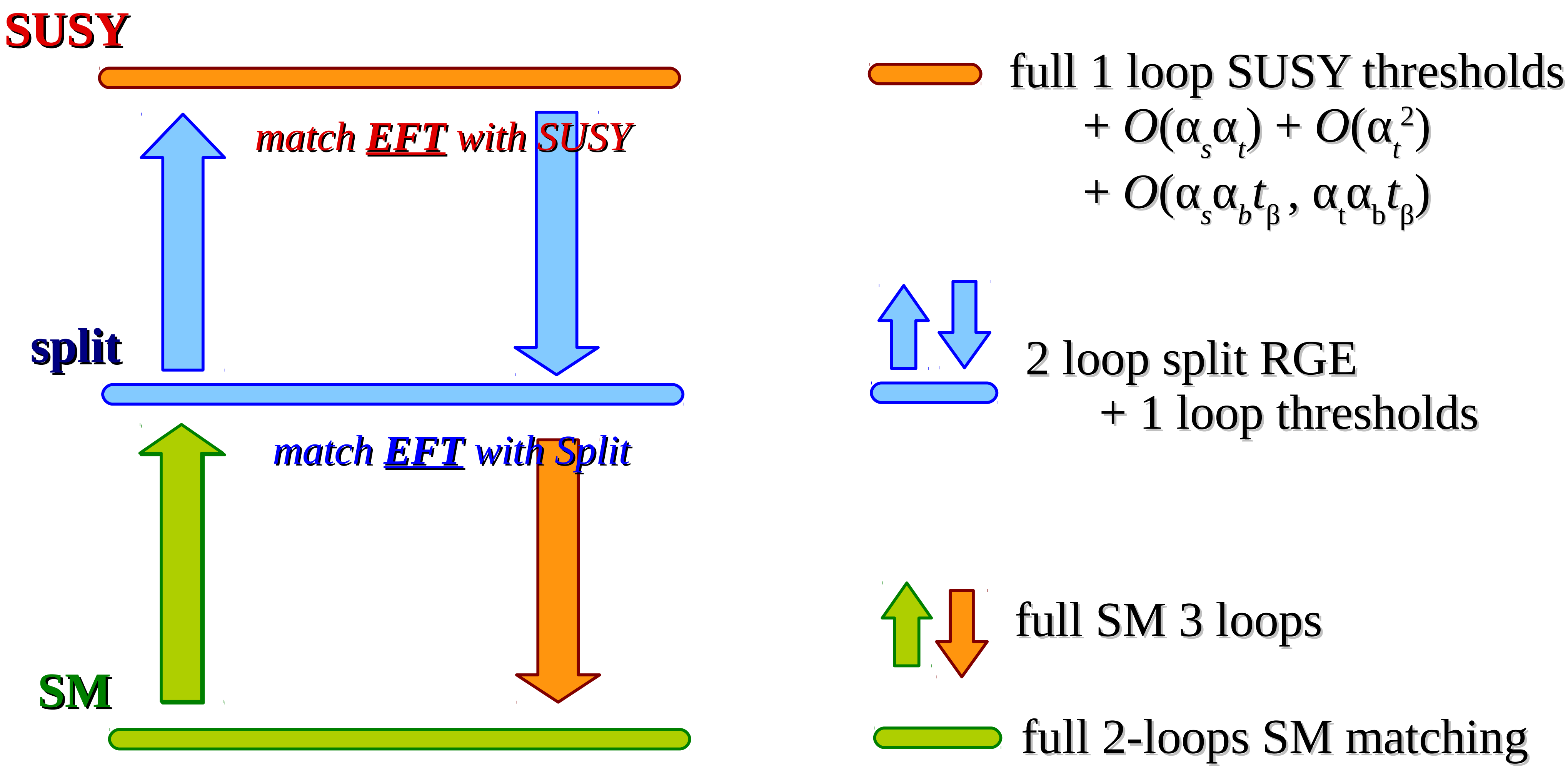
the EFT technique



Small improvement w.r.t. to a longstanding effort

Pokorski, Rosiek, Dabelstein, Zhang, Espinosa, Quiros, Hempfling, Hoang, Heinemeyer, Hollik, Weiglein, Brignole, Slavich, Zwirner, Degrassi, Martin, Giudice, Strumia, Wagner … many many others

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Our contribution: (mostly w.r.t. Bagnaschi *et al*. '14)

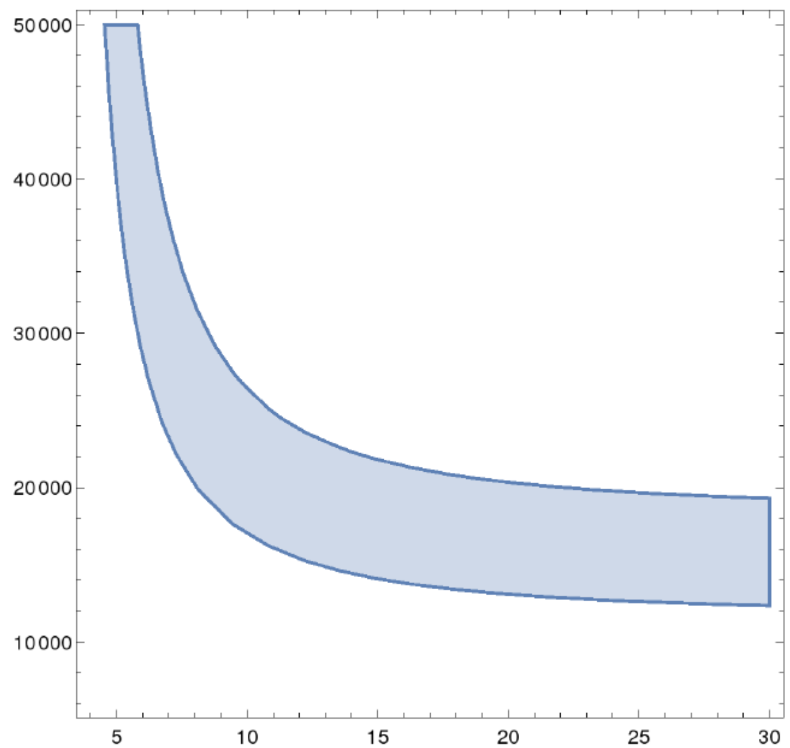
- Recomputation of $O(\alpha_s \alpha_t)$ corrections
- Computation of $O(\alpha_t^2)$ with scale dependence
- Inclusion bottom/tau corrections (w/ resummation of tanβ enhanced corr.)
- Computation both in DRbar and OS schemes
- Study of the uncertainties and comparison with existing computations
- A "fast" Mathematica® package: SusyHD

SusyHD

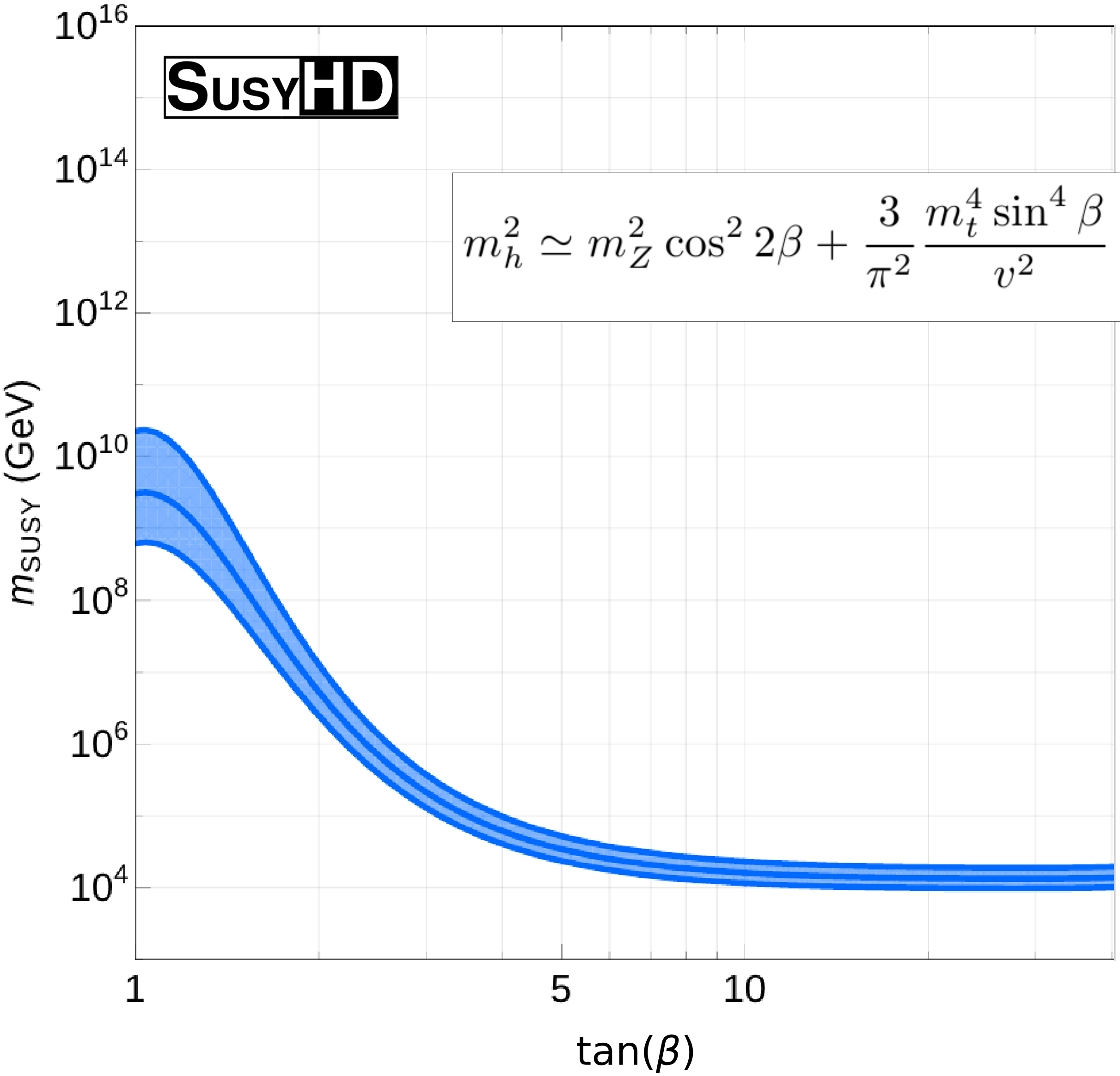
www.ictp.it/~susyhd

```
In[1]:= << SUSYHD`

In[2]:= mh := MHiggs[{tb, m0, At}]
        Δmh := ΔMHiggs[{tb, m0, At}]

In[4]:= tb := 20;
        m0 := 2000;
        At := 5000;
        mh // Timing
        Δmh // Timing

Out[7]= {0.006999, 125.033}

Out[8]= {0.039994, 1.30843}

In[9]:= RegionPlot[125 - Δmh < mh < 125 + Δmh, {tb, 4, 30}, {m0, 6000, 50 000}
```

Out[9]=



SUSY breaking scale?

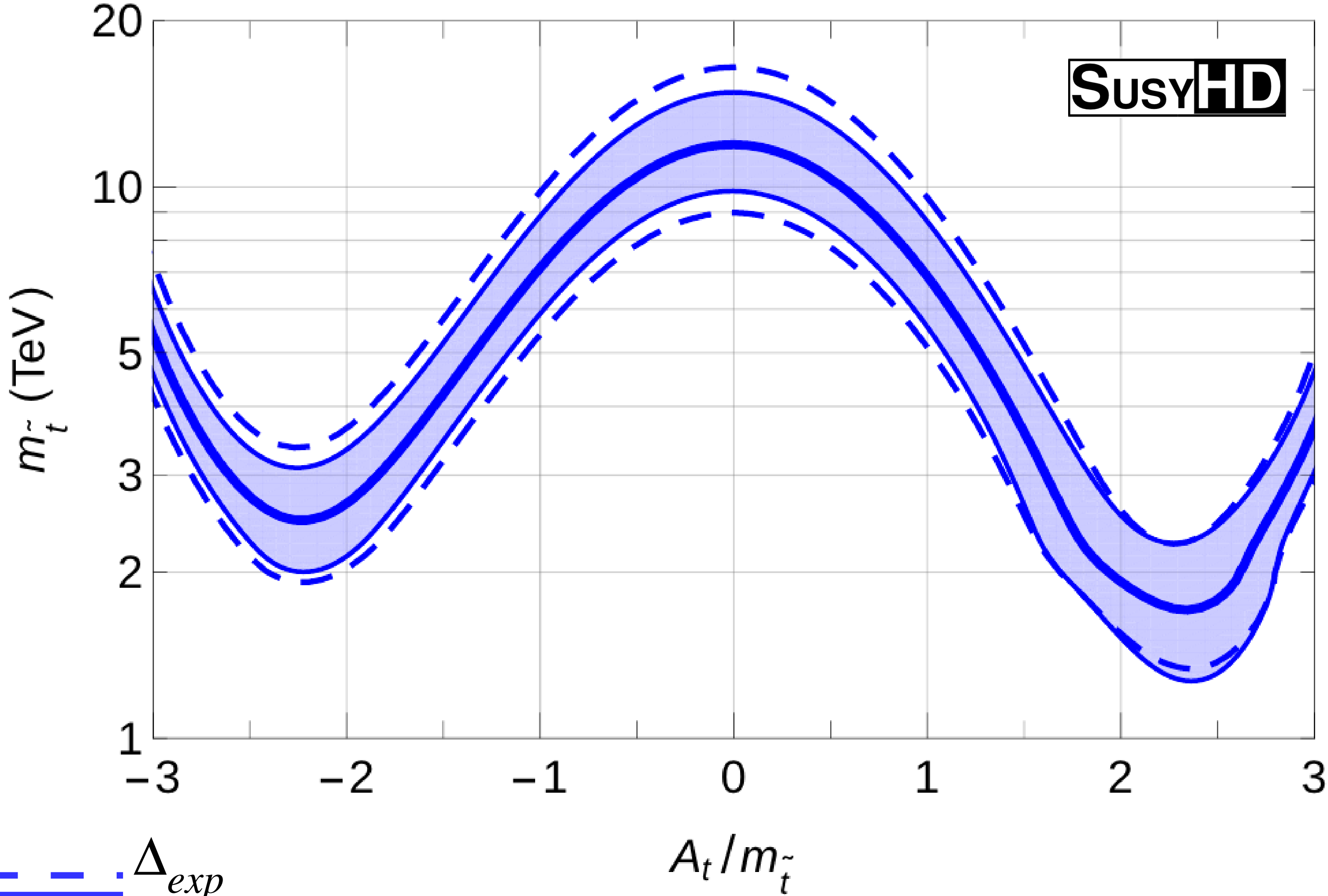


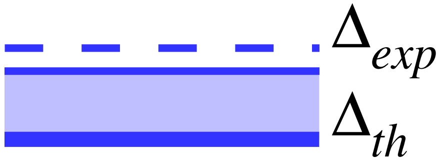
$$m_h^2 \simeq m_Z^2 \cos^2 2\beta + \frac{3}{\pi^2} \frac{m_t^4 \sin^4 \beta}{v^2} \left[\log \frac{m_{\tilde{t}}^2}{m_t^2} + \tilde{X}_t^2 \left(1 - \frac{\tilde{X}_t^2}{12} \right) \right] + \ldots$$

see also Giudice, Strumia '11

A "natural" SUSY-like spectrum:

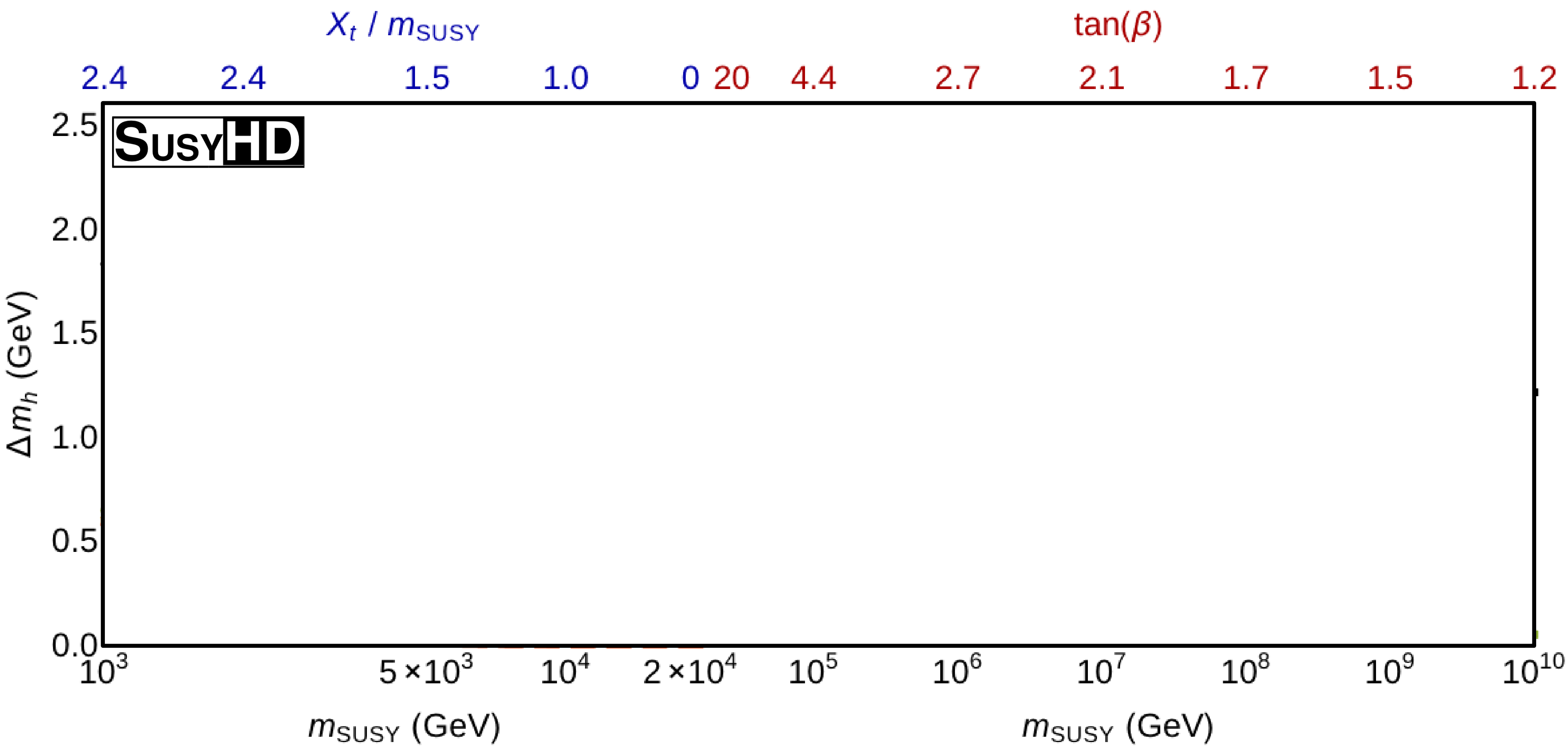
$\tan\beta = 20$, $\mu = 300$ GeV , $m_{SUSY} = 2$ TeV





$$\partial A_t / \partial \mu > 0$$

Estimate of the Uncertainties:



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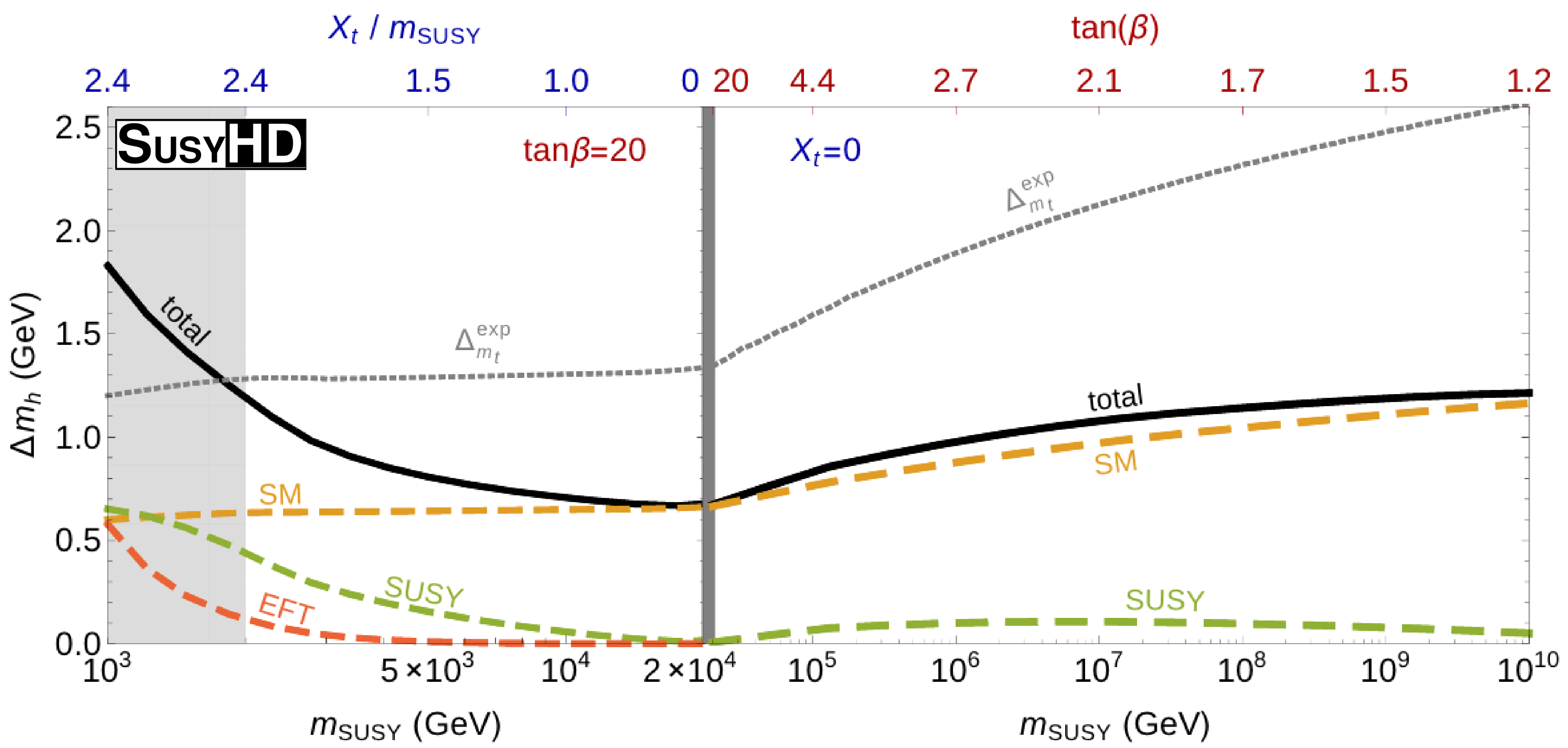

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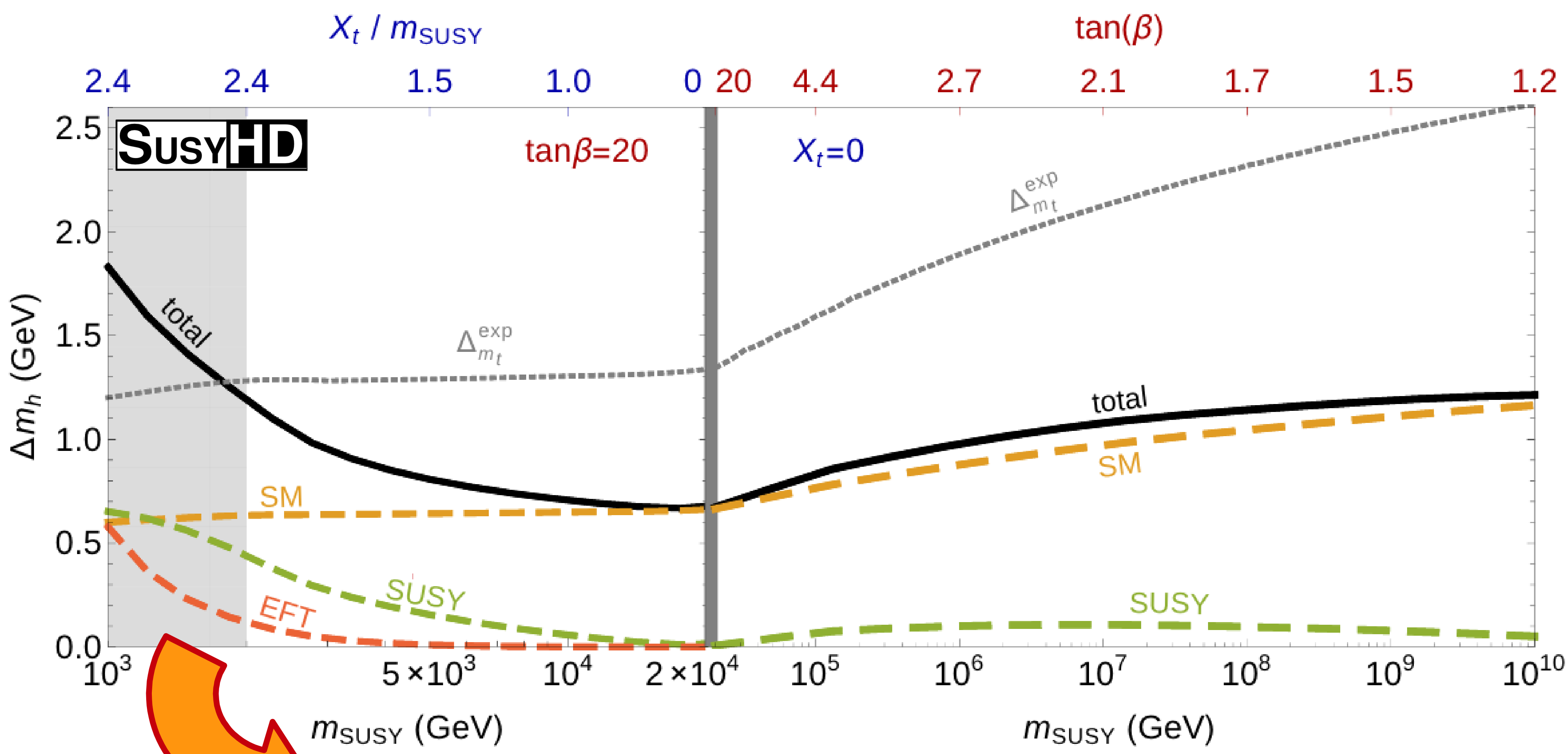
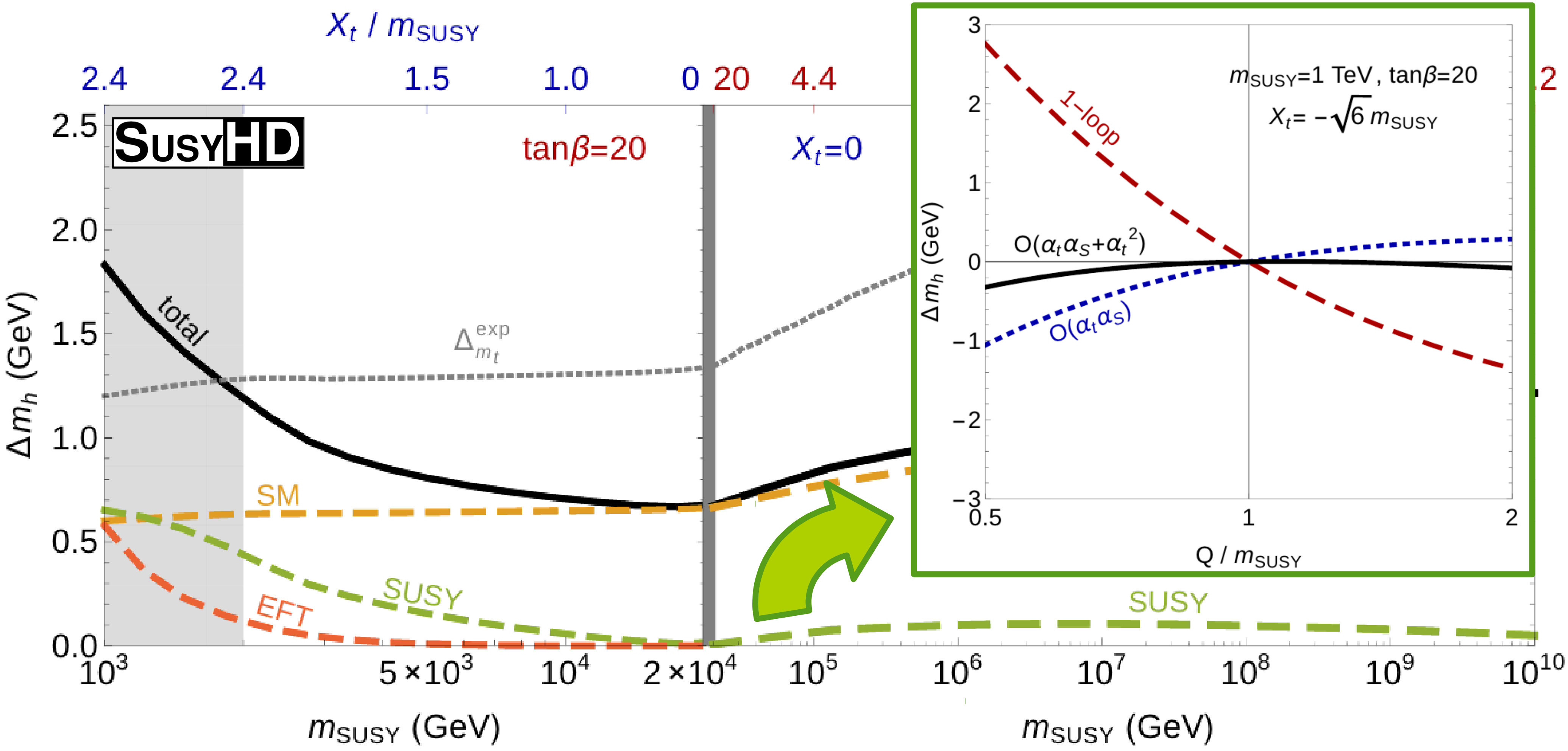
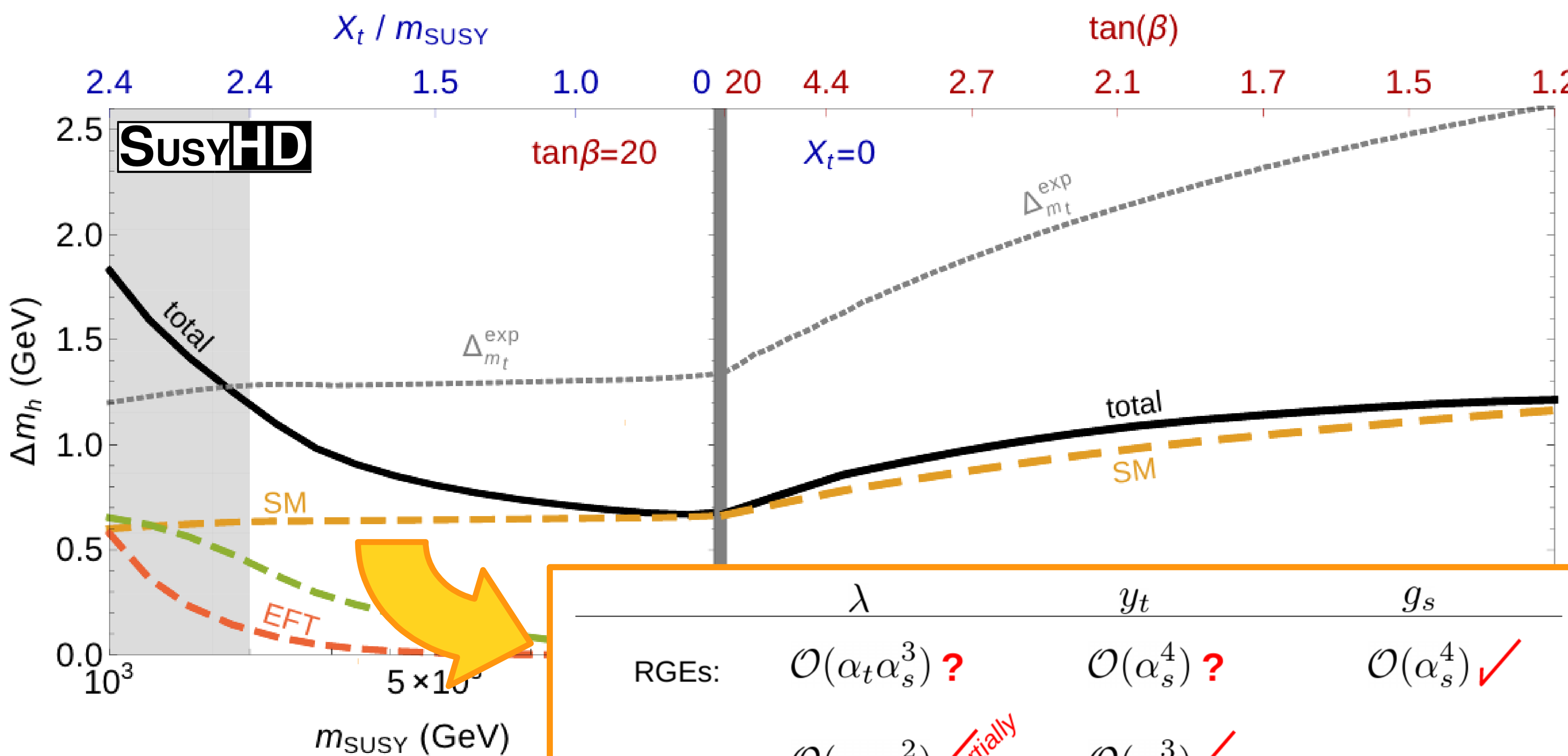


$$c_6 \frac{(H^\dagger H)^3}{m_{\rm SUSY}^2} + c_t \frac{H^\dagger H}{m_{\rm SUSY}^2} H Q U^c + \ldots$$

Estimate of the Uncertainties:

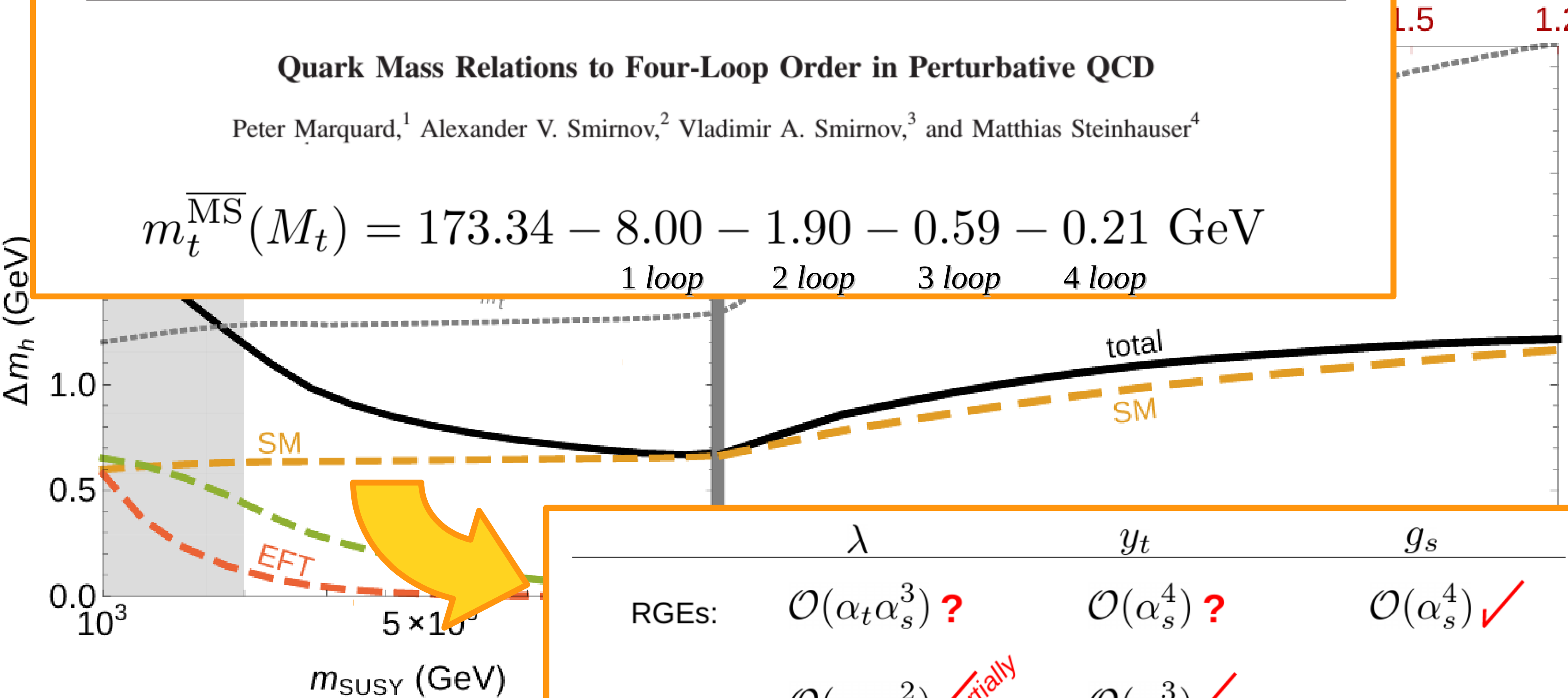


Estimate of the Uncertainties:



	λ	y_t	g_s
RGEs:	$\mathcal{O}(\alpha_t\alpha_s^3)$?	$\mathcal{O}(\alpha_s^4)$?	$\mathcal{O}(\alpha_s^4)$ ✓
Thresholds:	$\mathcal{O}(\alpha_t\alpha_s^2)$ ✓ partially	$\mathcal{O}(\alpha_s^3)$ ✓	

Estimate of the Uncertainties:



PRL **114,** 142002 (2015) PHYSICAL REVIEW LETTERS week ending 10 APRIL 2015

Quark Mass Relations to Four-Loop Order in Perturbative QCD

Peter Marquard,[1] Alexander V. Smirnov,[2] Vladimir A. Smirnov,[3] and Matthias Steinhauser[4]

$$m_t^{\overline{\mathrm{MS}}}(M_t) = 173.34 - \underbrace{8.00}_{\text{1 loop}} - \underbrace{1.90}_{\text{2 loop}} - \underbrace{0.59}_{\text{3 loop}} - \underbrace{0.21}_{\text{4 loop}} \text{ GeV}$$

	λ	y_t	g_s
RGEs:	$\mathcal{O}(\alpha_t\alpha_s^3)$ **?**	$\mathcal{O}(\alpha_s^4)$ **?**	$\mathcal{O}(\alpha_s^4)$ ✓
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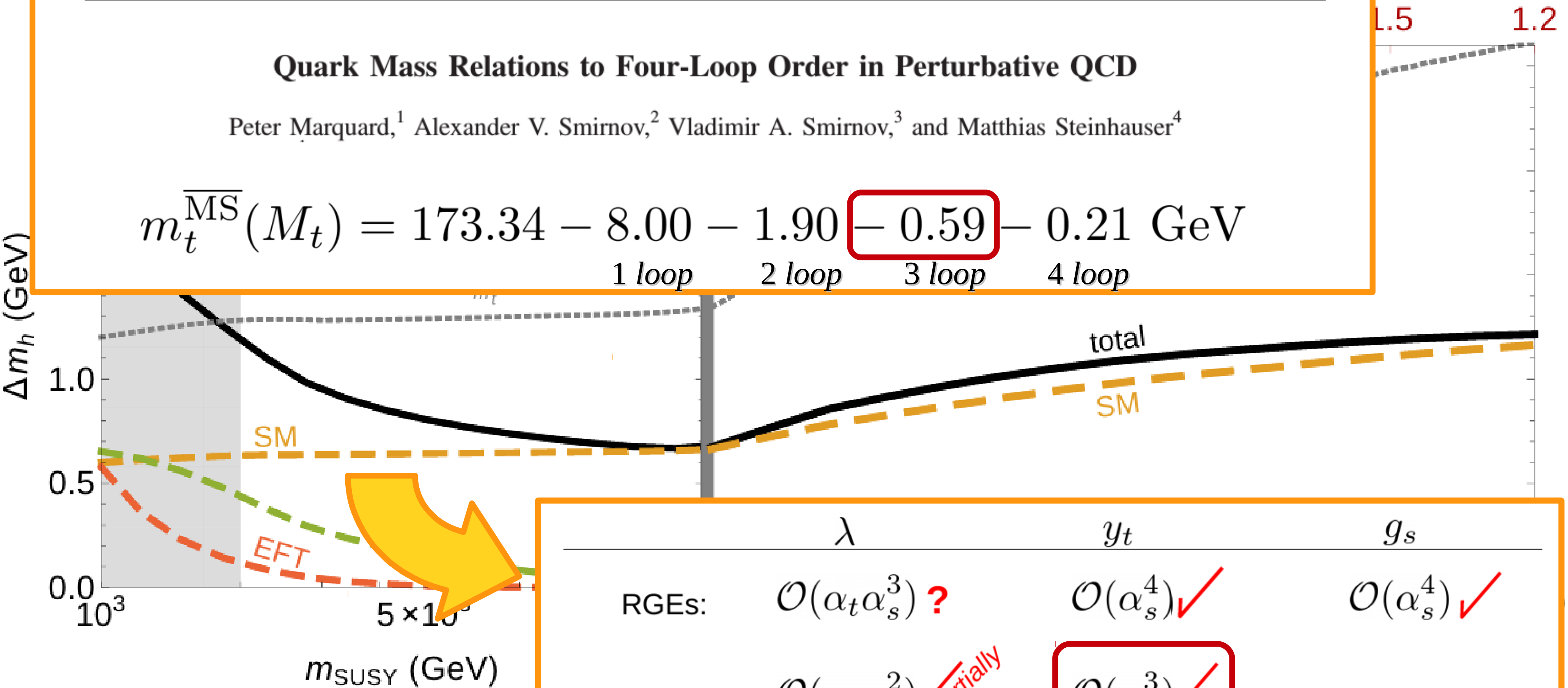
1 *loop* 2 *loop* 3 *loop* 4 *loop*



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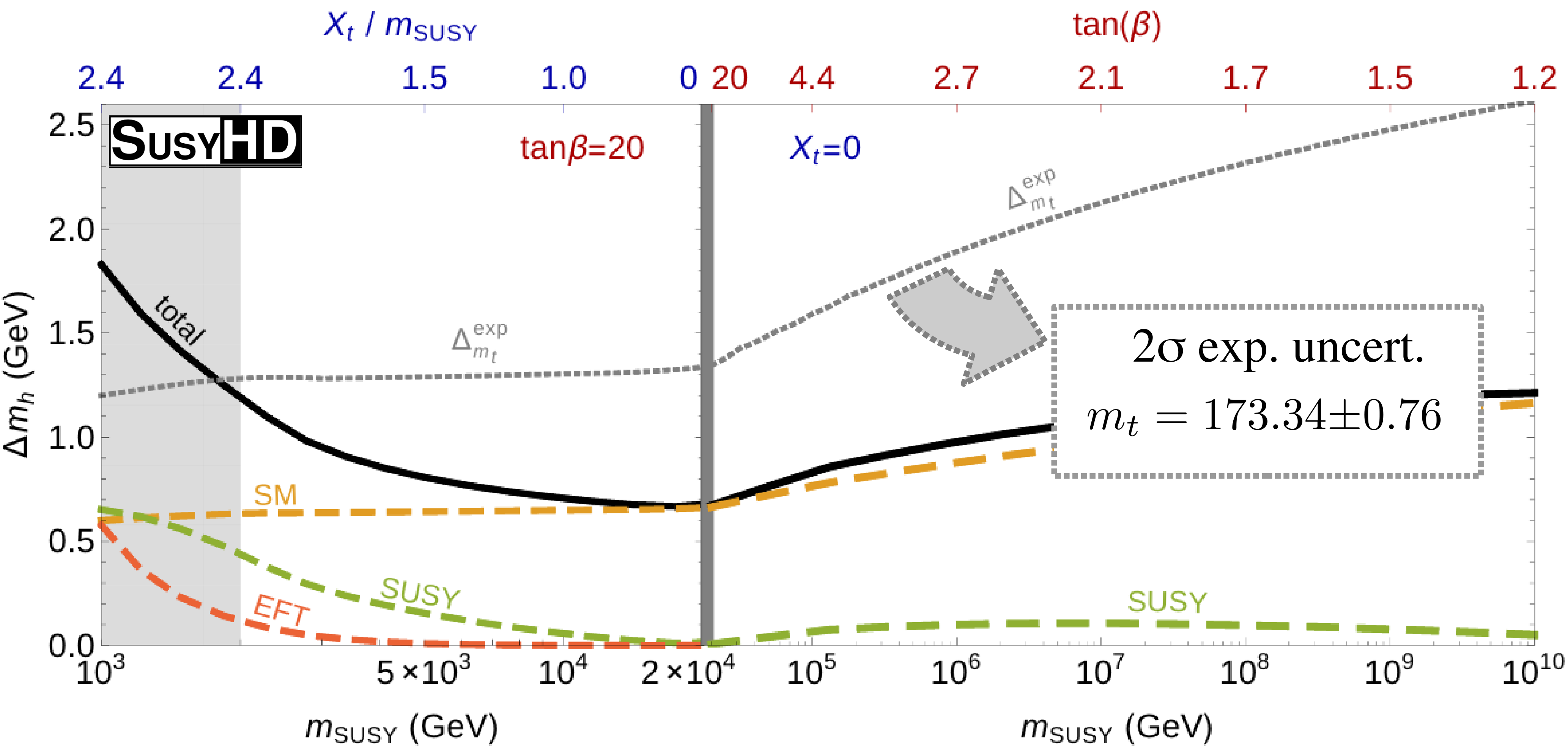
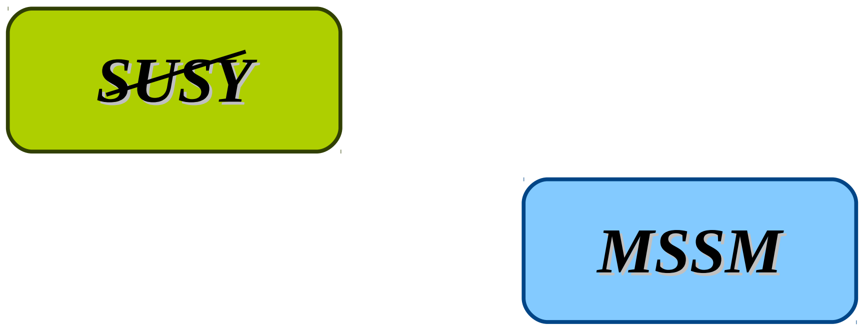


Back to the Simple

Minimal Gauge Mediation

Dine, Nir, Shirman
Rattazzi, Sarid '96



Minimal Gauge Mediation

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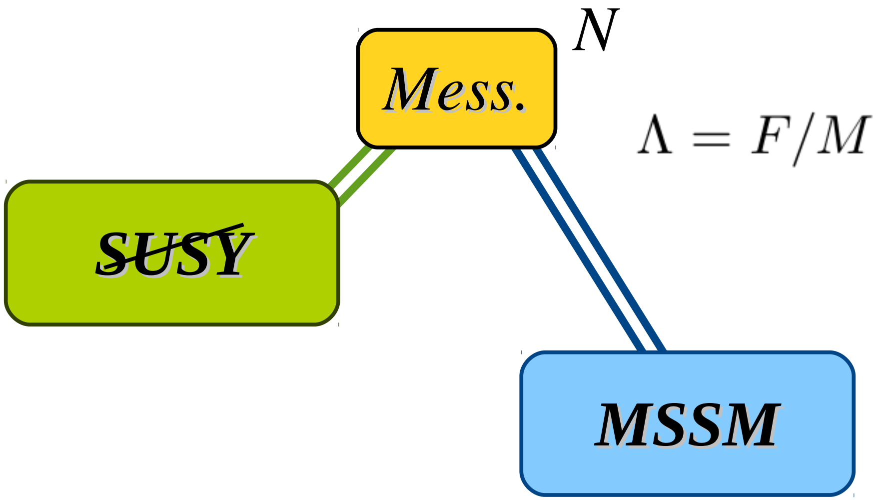

Minimal Gauge Mediation

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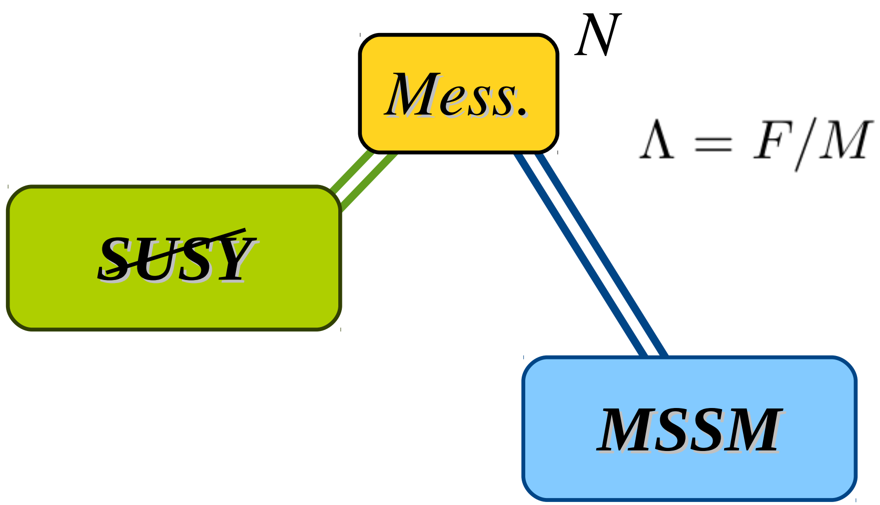


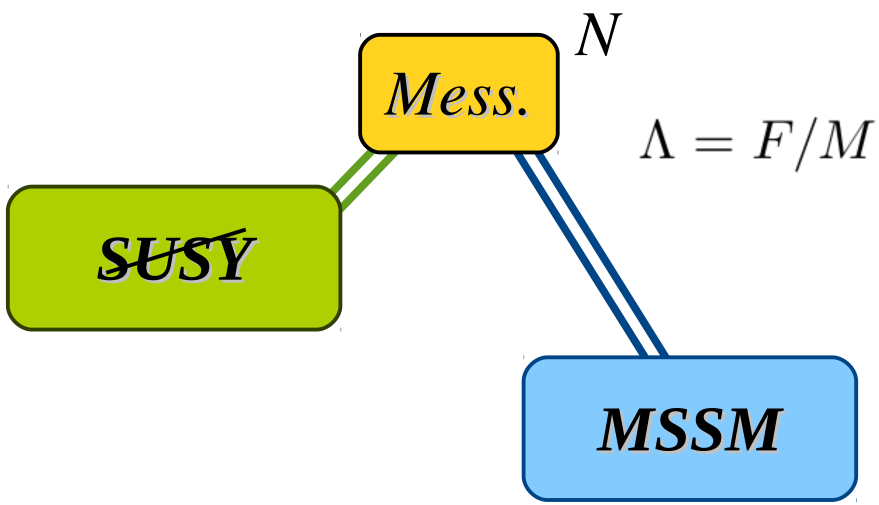
gauge mediated spectrum:

gauginos $M_j = N \frac{\alpha_j}{4\pi} \Lambda$

scalars $m_i = 2\sqrt{N} C_{ij} \frac{\alpha_j}{4\pi} \Lambda$

Minimal Gauge Mediation

Dine, Nir, Shirman
Rattazzi, Sarid '96



gauge mediated spectrum:

gauginos $M_j = N \frac{\alpha_j}{4\pi} \Lambda$

scalars $m_i = 2\sqrt{N} C_{ij} \frac{\alpha_j}{4\pi} \Lambda$

⇨ **flavor blind spectrum: NO FCNC**

still potential problem with EDMs

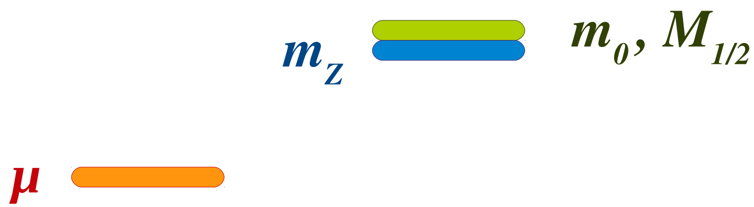
No naturalness → no μ problem:

SUSY term

μ

No naturalness → no μ problem:

No naturalness → no μ problem:



EWSB ~ m_0

No naturalness → no μ problem:

μ

m_0, $M_{1/2}$

$$|\mu|^2 \simeq -m_{H_u}^2 + \ldots$$

m_Z

EWSB « m_0

No naturalness → no μ problem:

μ m_0, $M_{1/2}$ $|\mu|^2 \simeq -m_{H_u}^2 + \ldots$

m_Z EWSB « m_0

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

generated radiatively

No naturalness → no μ problem:

μ m_0, $M_{1/2}$ $|\mu|^2 \simeq -m^2_{H_u} + \ldots$

m_Z EWSB « m_0

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

⇒ $A_t \lesssim m_0$ *no maximal mixing*

No naturalness → no μ problem:

μ ——— ——— $m_0, M_{1/2}$ $\quad |\mu|^2 \simeq -m^2_{H_u} + \ldots$

——— m_Z $\quad$ EWSB « m_0

$B_\mu, A = 0$ at the scale M $\quad$ <u>generated radiatively</u>

➡ $A_t \lesssim m_0$ *no maximal mixing*

➡ $B_\mu \ll m_0^2$ tan(β) ~ 30-60

No naturalness → no μ problem:

μ — $m_0, M_{1/2}$ — $|\mu|^2 \simeq -m_{H_u}^2 + \ldots$

m_Z — EWSB « m_0

$B_\mu, A = 0$ at the scale M — <u>generated radiatively</u>

→ $A_t \lesssim m_0$ *no maximal mixing*

→ $B_\mu \ll m_0^2$ tan(β) ~ 30-60

→ *no CP phases* → *no EDMs*

$$MSSM \quad + \quad Mess.$$

$$\mu \qquad\qquad N,\, M,\, \Lambda$$

4 parameters

$$MSSM \quad + \quad Mess.$$

$$\mu \qquad\qquad N, M, \Lambda$$

4 parameters

$$EWSB \Rightarrow \quad \mu \sim m_0$$

$$m_h \Rightarrow \quad \Lambda \sim \mathrm{PeV}$$

$MSSM \quad + \quad Mess.$

$\mu \qquad\qquad N, M, \Lambda$

4 parameters

$EWSB \Rightarrow \mu \sim m_0$

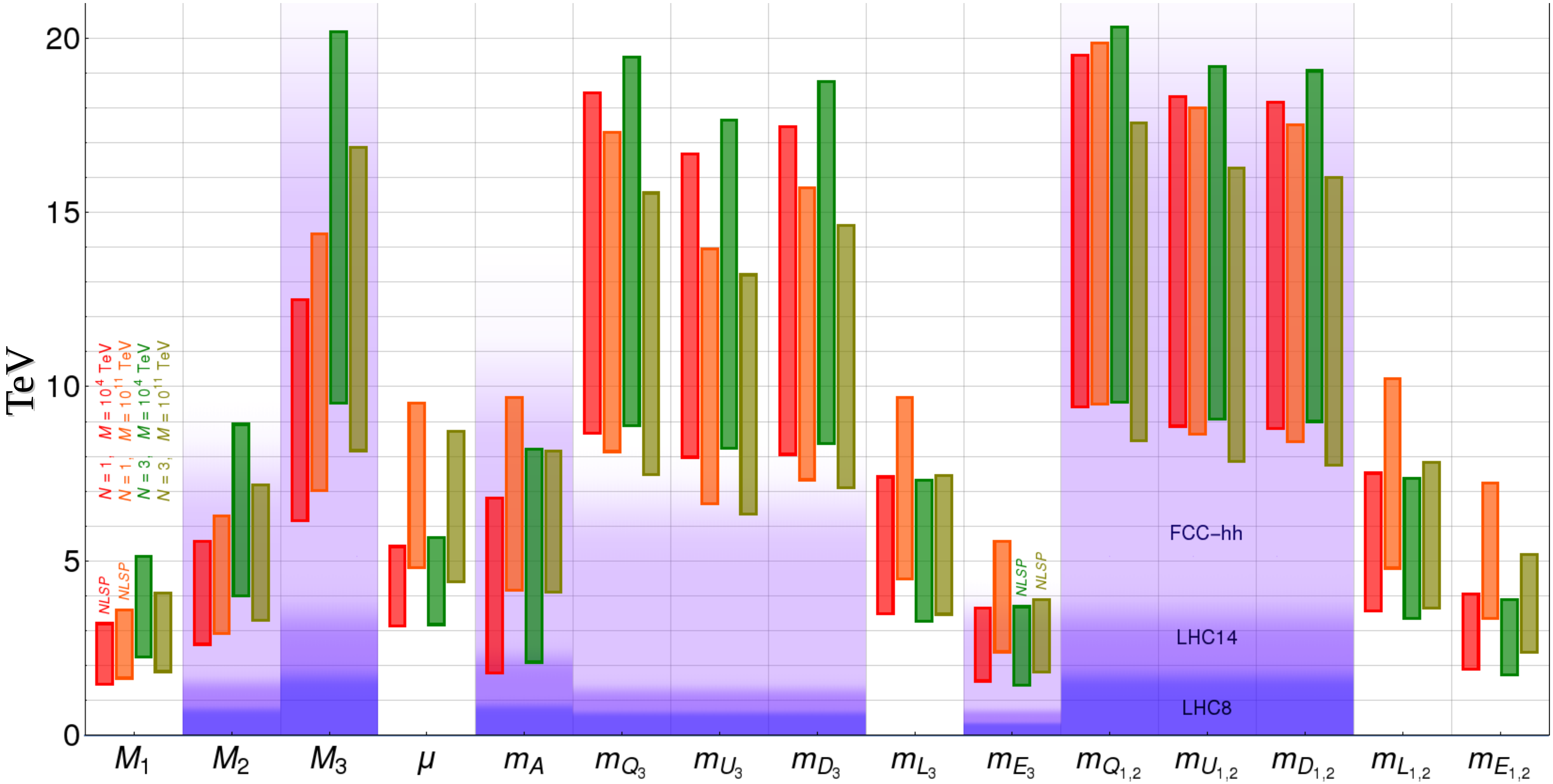
$m_h \Rightarrow \Lambda \sim \text{PeV}$

2 parameters

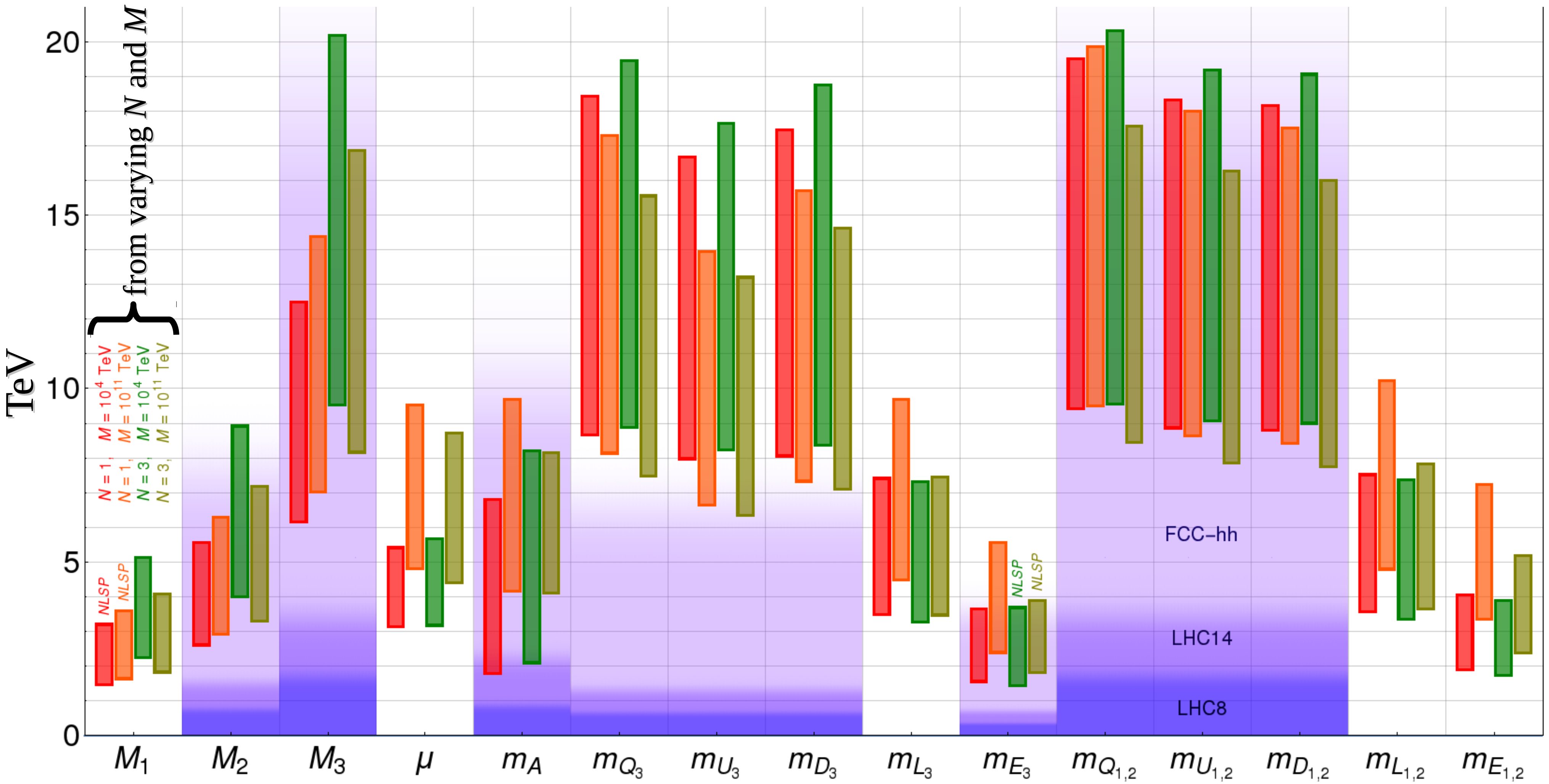
$N\,,\,M$

but small effect on spectrum

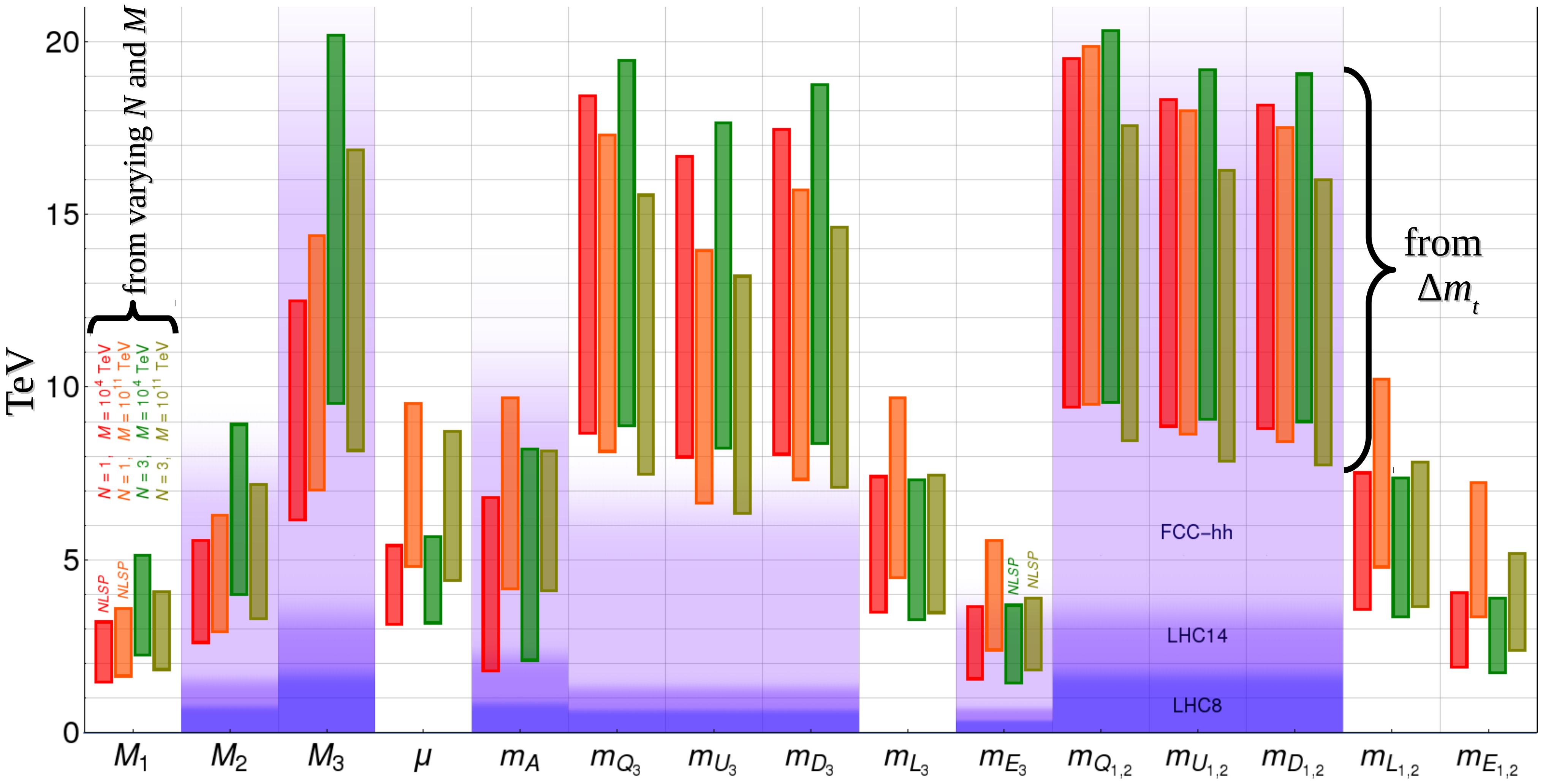
Predicting the MGM spectrum



Predicting the MGM spectrum



Predicting the MGM spectrum



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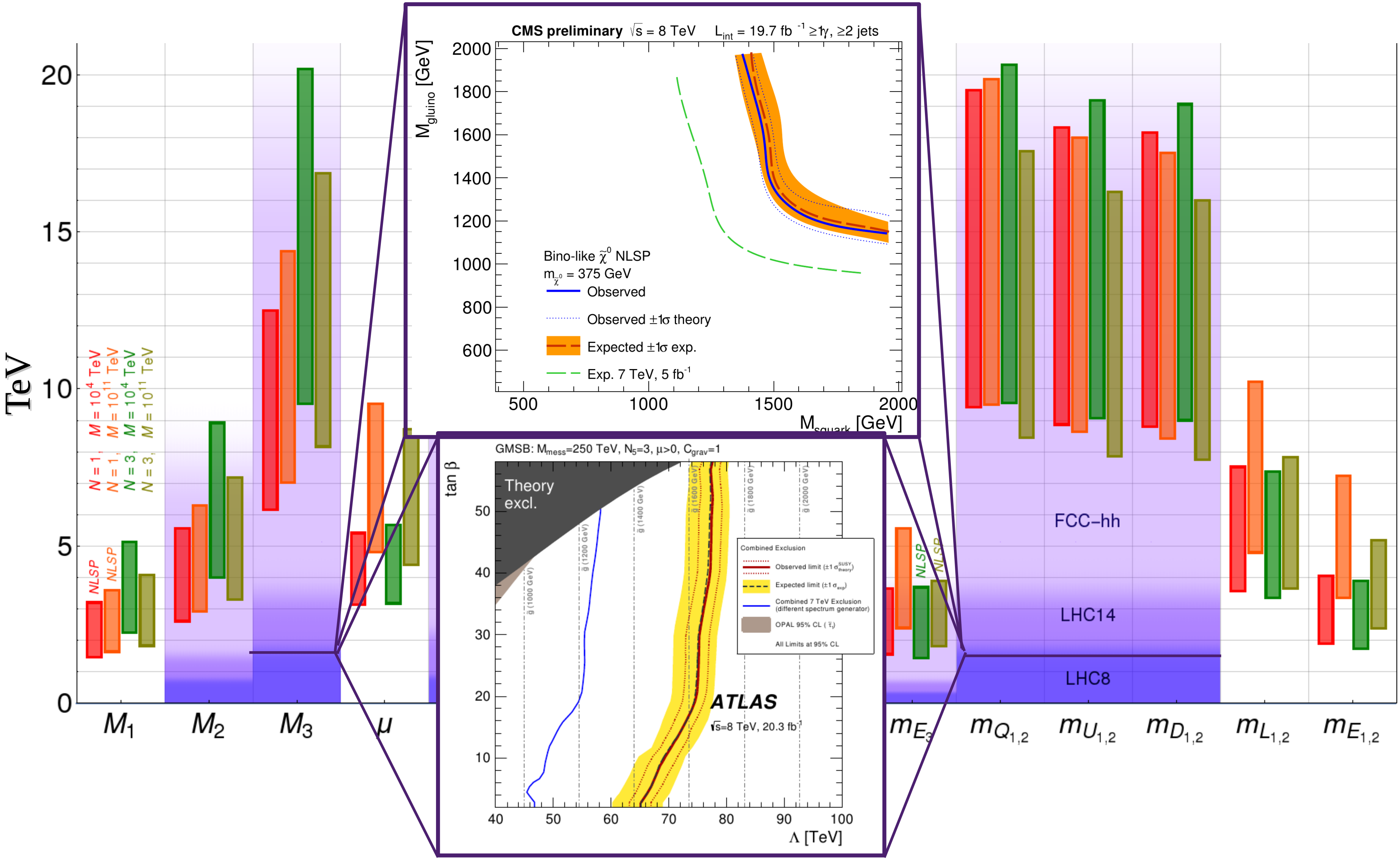

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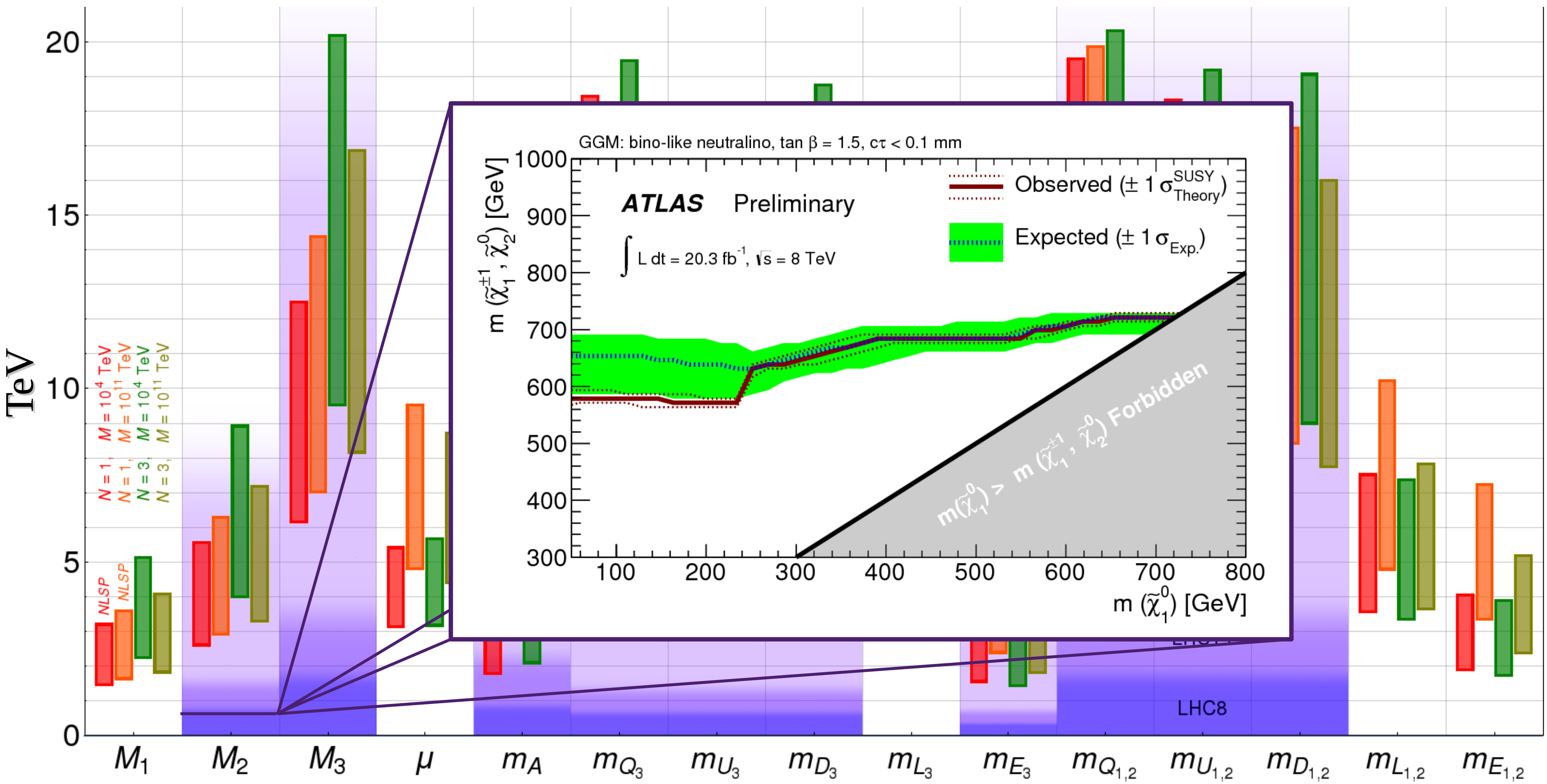
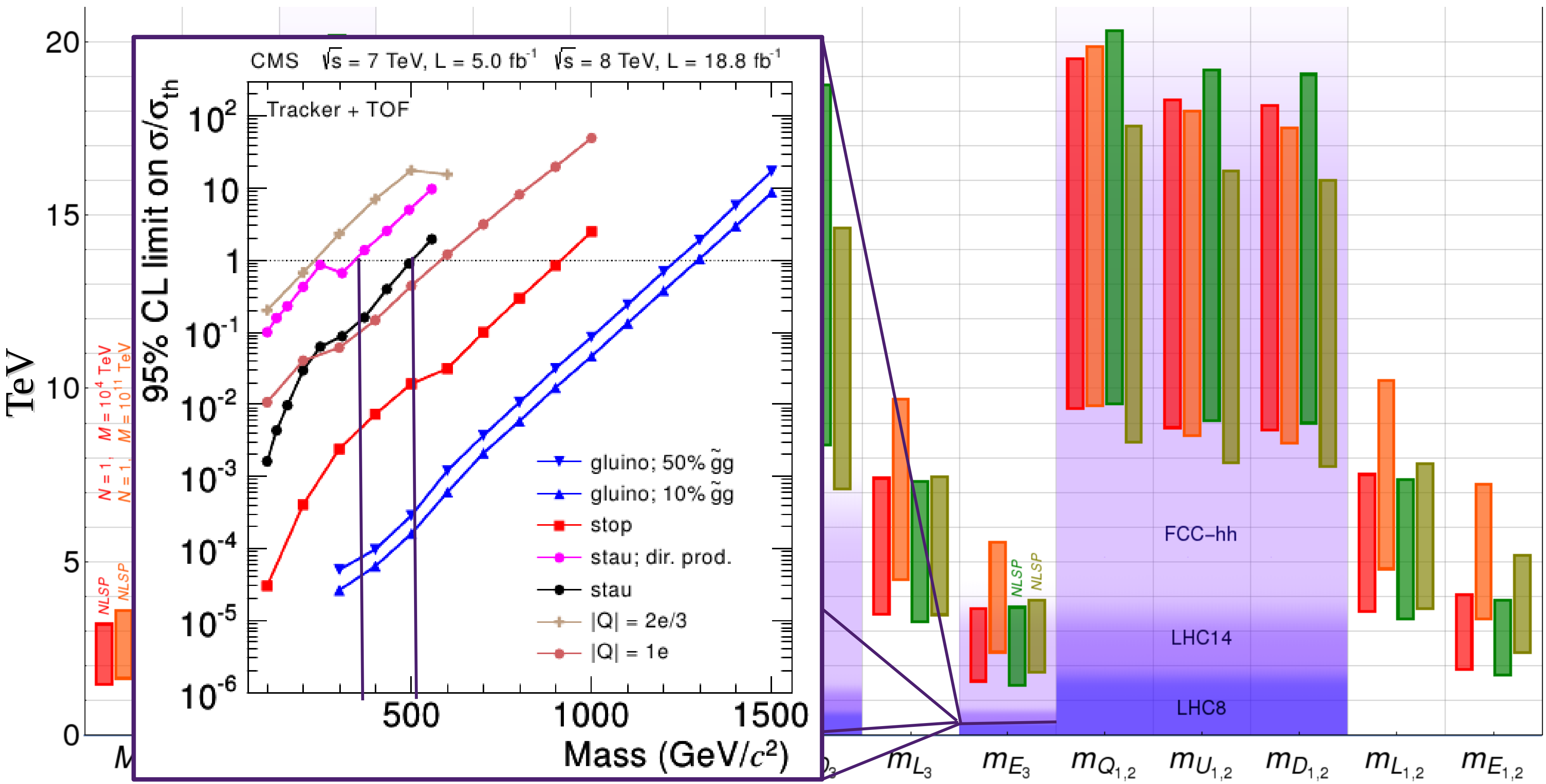
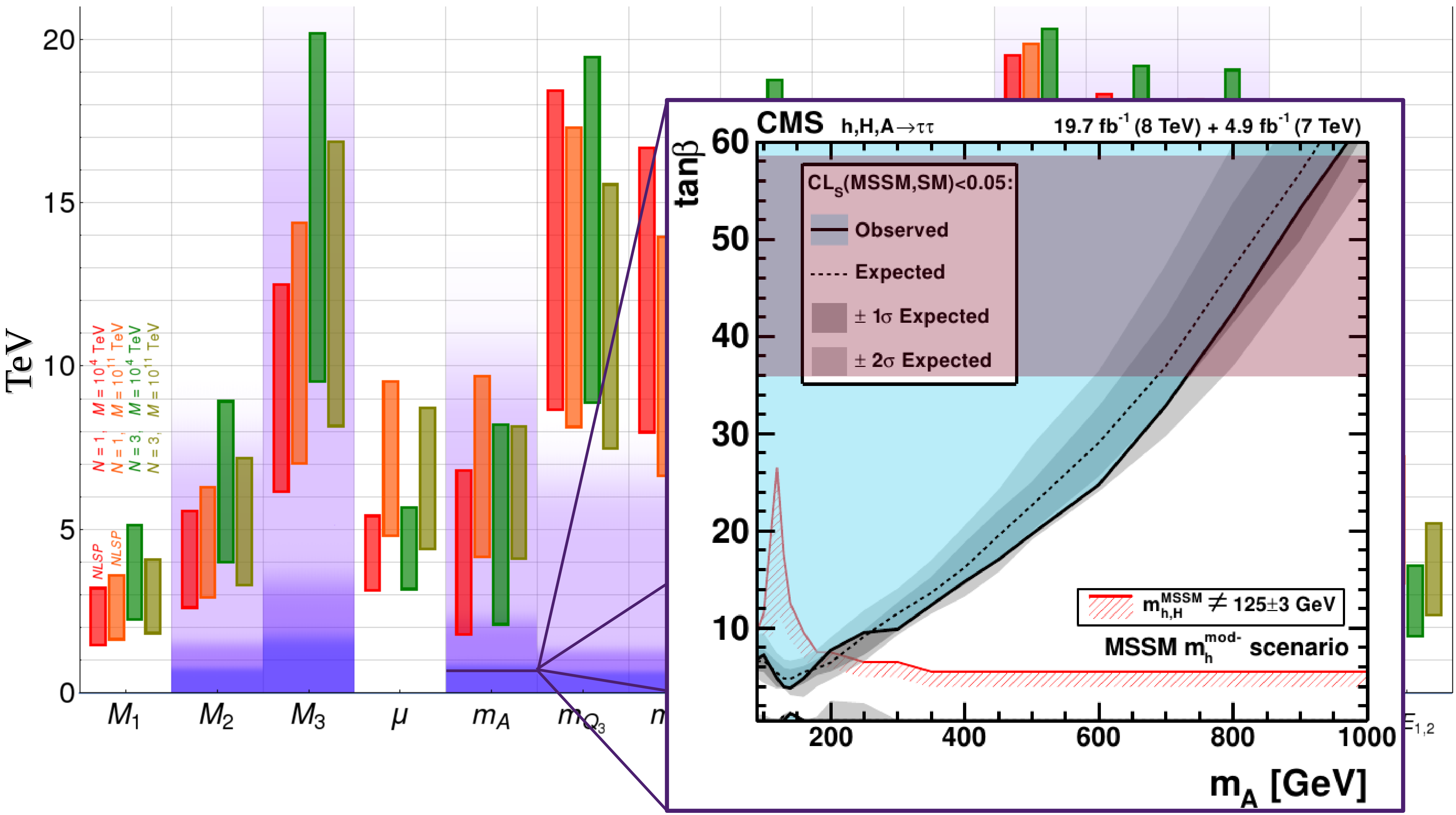


Predicting the MGM spectrum



Predicting the MGM spectrum



MGM:

minimal and most predictive implementation of SUSY

it explains:

- absense of deviation in flavor
- absence of EDMs
- absence of DM in WIMP searches
- gauge coupling unification
- absence of sparticles at the LHC!

MGM:

minimal and most predictive implementation of SUSY

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- absence of sparticles at the LHC!

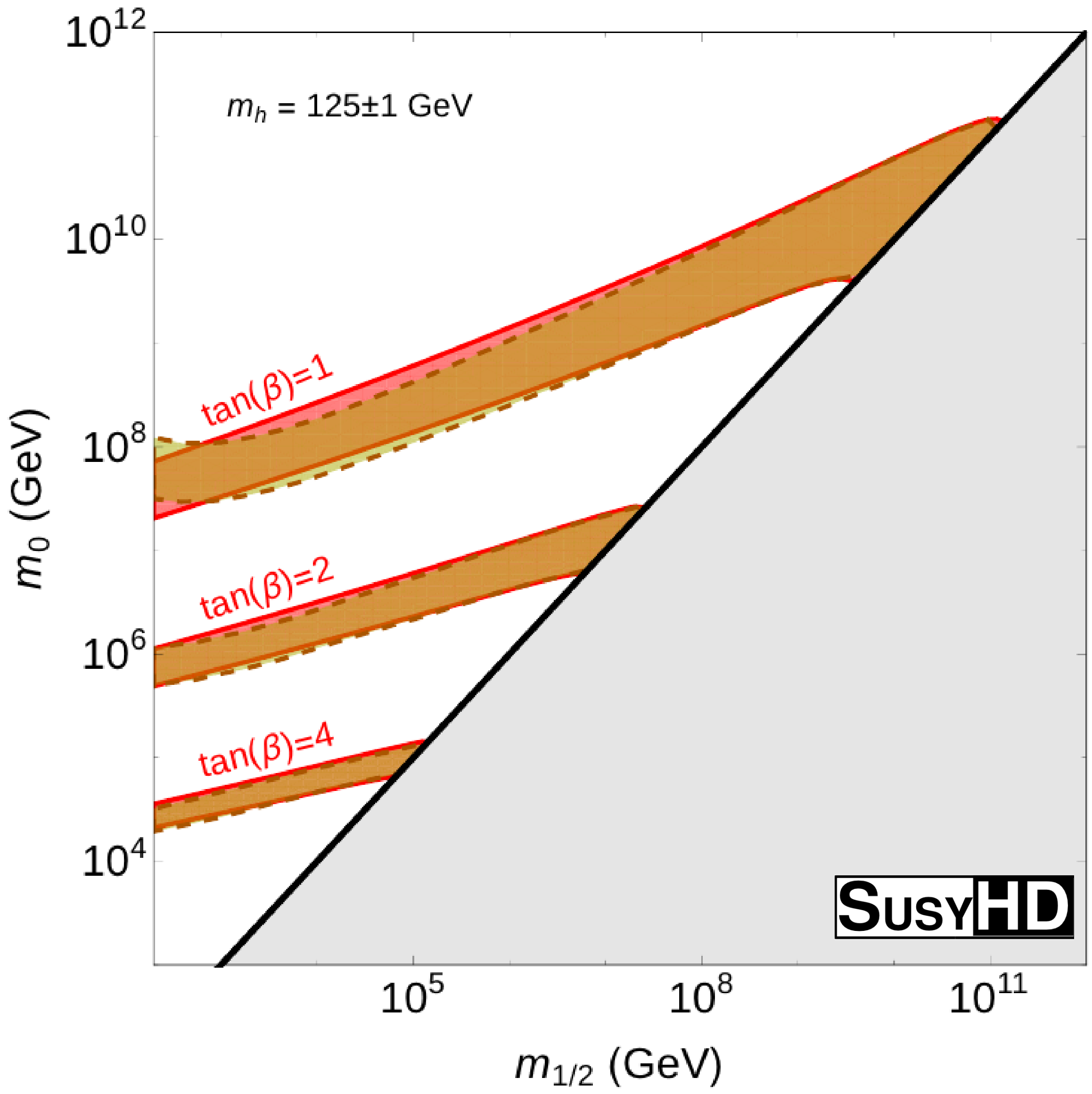
Perfect target for an 100 TeV collider?

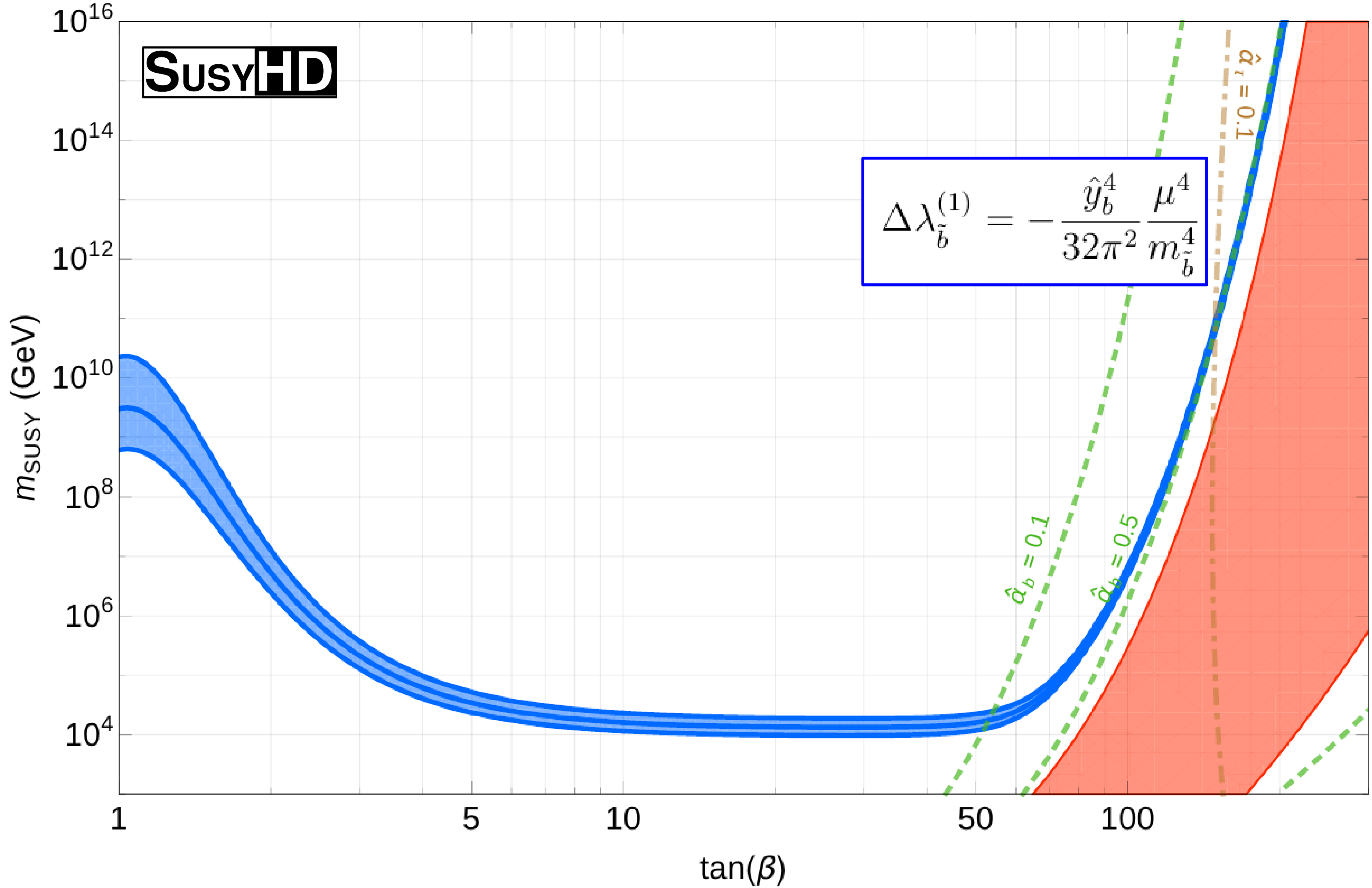
Improvement on *top* mass

(and SM computations) **required**!

Backup

Effects from splitting fermions

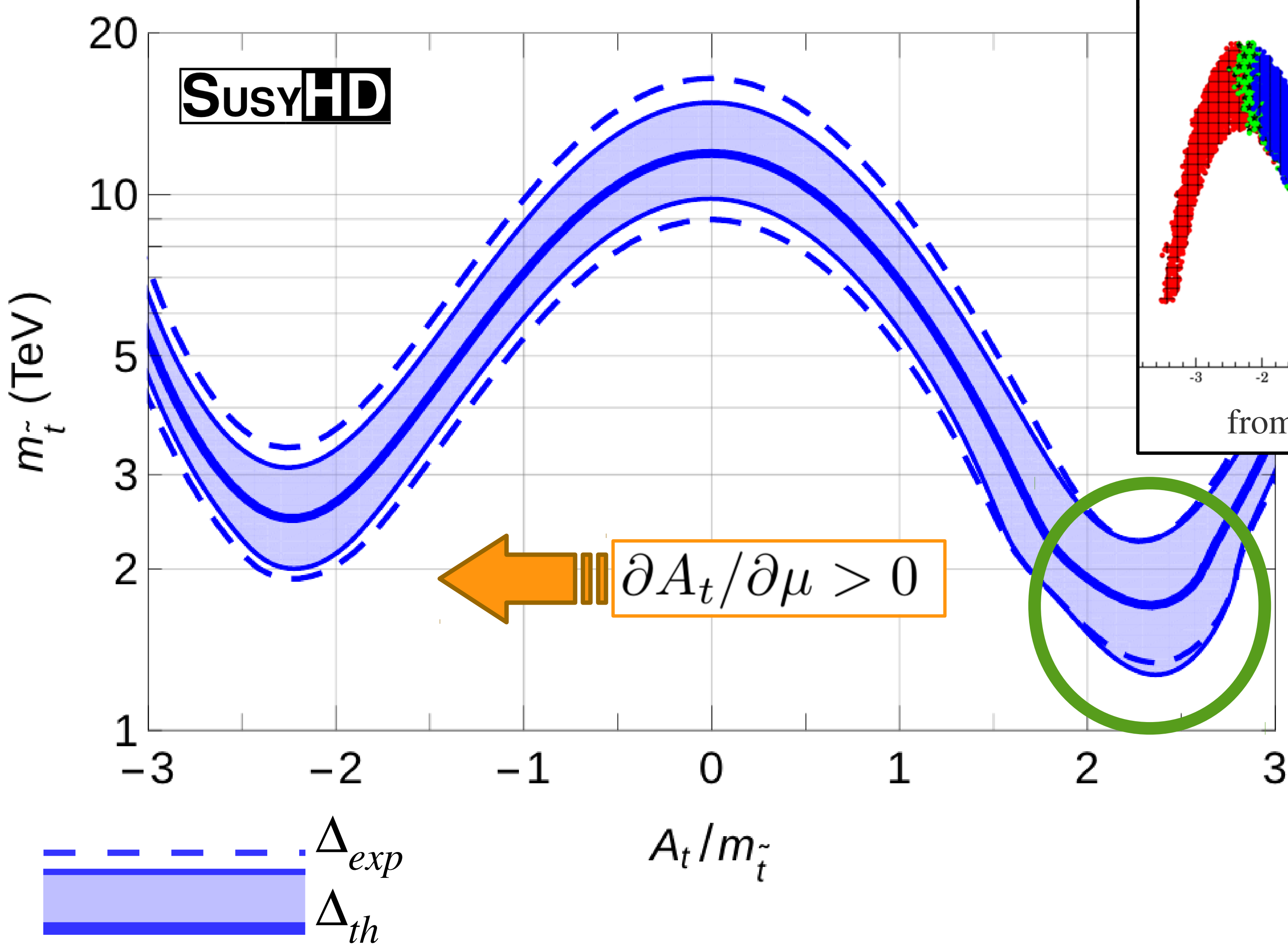


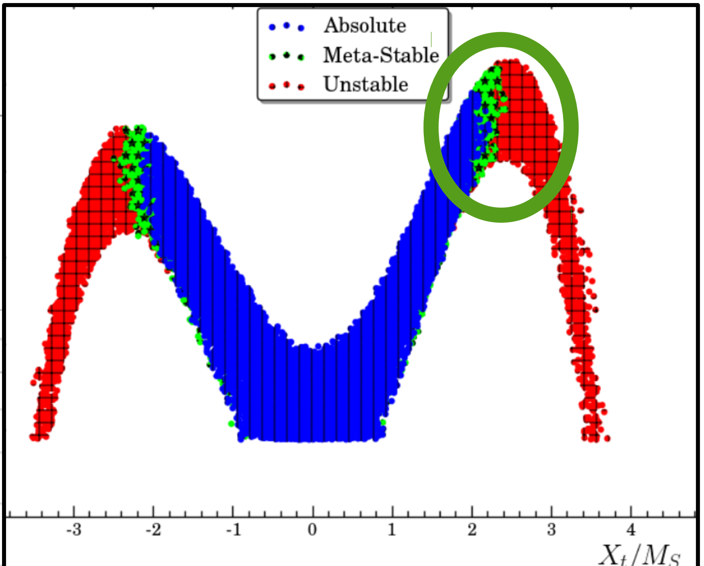


SusyHD
$\Delta\lambda^{(1)}_{\tilde{b}} = -\frac{\hat{y}_b^4}{32\pi^2}\frac{\mu^4}{m_{\tilde{b}}^4}$
$\hat{\alpha}_b = 0.1$
$\hat{\alpha}_b = 0.5$
$\hat{\alpha}_\tau = 0.1$
$m_{\rm SUSY}$ (GeV)
10^{16}
10^{14}
10^{12}
10^{10}
10^{8}
10^{6}
10^{4}
1
5
10
50
100
tan(β)

A “natural” SUSY-like spectrum:

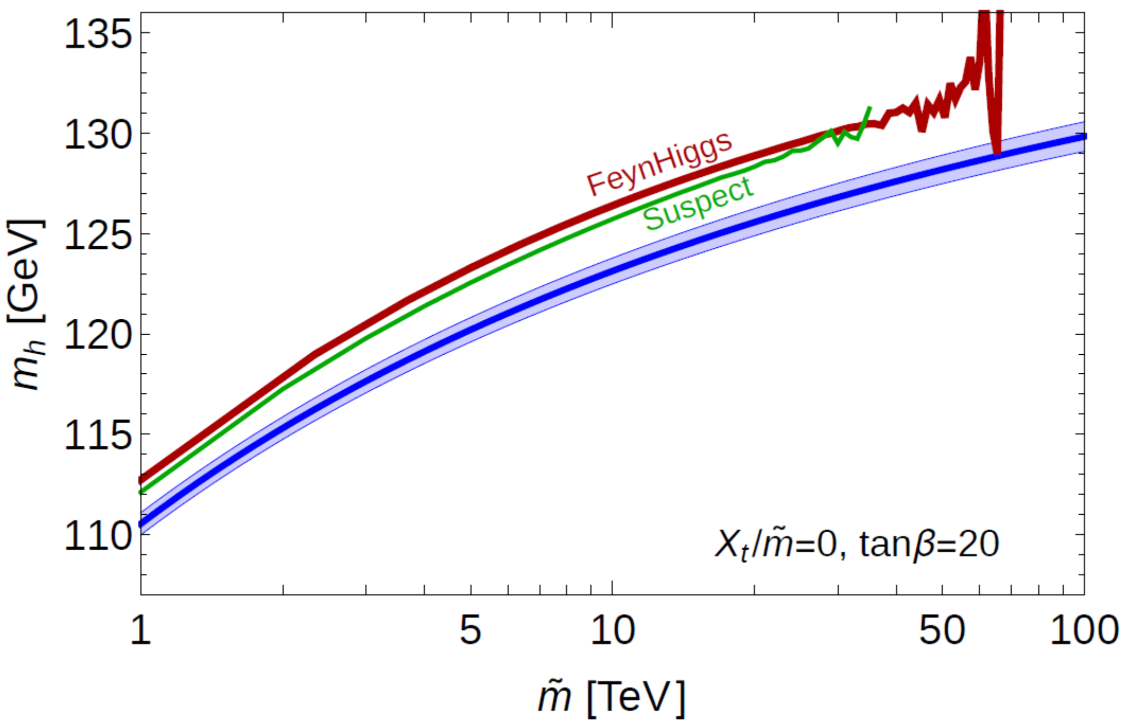
$\tan\beta = 20\ ,\quad \mu = 300\ \text{GeV}\ ,\quad m_{SUSY} = 2\ \text{TeV}$





from: Chowdhuri et al. '13

Comparison with existing codes



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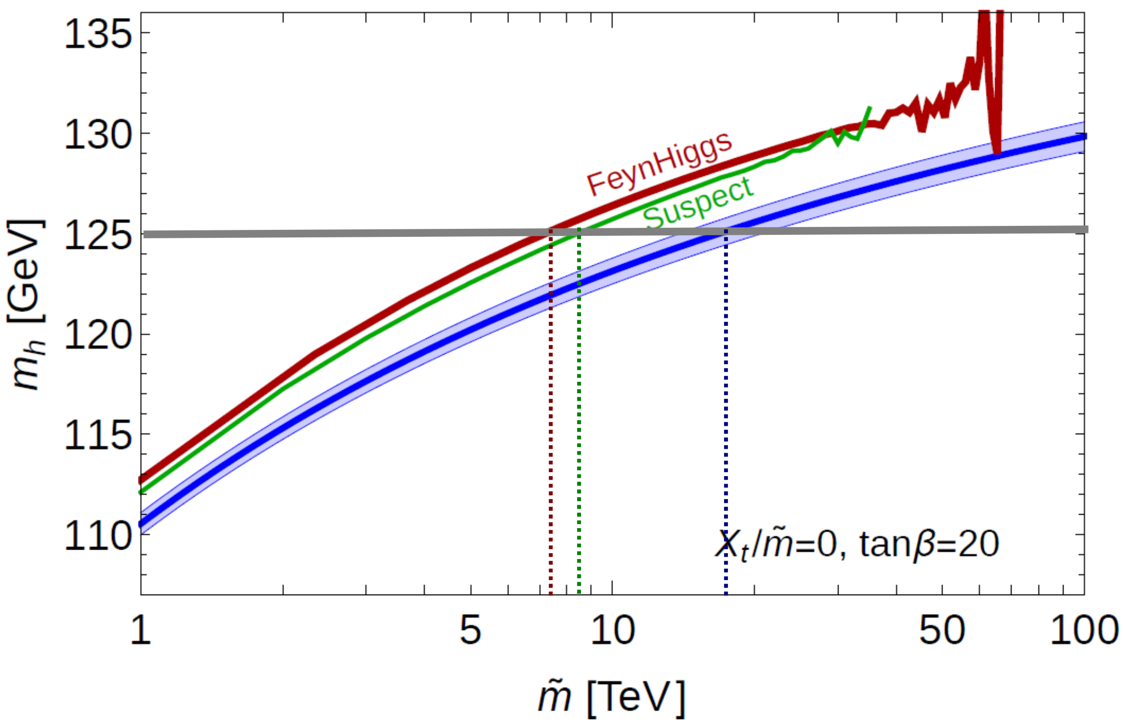

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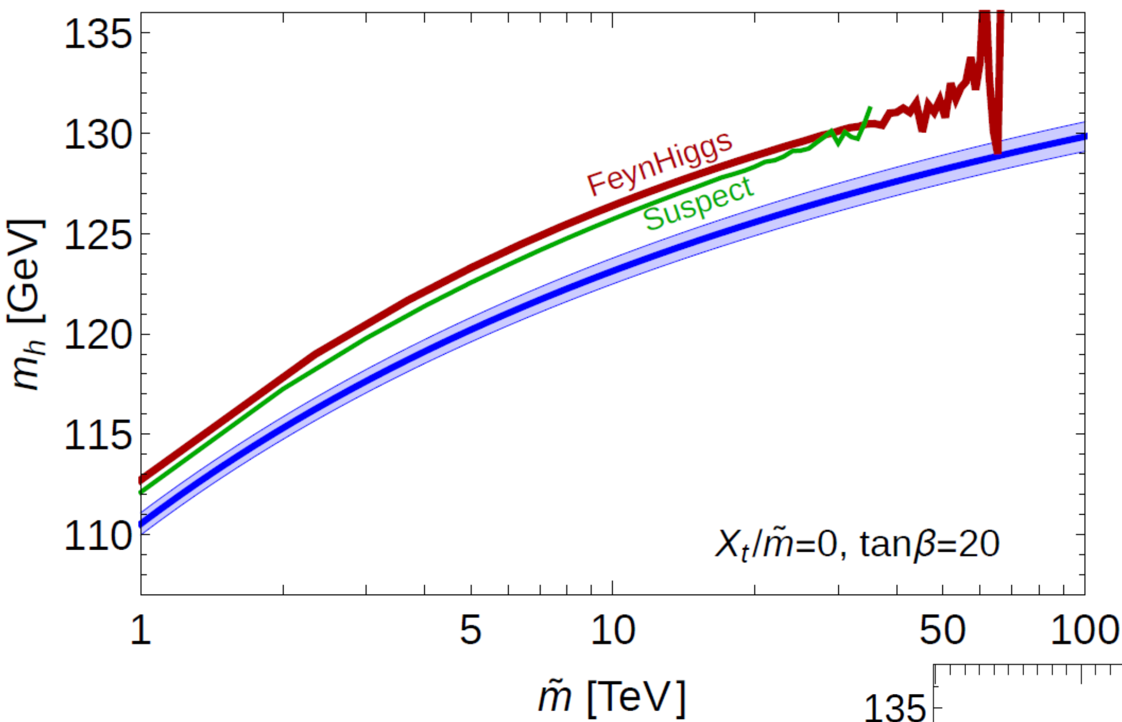

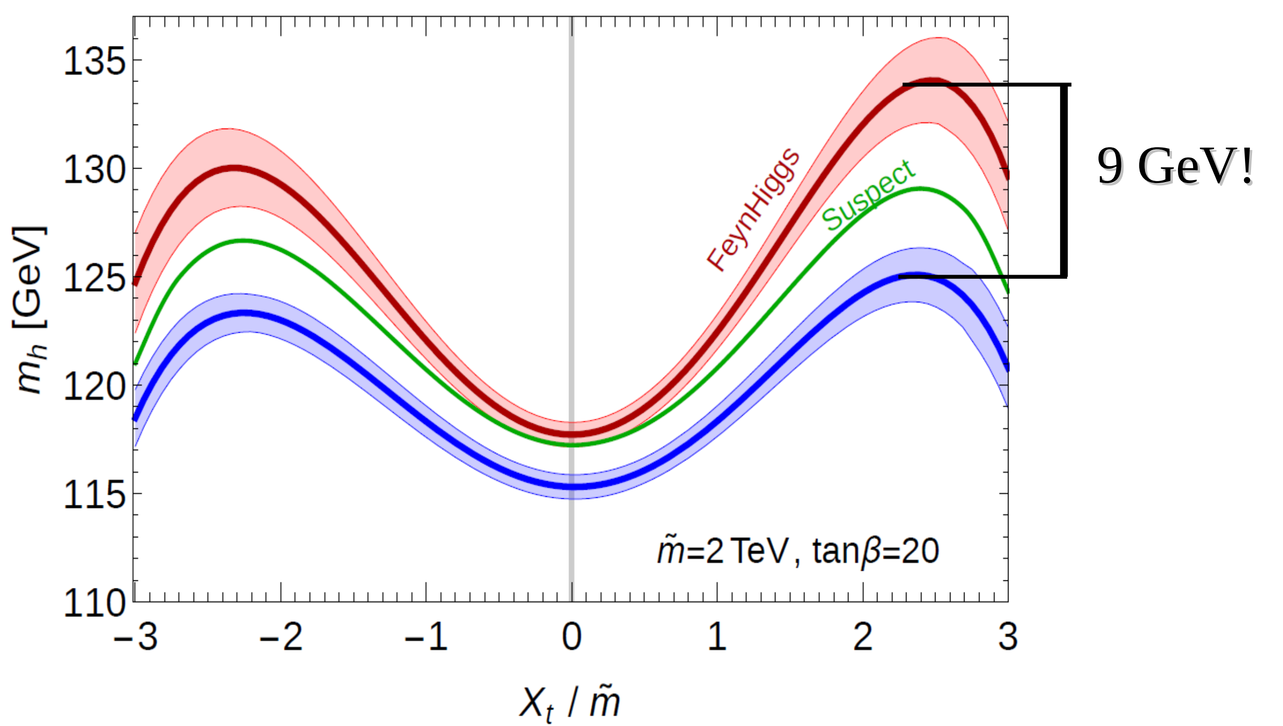

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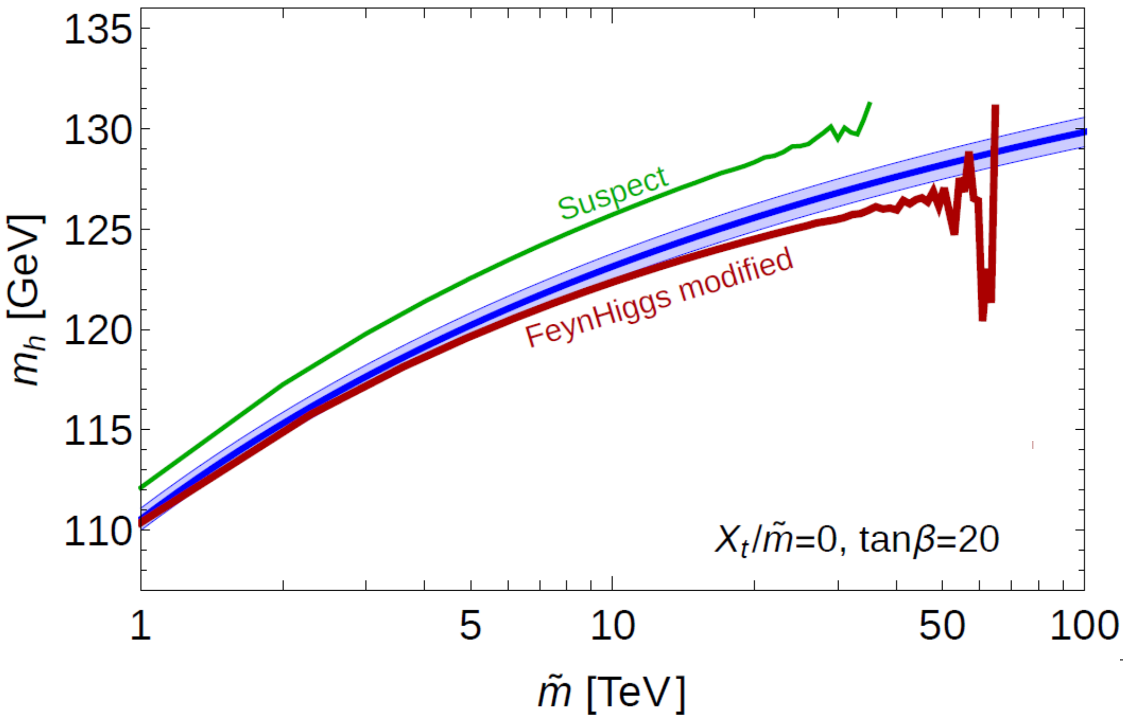
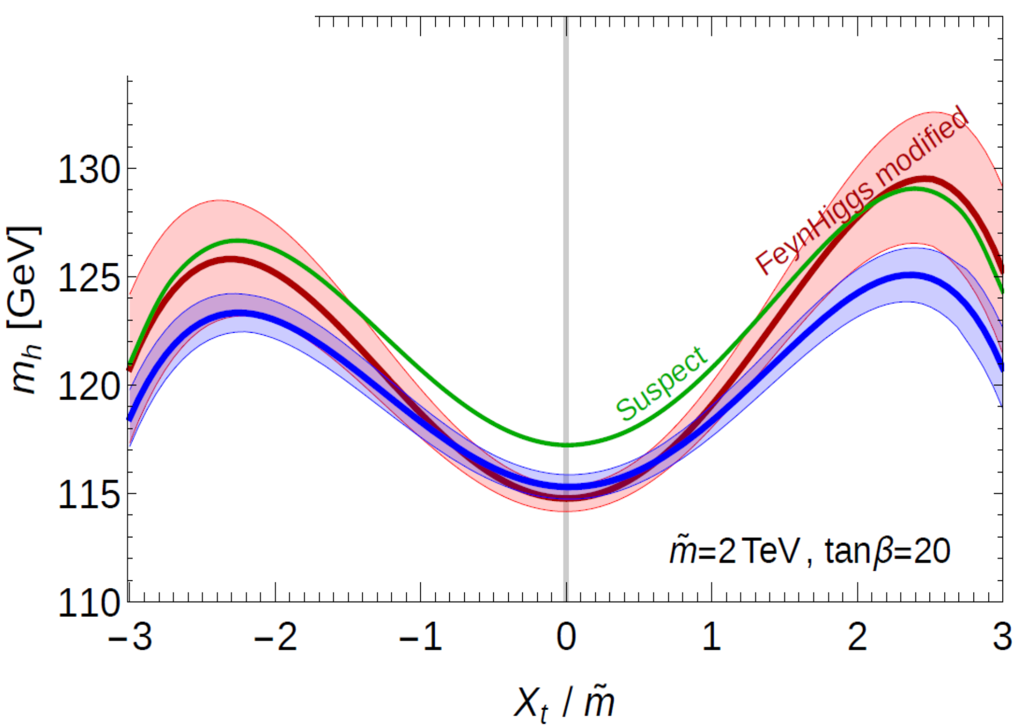
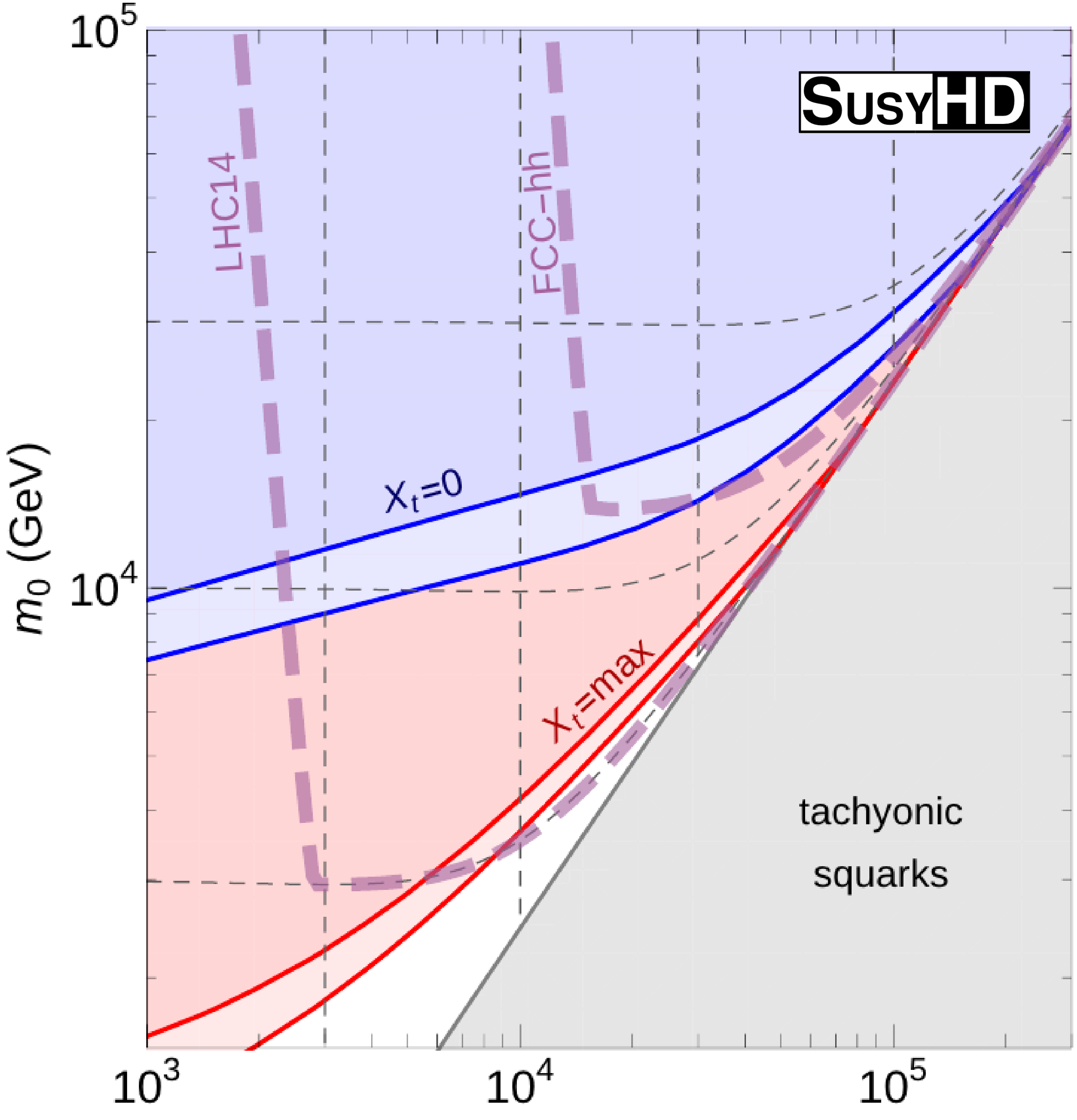
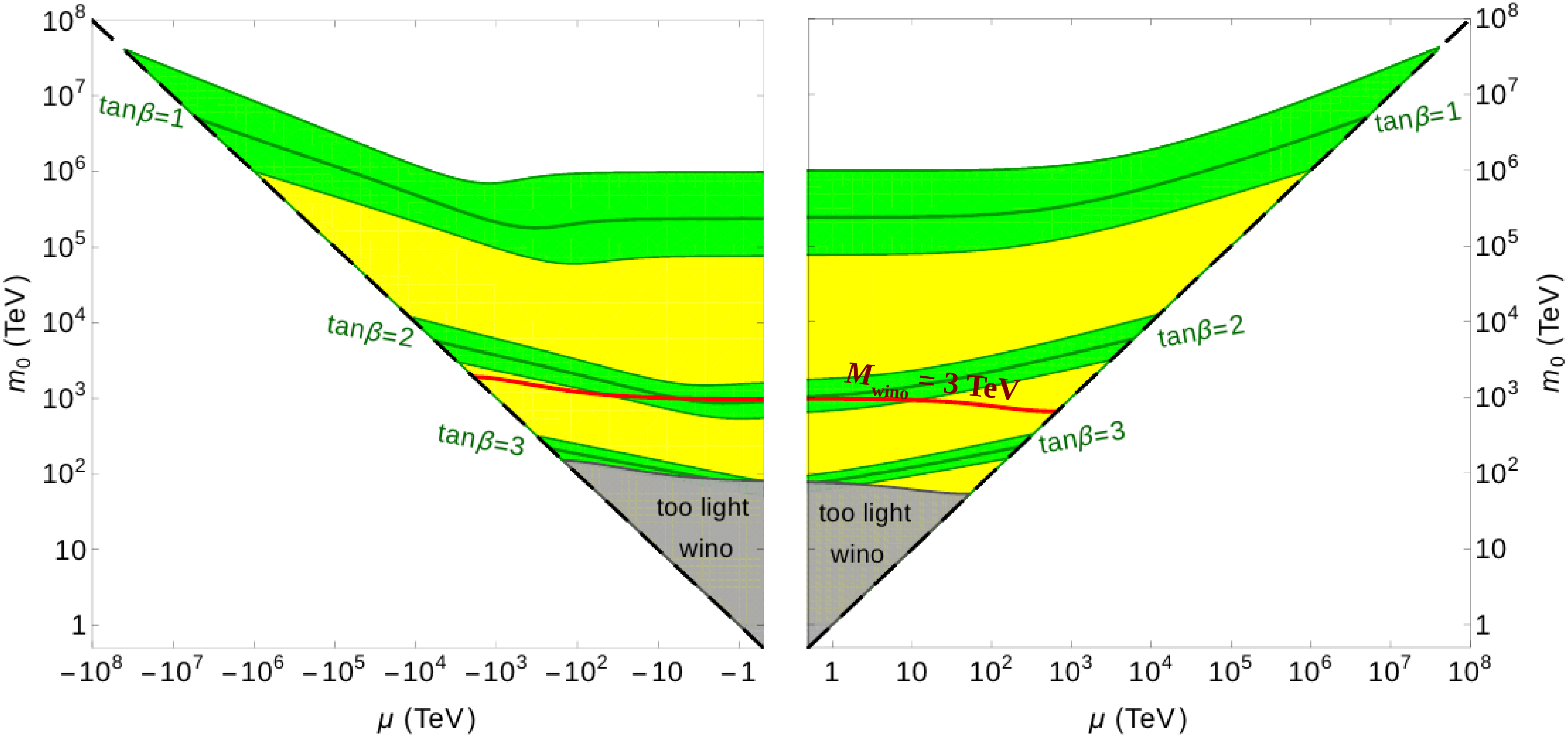


after 2-loop
top Yukawa corrections





SusyHD
LHC14
FCC–hh
X_t=0
X_t=max
tachyonic
squarks
10^5
10^4
m_0 (GeV)
10^3
10^4
10^5
$m_{1/2}$ (GeV)



tanβ=1
tanβ=2
tanβ=3
$M_{\rm wino}$ = 3 TeV
too light wino
too light wino
m_0 (TeV)
μ (TeV)
μ (TeV)
m_0 (TeV)