Gearing up for LHC13 -- Conference

13-16 October 2015 GGI, Florence

SUSY and the Higgs

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JHEP 1507 (2015) 159 – [1504.05200] SusyHD

The Quest for SUSY

(beyond the hierarchy problems)

Poincaré $\rightarrow$ SUSY

$\mathcal{P}$ $\quad$ $\mathcal{S}$

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

Poincaré $\rightarrow$ SUSY

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Remarkable features in QFT:

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

Poincaré $\rightarrow$ 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?

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SUSY breaking scale?

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

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

Legend: $\sqrt{s}$ = 7 TeV full data; $\sqrt{s}$ = 8 TeV partial data; $\sqrt{s}$ = 8 TeV full data

10^{-1} — 1 — Mass scale [TeV]

*Only a selection of the available mass limits on new states or phenomena is shown. All limits quoted are observed minus 1σ theoretical signal cross section uncertainty.


Leah Saulnier '12

The CC problem:

$$\Lambda = -m_K^2 f_K^2 - \frac{1}{2} m_h^2 v^2 + \cdots + M_{\mathrm{NP}}^4$$

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10^{-47} GeV^4 | 10^{-3} GeV^4 | 10^{8} GeV^4

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* (non anthropic)

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SUSY is the only known* solution

$$\Lambda \sim M_{\rm SUSY}^4$$

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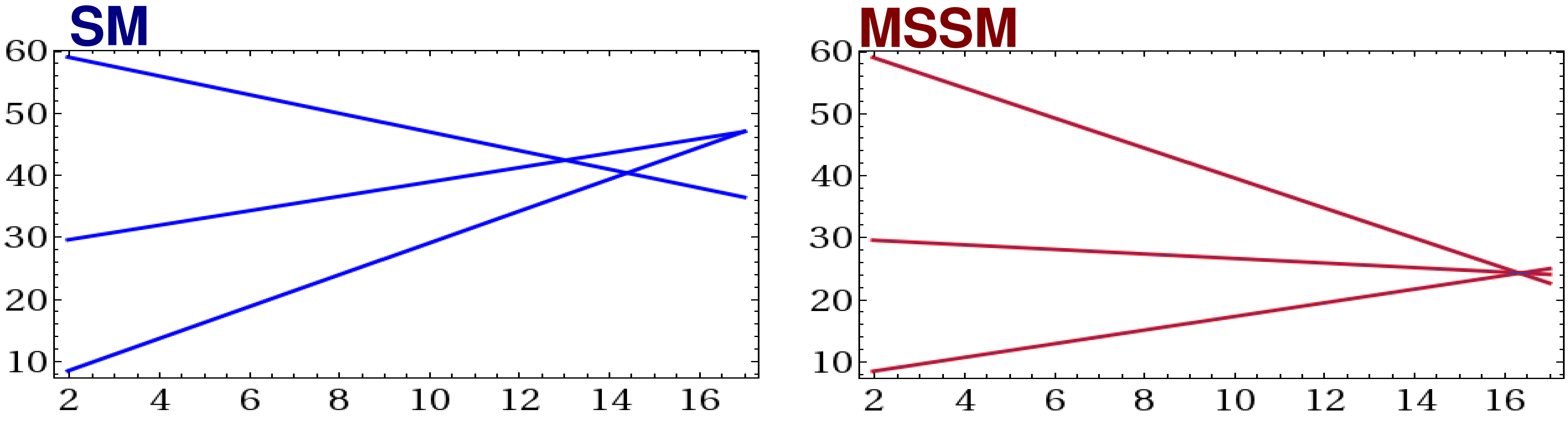
stronger pressure for low energy SUSY

* (non anthropic)

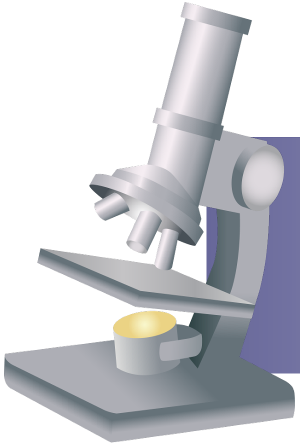
Weaker hint:

Gauge Coupling Unification



$$m_{\rm SUSY} \lesssim \text{few} \cdot 10 \text{ TeV}$$

SUSY breaking scale?



Back to Experiments

Use Precision Data

In SUSY the Higgs mass is calculable:

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

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

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only *log*-dependence on new physics scale

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only *log*-dependence on new physics scale

⇒ high precision to get reliable constraints

In SUSY the Higgs mass is calculable:

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

$$m_h^2 \simeq \underbrace{m_Z^2 \cos^2 2\beta}_{90^2} + \underbrace{\frac{3}{\pi^2}\frac{m_t^4 \sin^4\beta}{v^2}\left[\log\frac{m_{\tilde{t}}^2}{m_t^2} + \tilde{X}_t^2\left(1 - \frac{\tilde{X}_t^2}{12}\right)\right] + \ldots}_{90^2}$$

$125^2 \approx$ 90^2 + 90^2

$$\Rightarrow\ \delta m_h \sim \delta m_t$$

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$$125^2 \approx 90^2 + 90^2$$

$$\Rightarrow \delta m_h \sim \delta m_t$$

$$m_t^{\overline{\rm MS}}(M_t) = 173.34 - 8.00 - 1.90 - 0.59 - 0.21 \text{ GeV}$$

1 loop, 2 loop, 3 loop, 4 loop

Exploiting the Hierarchy Problem:

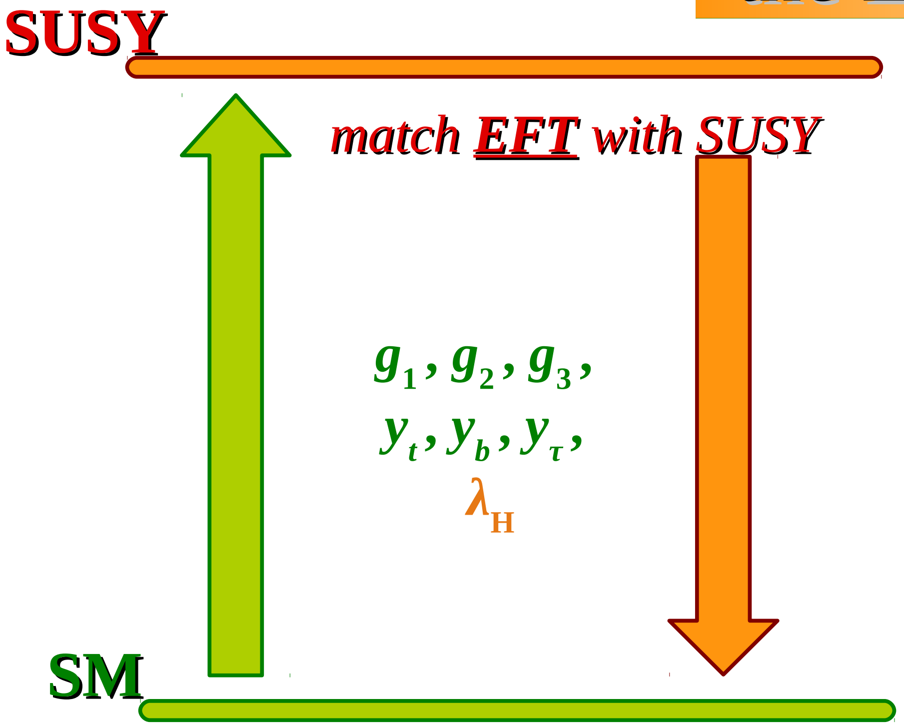
the EFT technique

SUSY

SM

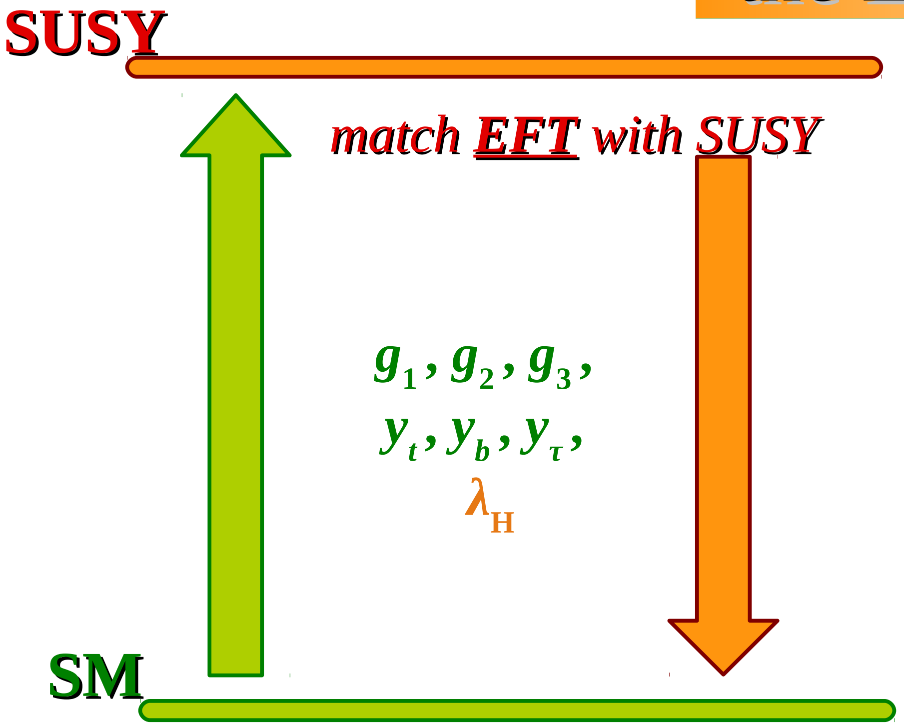
Exploiting the Hierarchy Problem:

the EFT technique



Exploiting the Hierarchy Problem:

the EFT technique



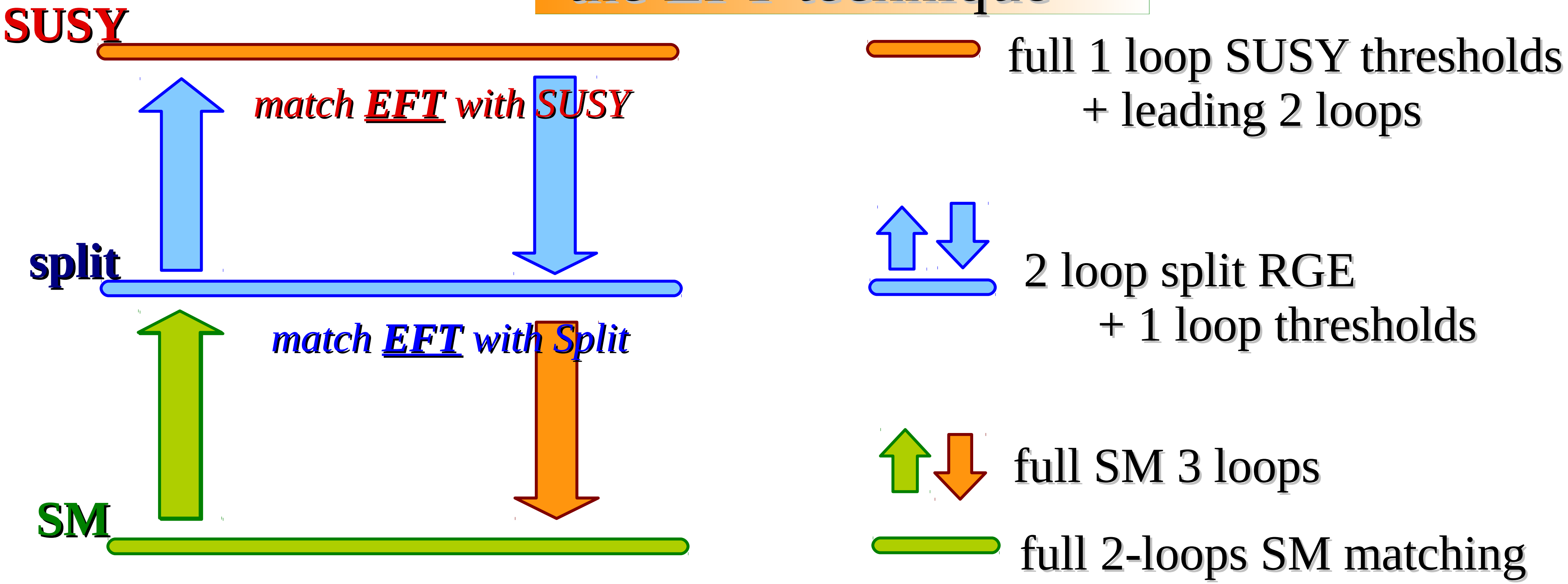
full 1 loop SUSY thresholds
+ leading 2 loops

full SM 3 loops

full 2-loops SM matching

Exploiting the Hierarchy Problem:

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

apologies to the missing ones

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

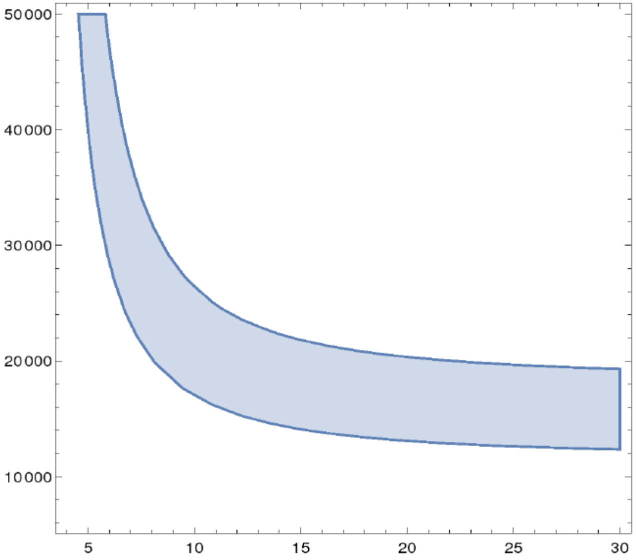
- Recomputation of $O(\alpha_s \alpha_t)$ corrections
- Computation of $O(\alpha_t^2)$ with scale dependence
- Inclusion bottom/tau corrections (w/ resummation of tanβ enhanced corr.)
- Computation both in DRbar and OS schemes
- Study of the uncertainties and comparison with existing computations
- A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

SusyHD

www.ictp.it/~susyhd

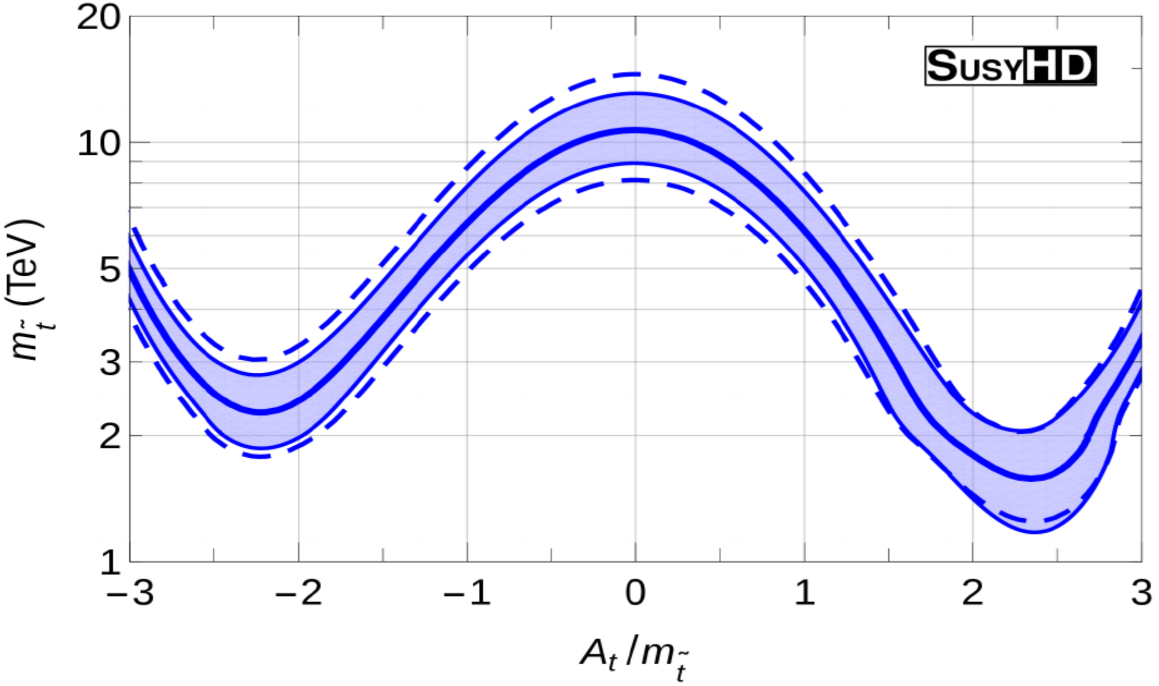
```
In[1]:=  << SUSYHD`

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]=



A “natural” SUSY-like spectrum:

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

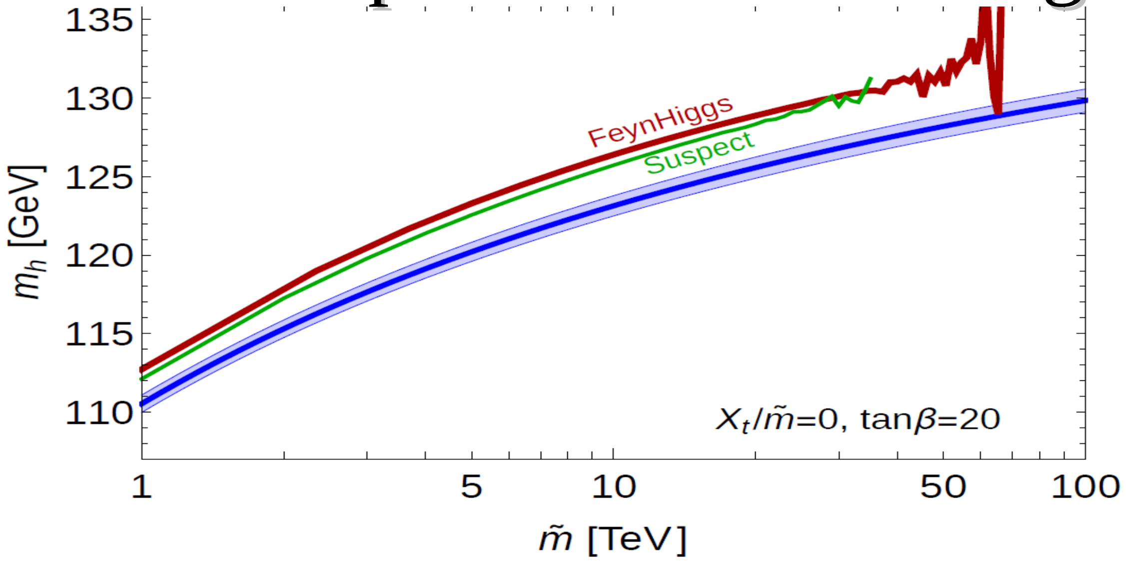


Δ_{exp}

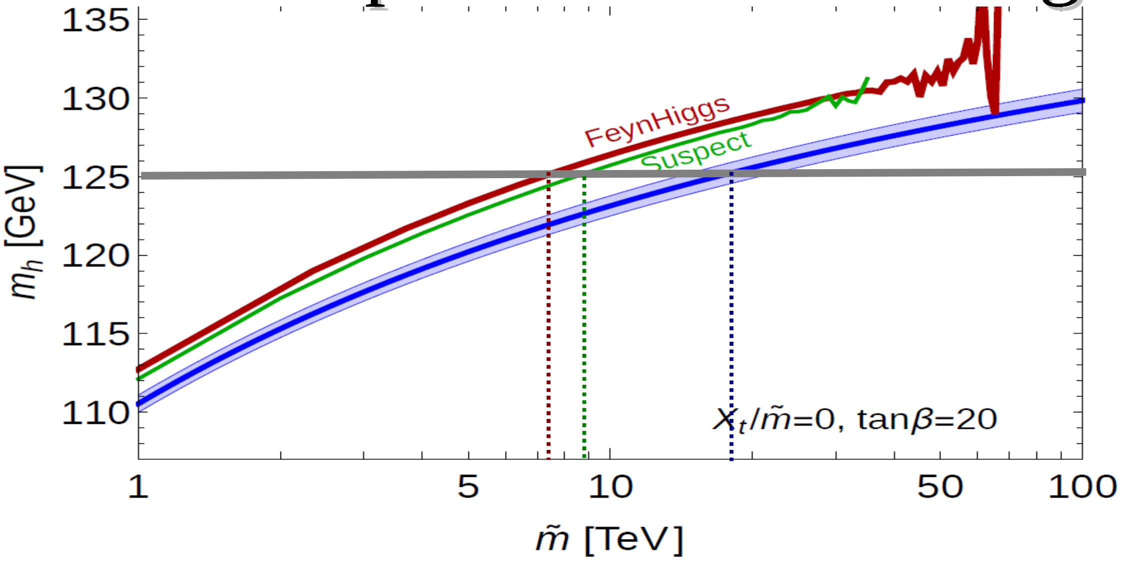
Δ_{th}

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

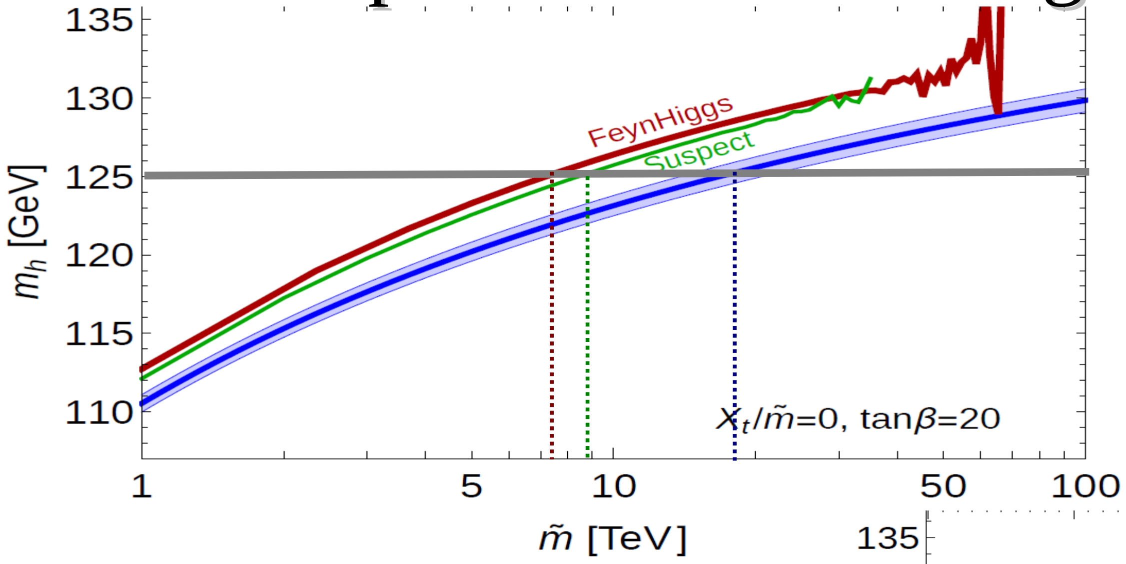
Comparison with existing codes

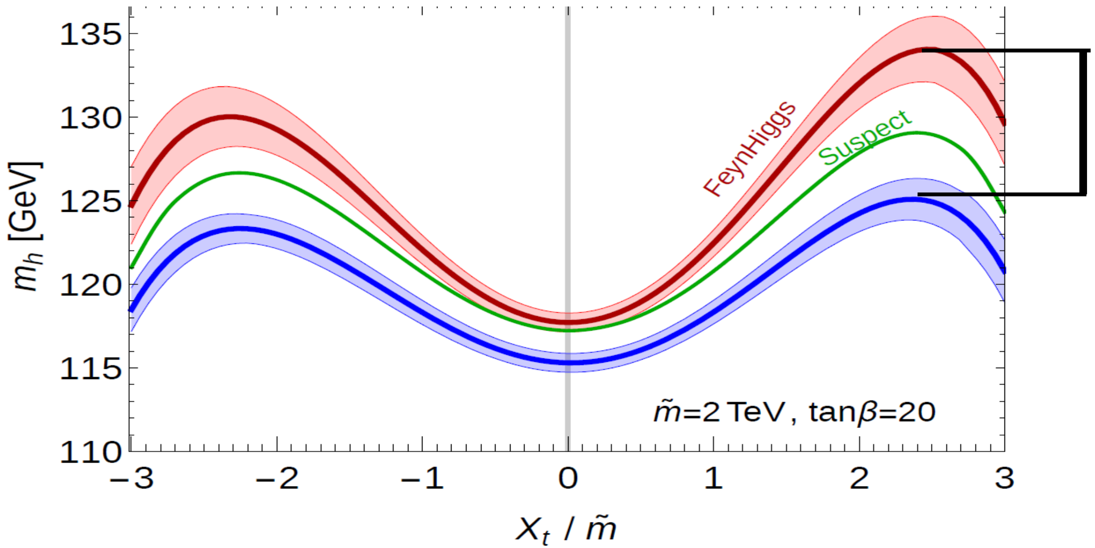


Comparison with existing codes



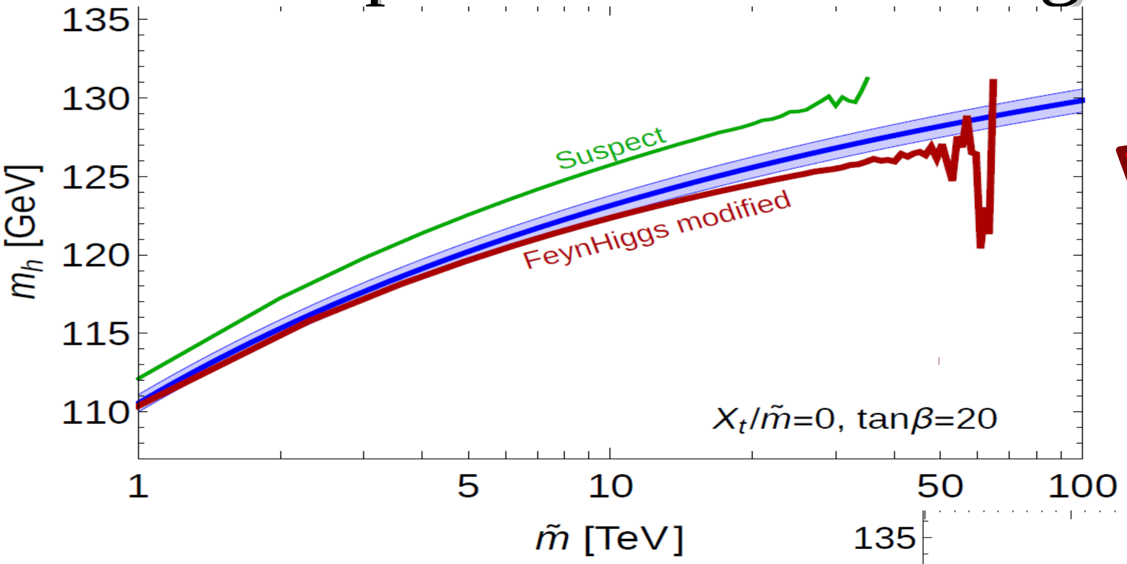
Comparison with existing codes



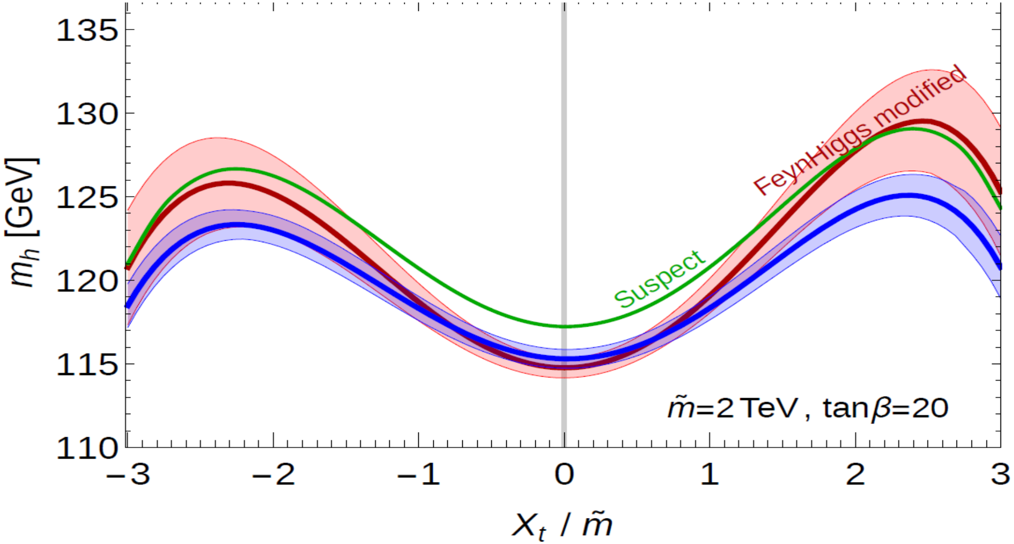


9 GeV!

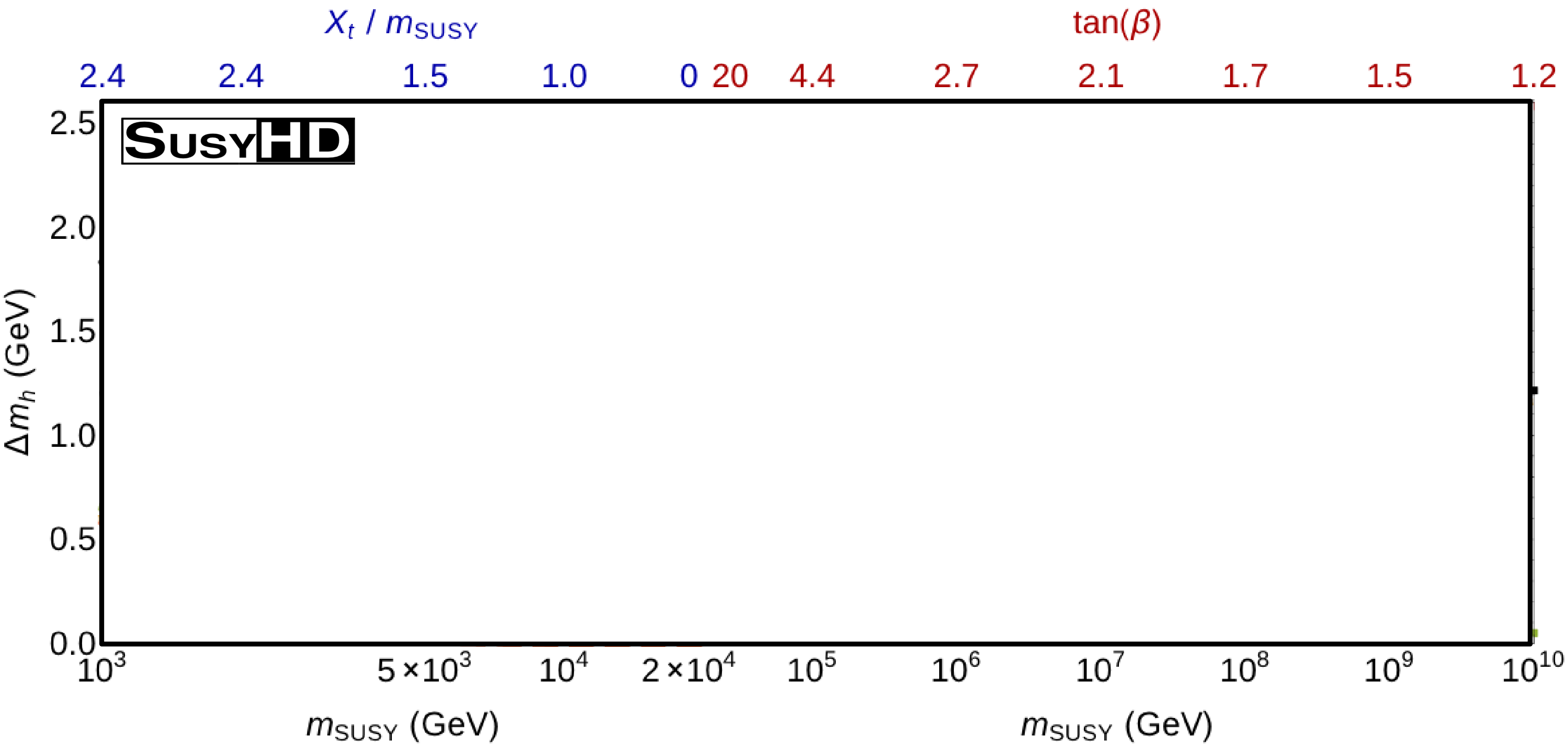
Comparison with existing codes



after 1-loop EW + 2-loop strong corrections to top Yukawa



Estimate of the Uncertainties:



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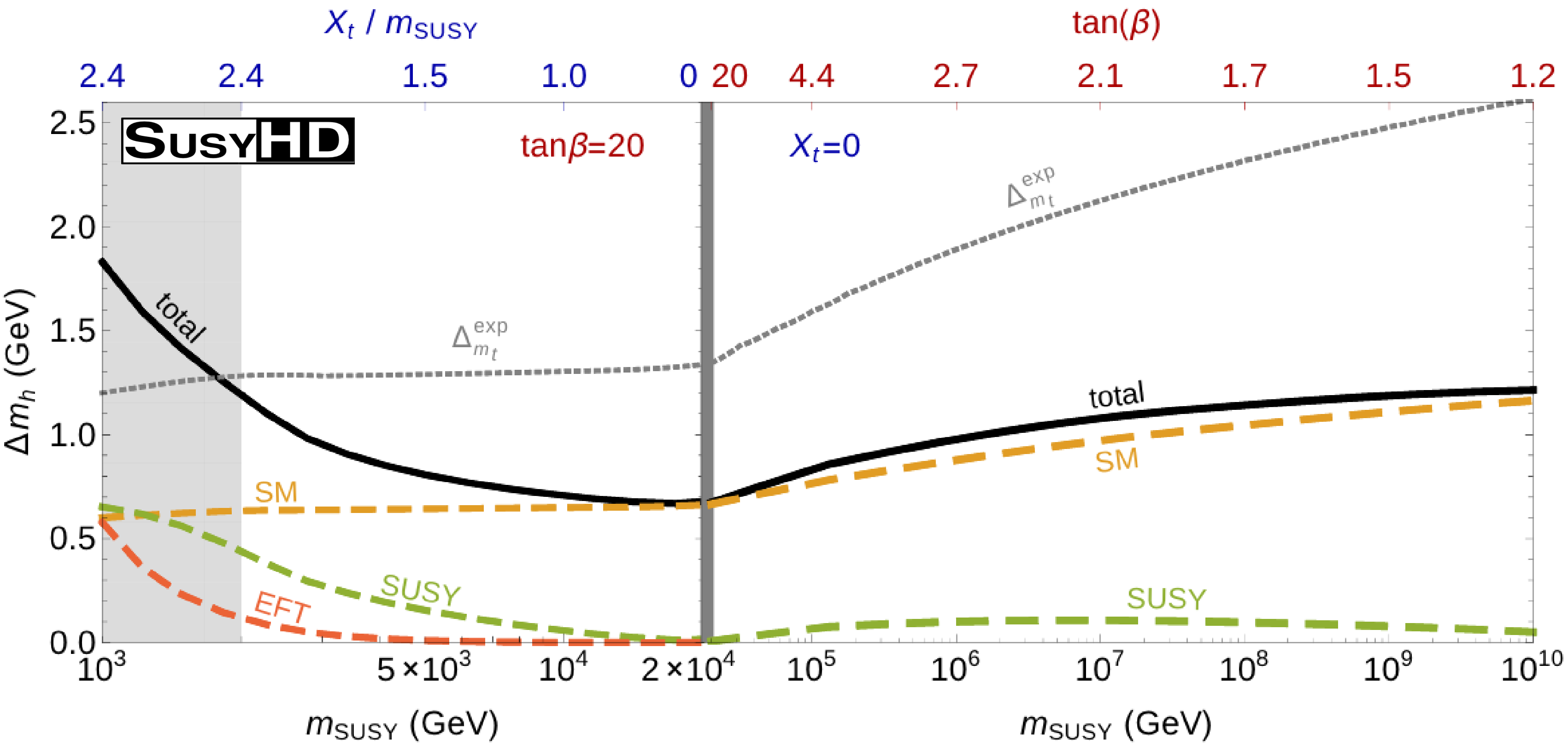

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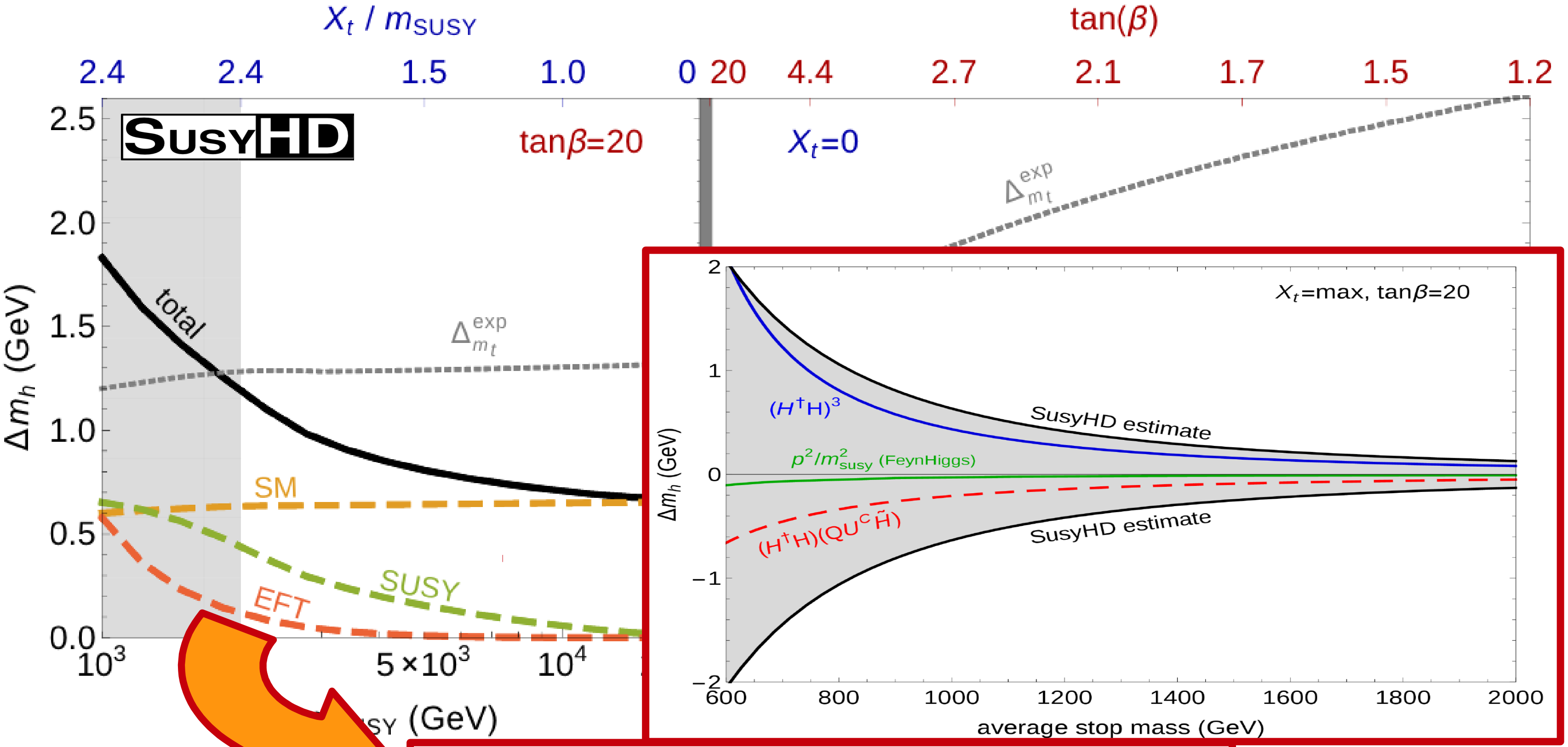
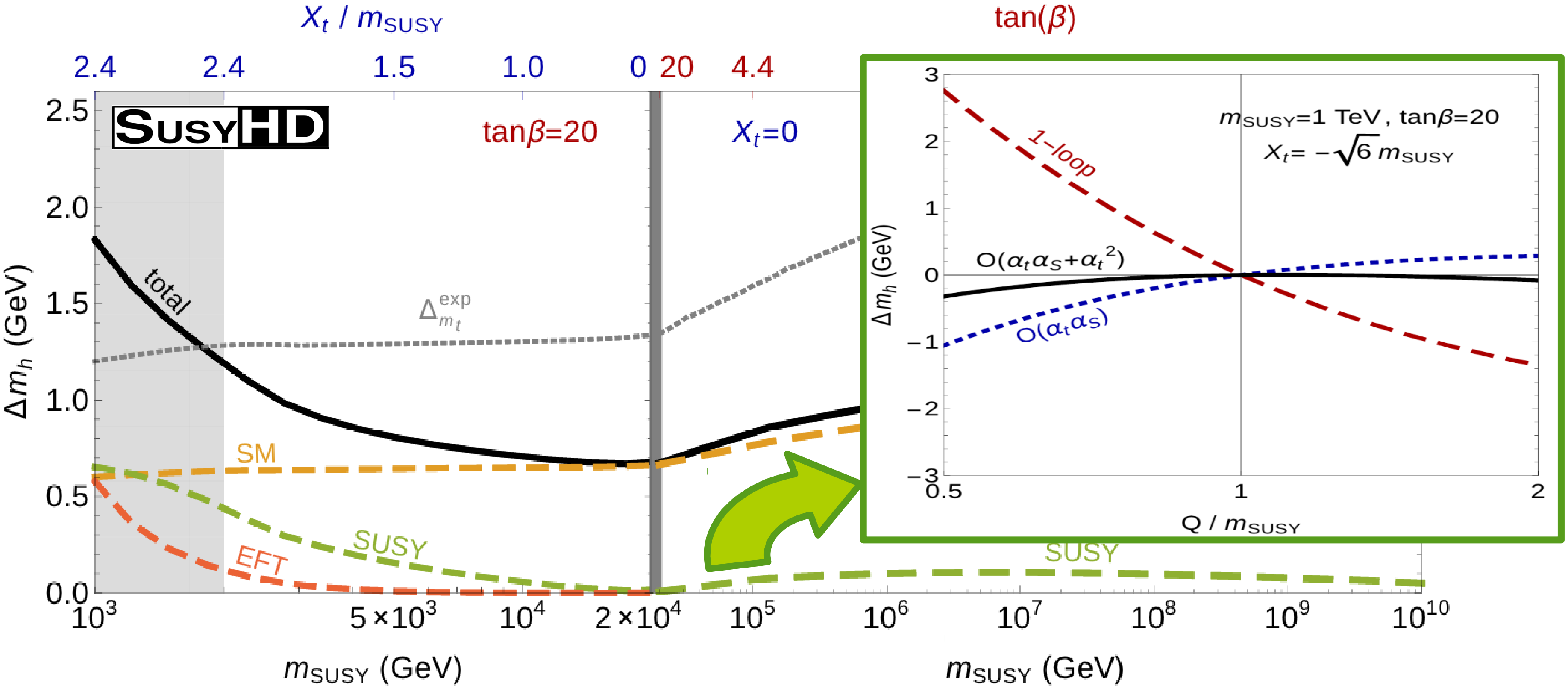


$$c_6 \frac{(H^\dagger H)^3}{m^2_{\text{SUSY}}} + c_t \frac{H^\dagger H}{m^2_{\text{SUSY}}} HQU^c + \ldots$$

Estimate of the Uncertainties:



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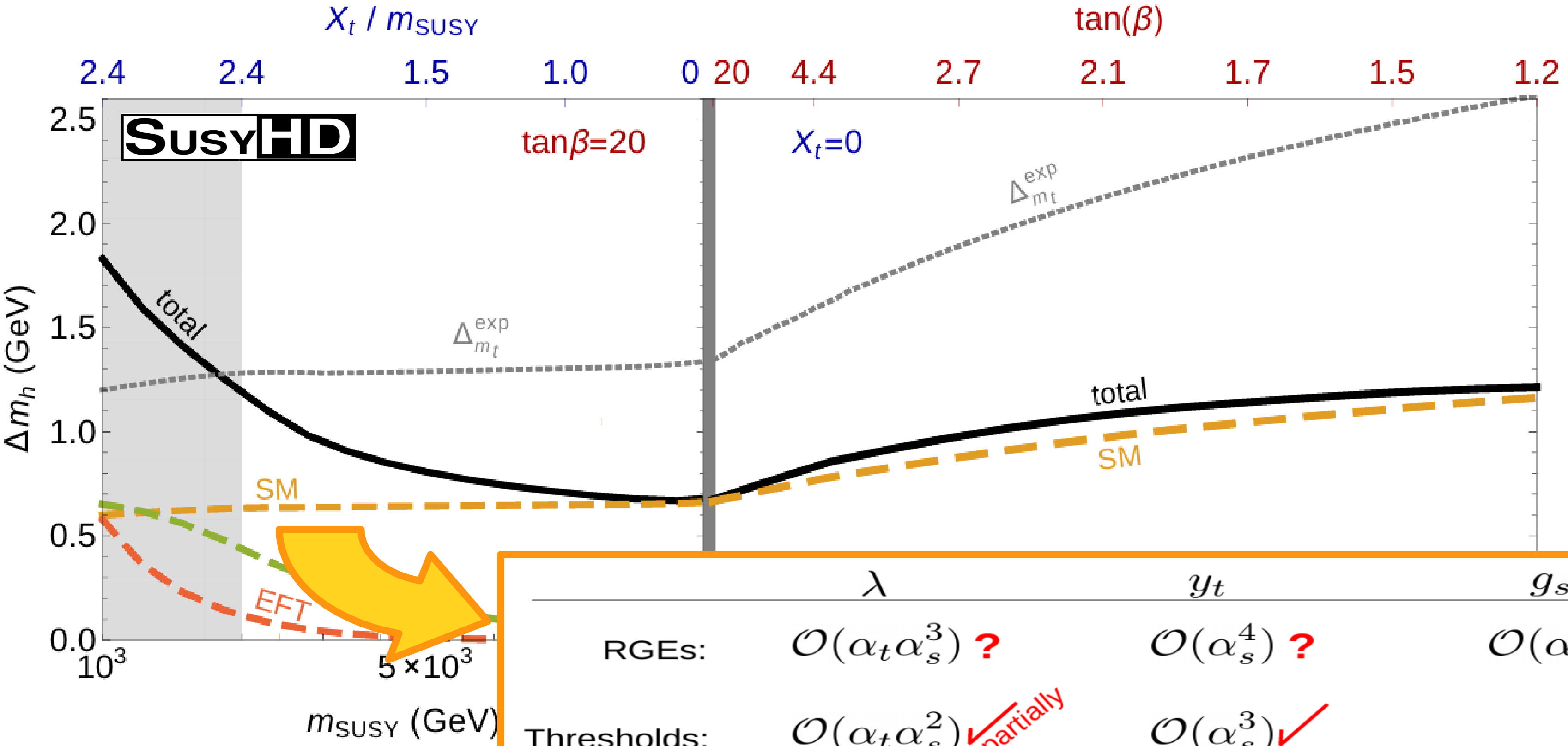


	λ	y_t	g_s
RGEs:	$\mathcal{O}(\alpha_t\alpha_s^3)$?	$\mathcal{O}(\alpha_s^4)$?	$\mathcal{O}(\alpha_s^4)$ ✓
Thresholds:	$\mathcal{O}(\alpha_t\alpha_s^2)$ ✓ partially	$\mathcal{O}(\alpha_s^3)$ ✓	

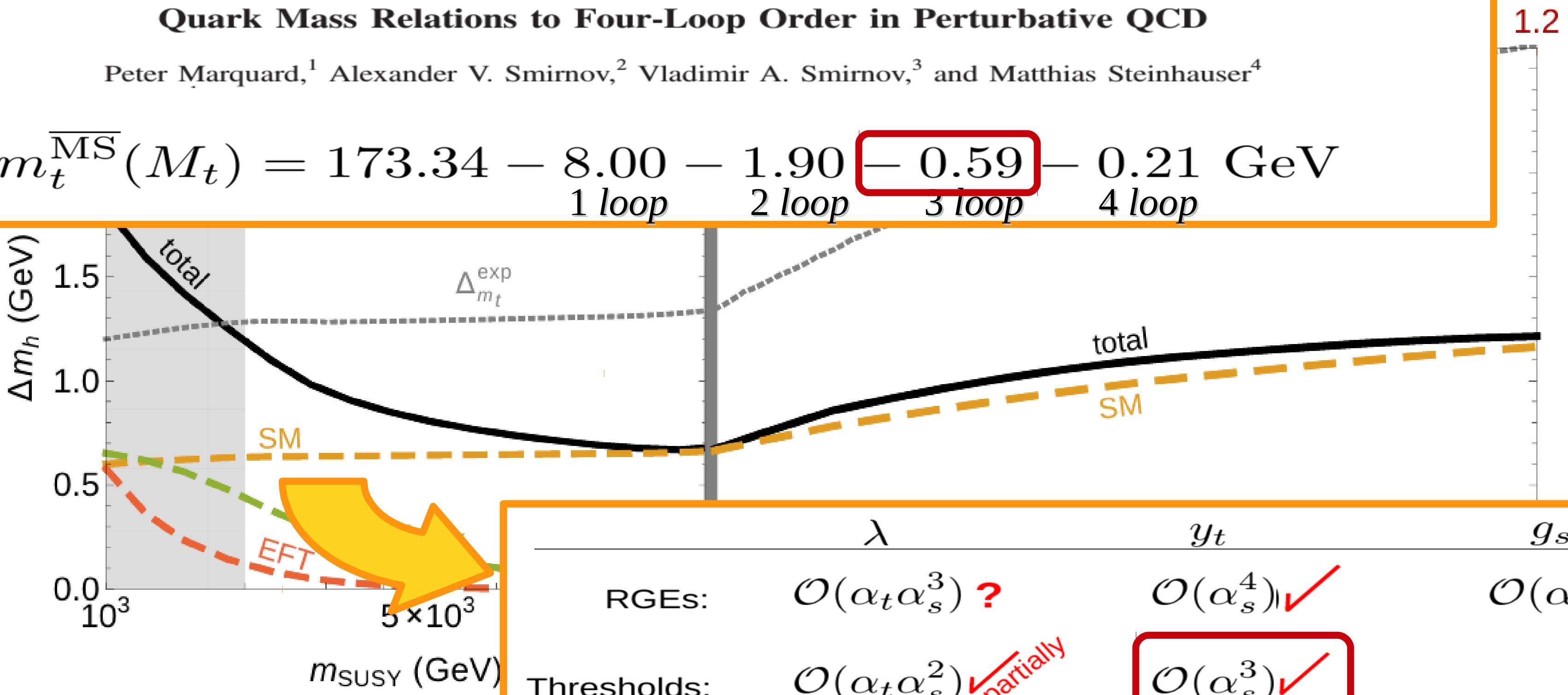
Estimate of the Uncertainties:

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]

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



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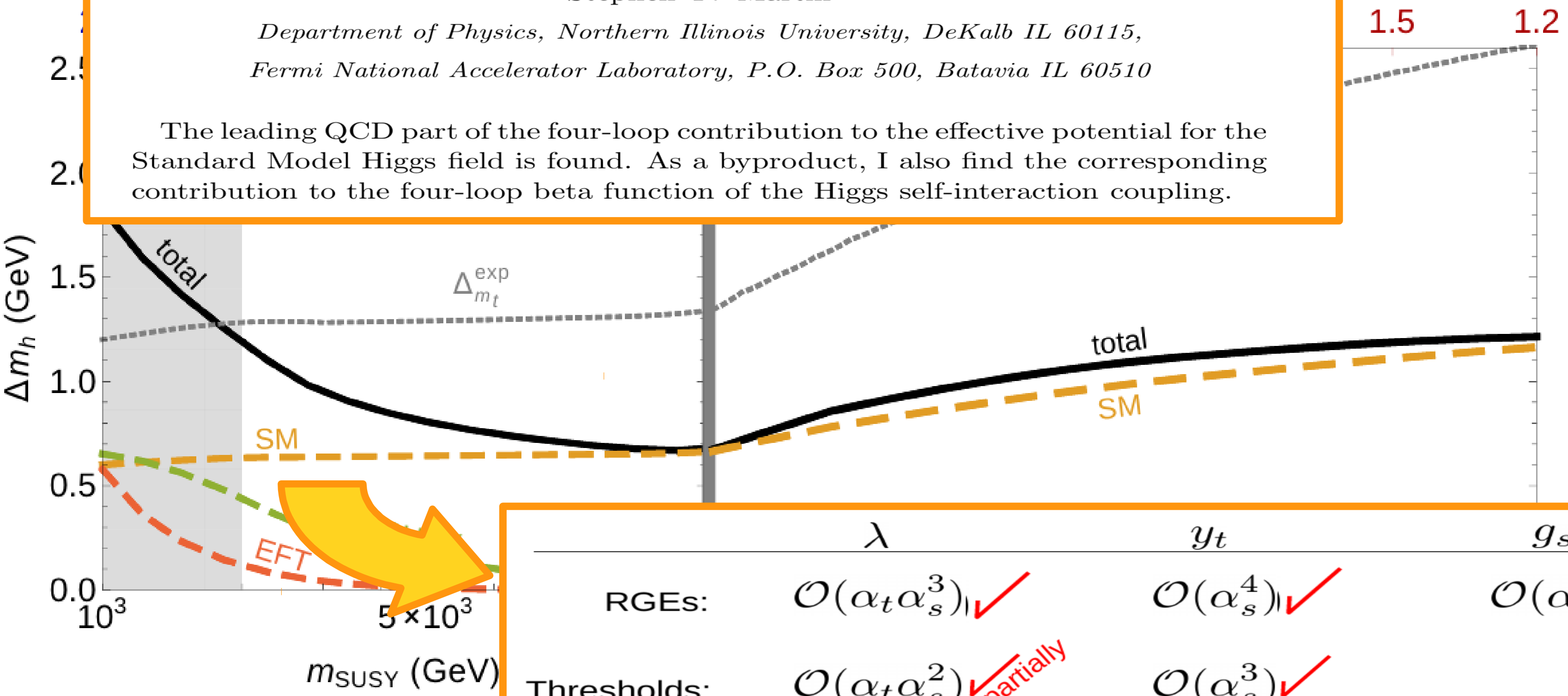

Four-loop Standard Model effective potential at leading order in QCD

Stephen P. Martin

Department of Physics, Northern Illinois University, DeKalb IL 60115,

Fermi National Accelerator Laboratory, P.O. Box 500, Batavia IL 60510

The leading QCD part of the four-loop contribution to the effective potential for the Standard Model Higgs field is found. As a byproduct, I also find the corresponding contribution to the four-loop beta function of the Higgs self-interaction coupling.

	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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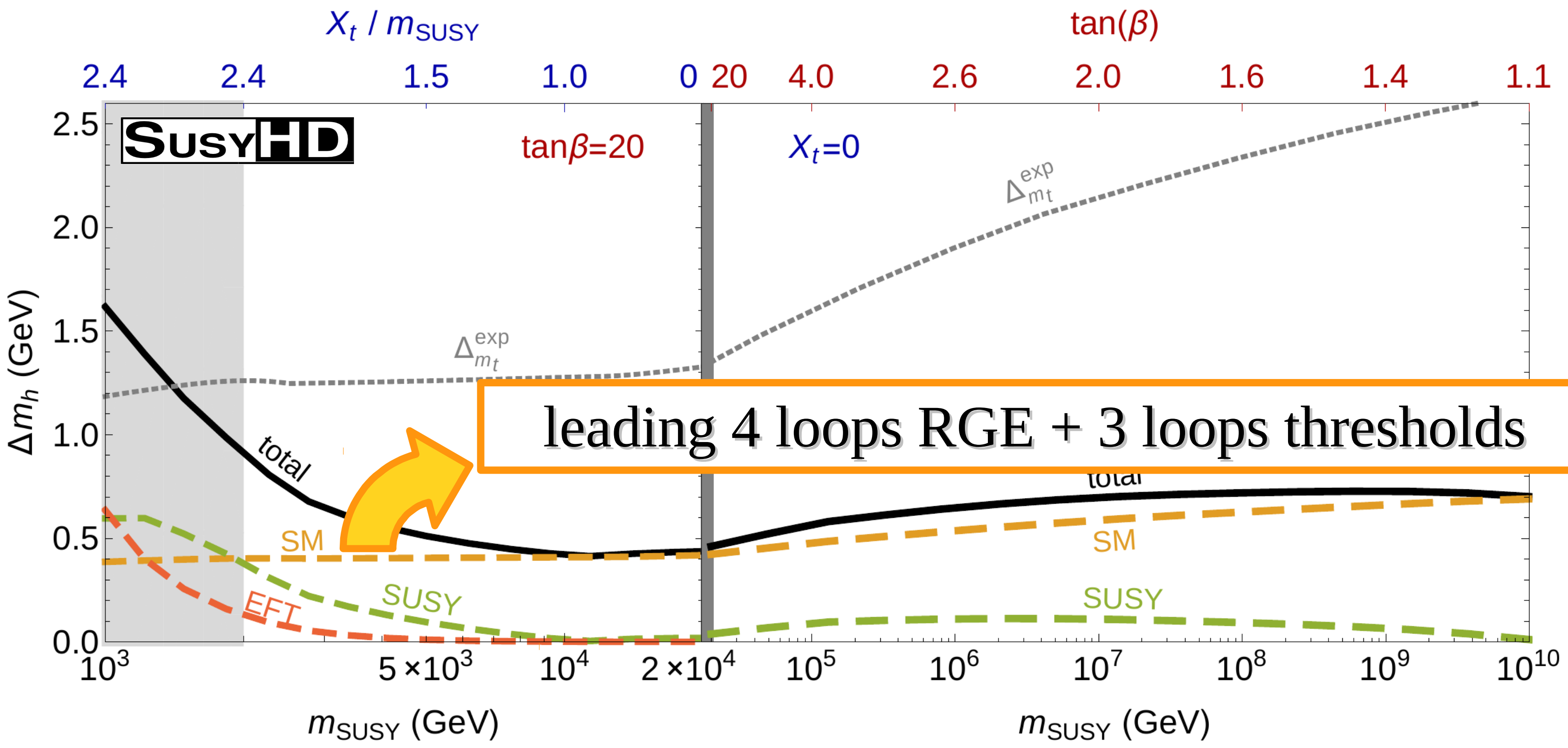
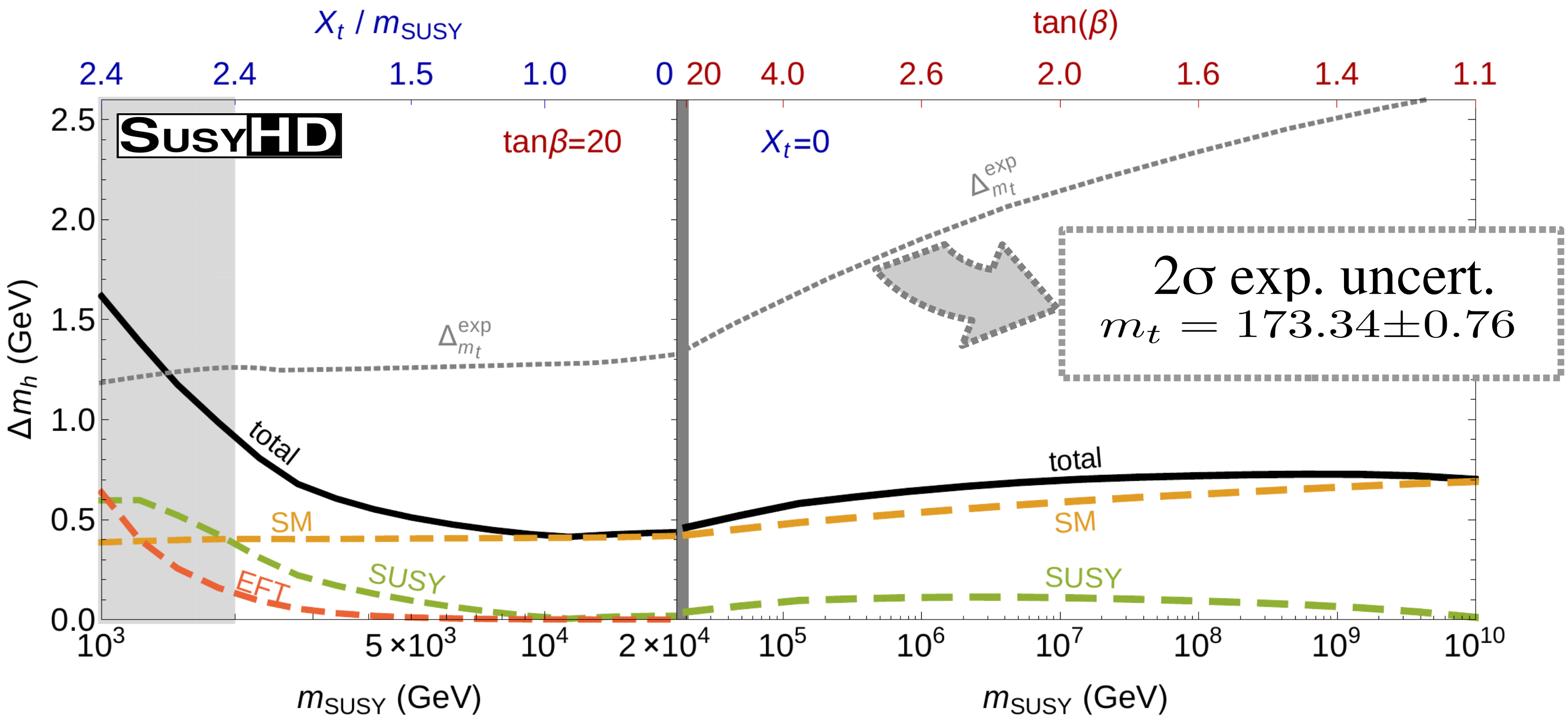
Estimate of the Uncertainties:



leading 4 loops RGE + 3 loops thresholds

Estimate of the Uncertainties:



Where is the Simplest SUSY?

The Simplest SUSY

(m_h, λ)

SM

The Simplest SUSY

(m_h, λ)

$$\underbrace{\text{SM} \quad + \quad \text{SUSY}}_{\text{MSSM} \ (\mu)}$$

The Simplest SUSY

(m_h, λ)

SM + SUSY + ~~SUSY~~

MSSM (μ) (F)

The Simplest SUSY

(m_h, λ)

SM + SUSY + ~~SUSY~~ + Mess.

MSSM (μ) (F) (M)

The Simplest SUSY

(m_h, λ)

$$\underbrace{\text{SM} + \text{SUSY}}_{\text{MSSM } (\mu)} + \cancel{\text{SUSY}}\,(F) + \text{Mess.}\,(M)$$

SM + SUSY + ~~SUSY~~ + Mess.

MSSM (μ) (F) (M)

μ , $\Lambda = F/M$ fixed by m_Z , m_h

weak dependence on log(M)

Minimal Gauge Mediation

Dine, Nir, Shirman
Rattazzi, Sarid '96

spectrum mostly fixed by usual GM relations

gauginos $M_j = N \frac{\alpha_j}{4\pi} \Lambda$ **scalars** $m_i = 2\sqrt{N} C_{ij} \frac{\alpha_j}{4\pi} \Lambda$ **higgsinos** μ

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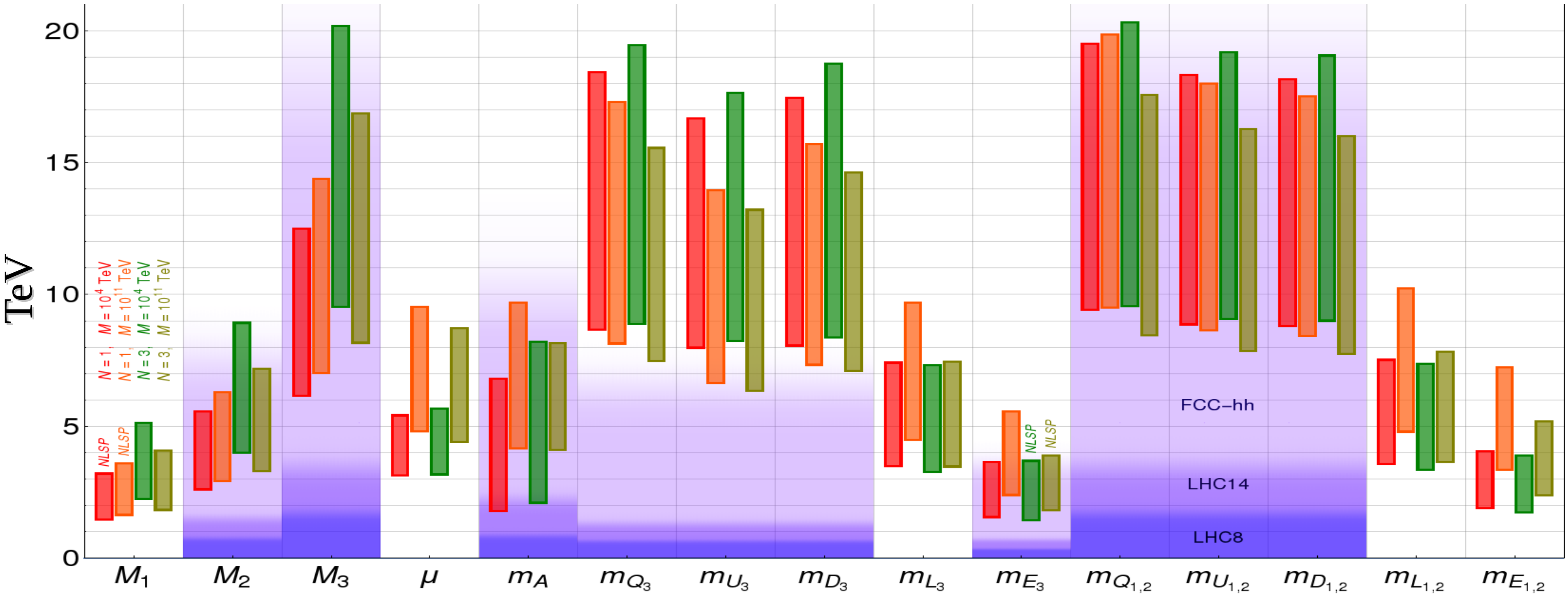
Predicting the MGM spectrum



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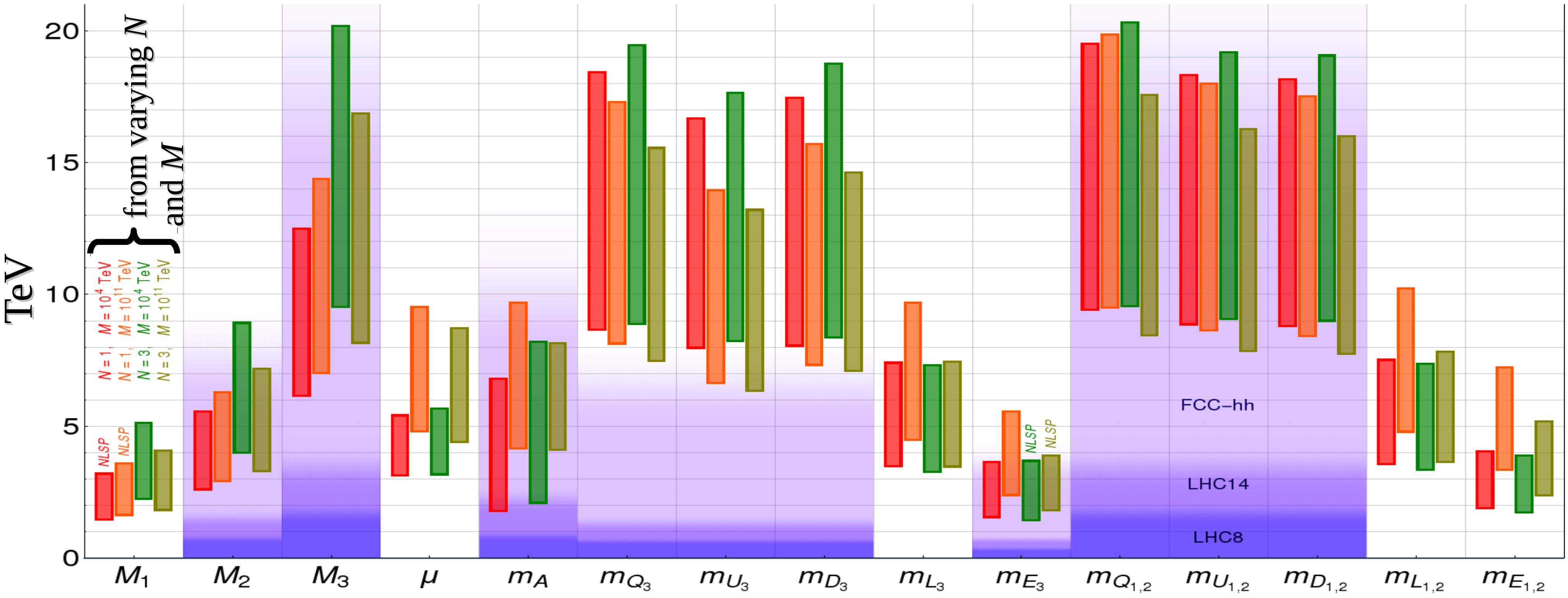

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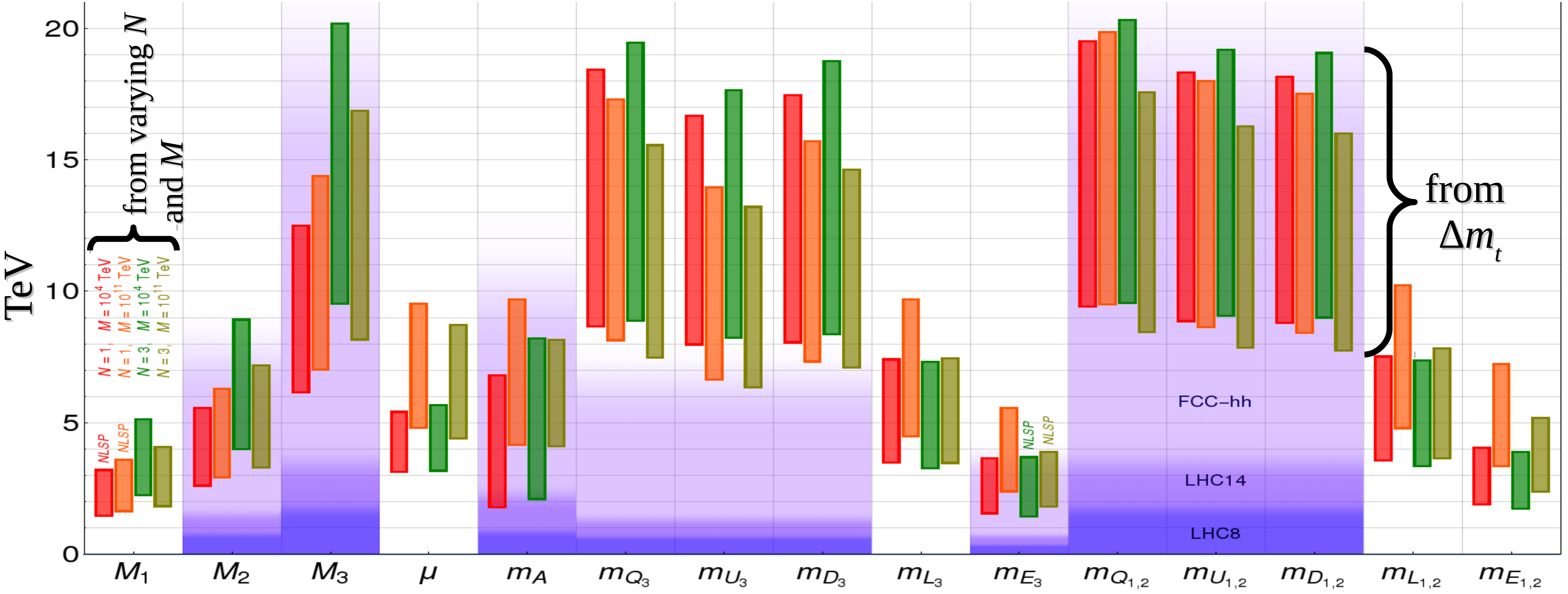

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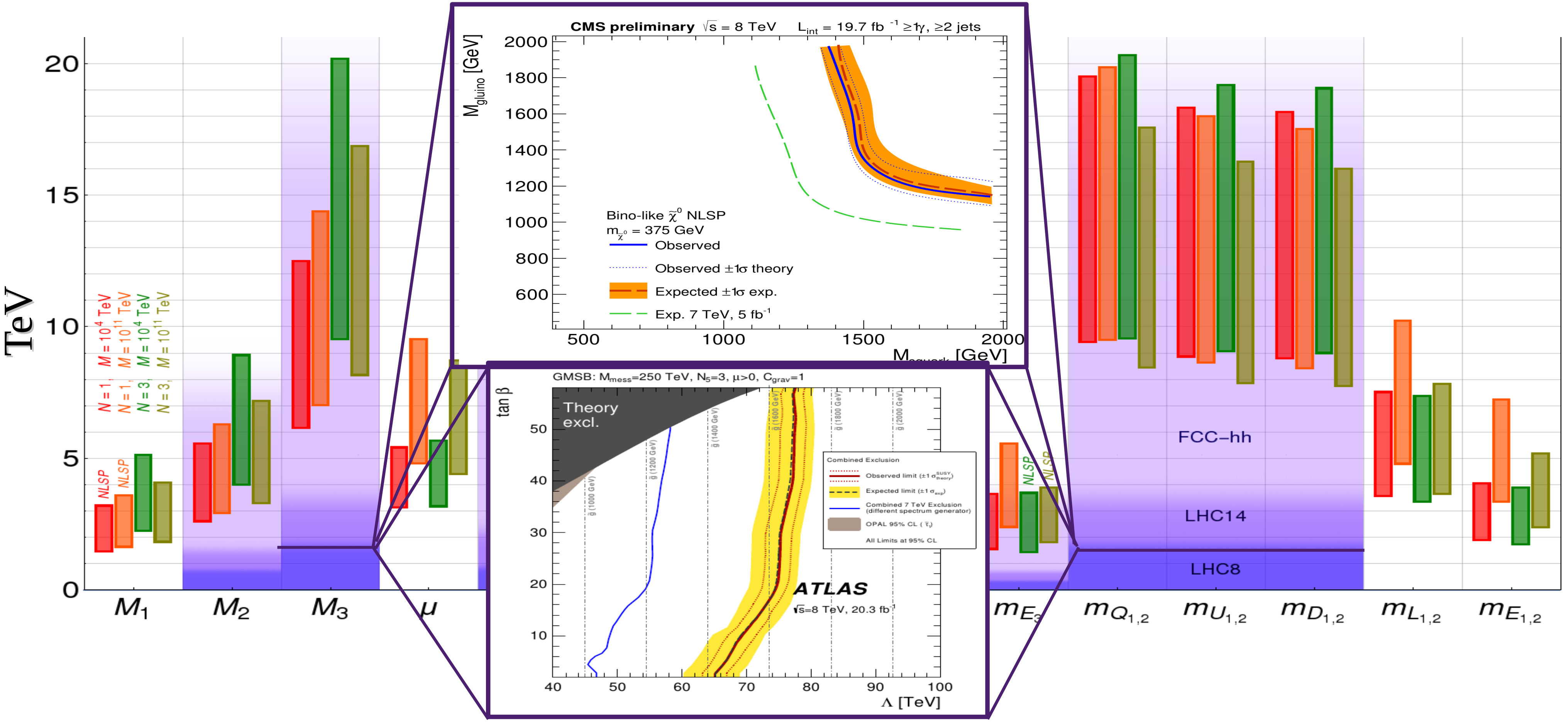

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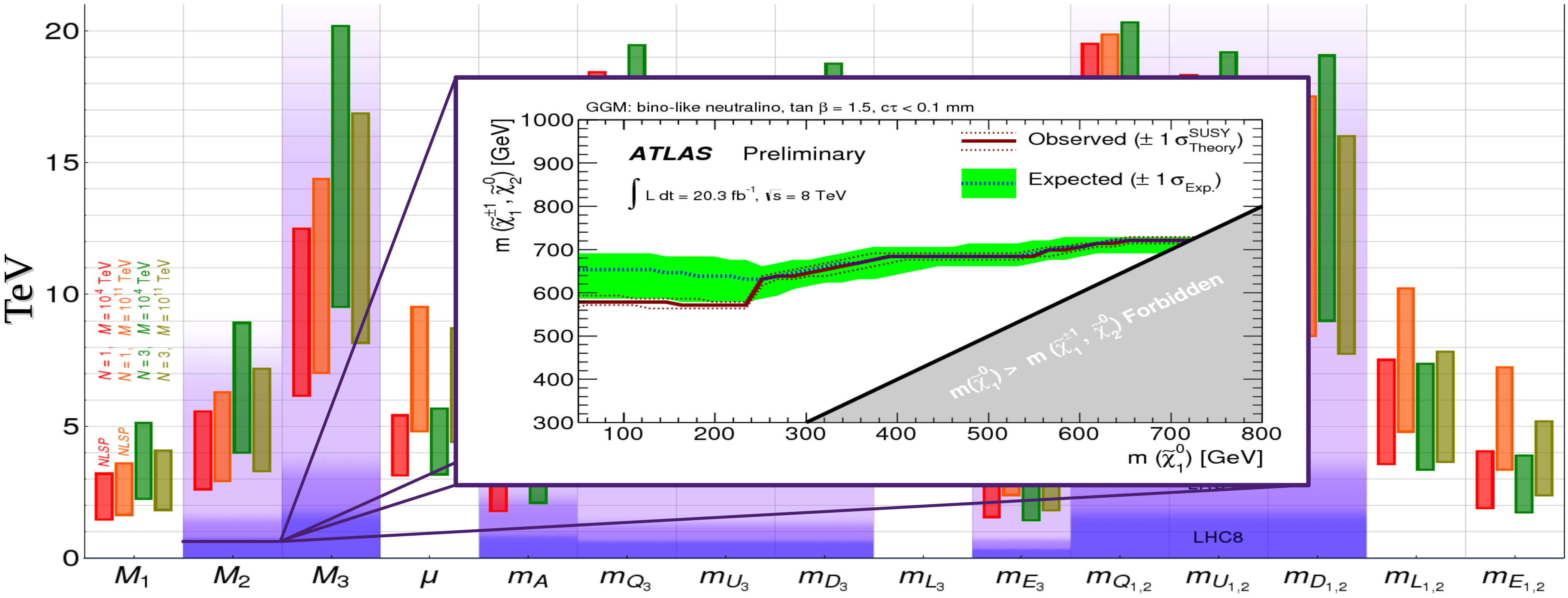

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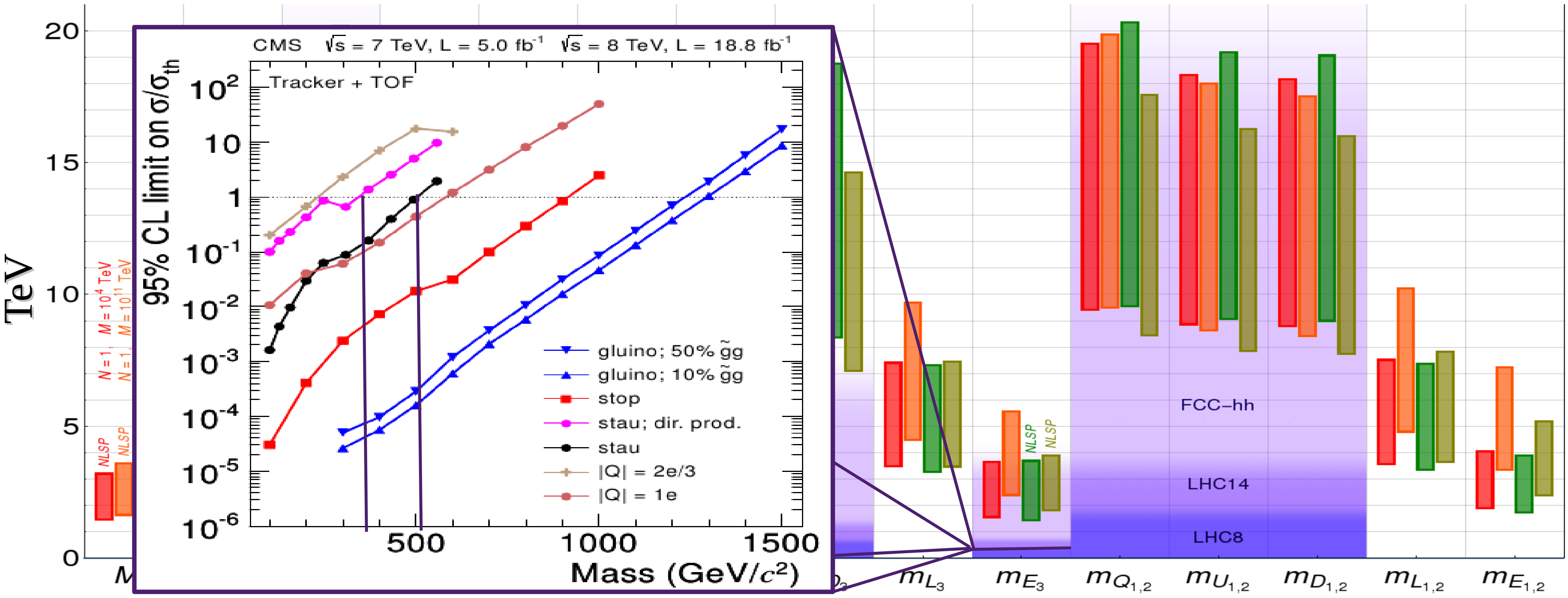

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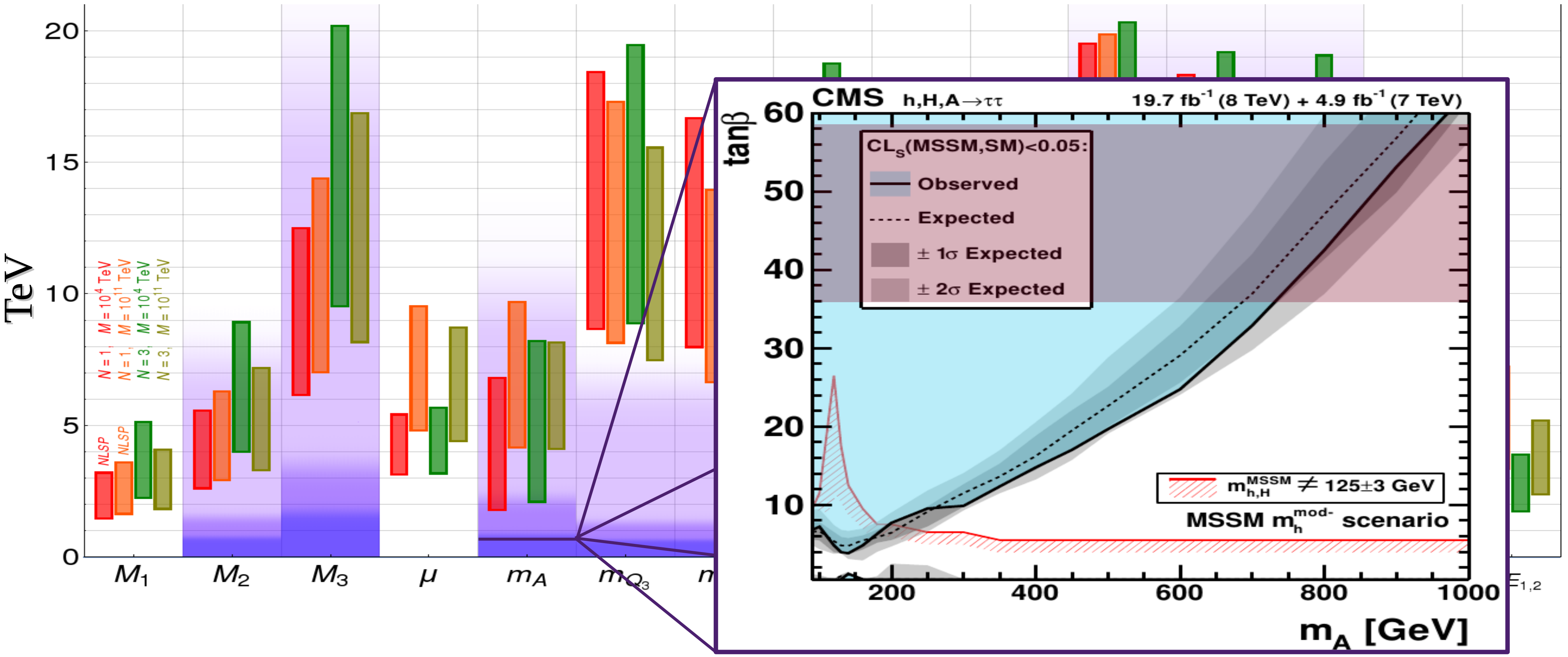

MGM:

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!

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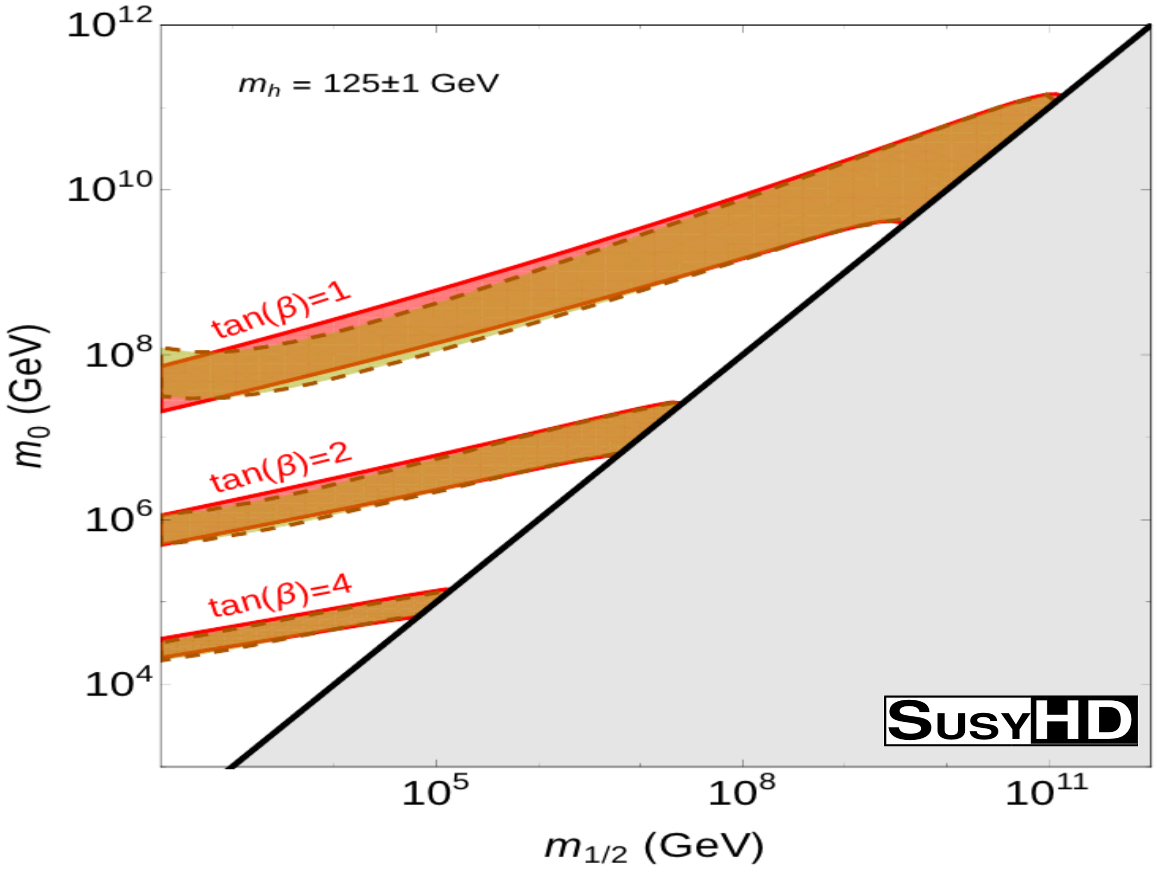
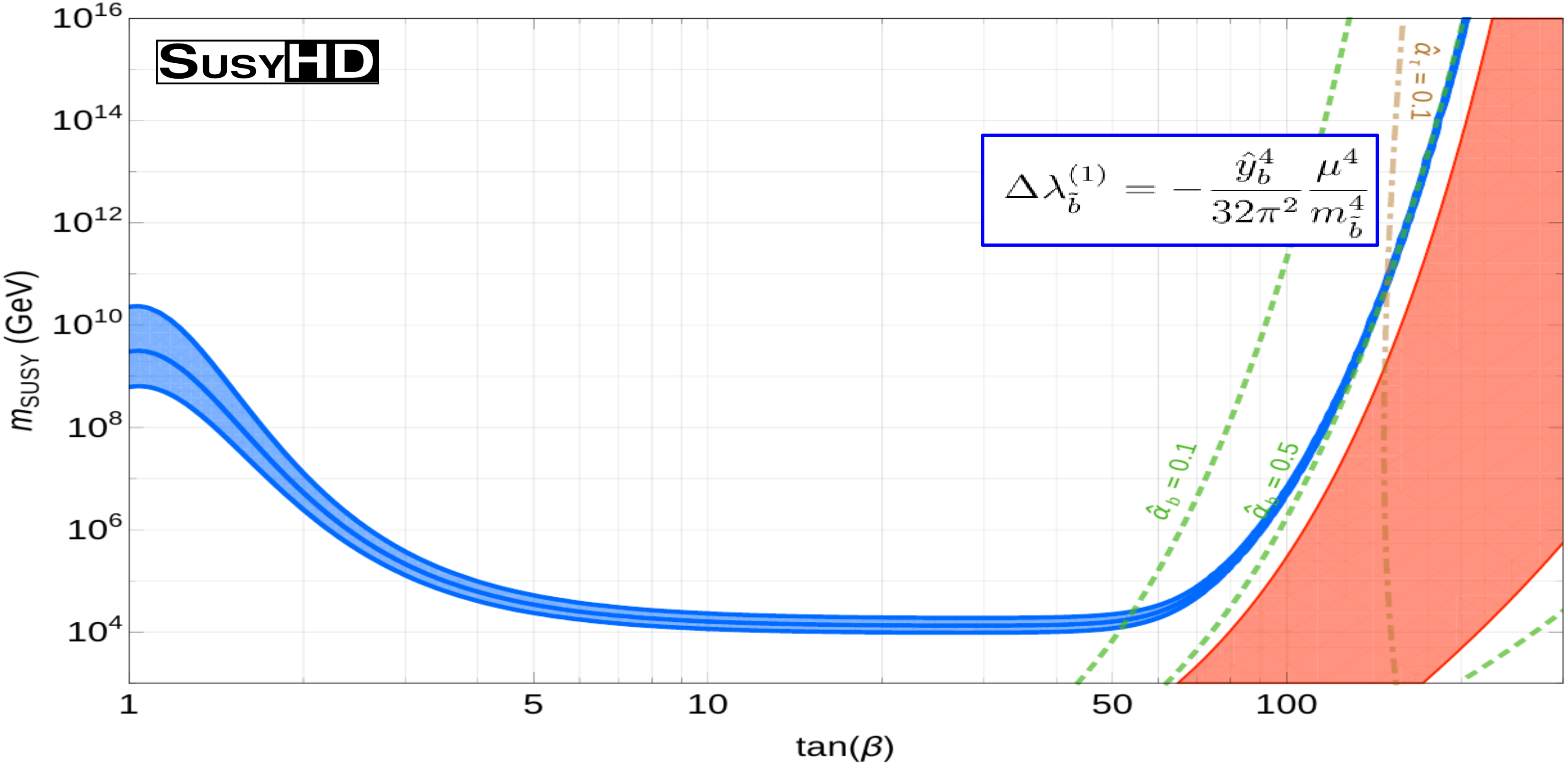
Perfect target for an 100 TeV collider?

Improvement on *top* mass **required**!

Backup

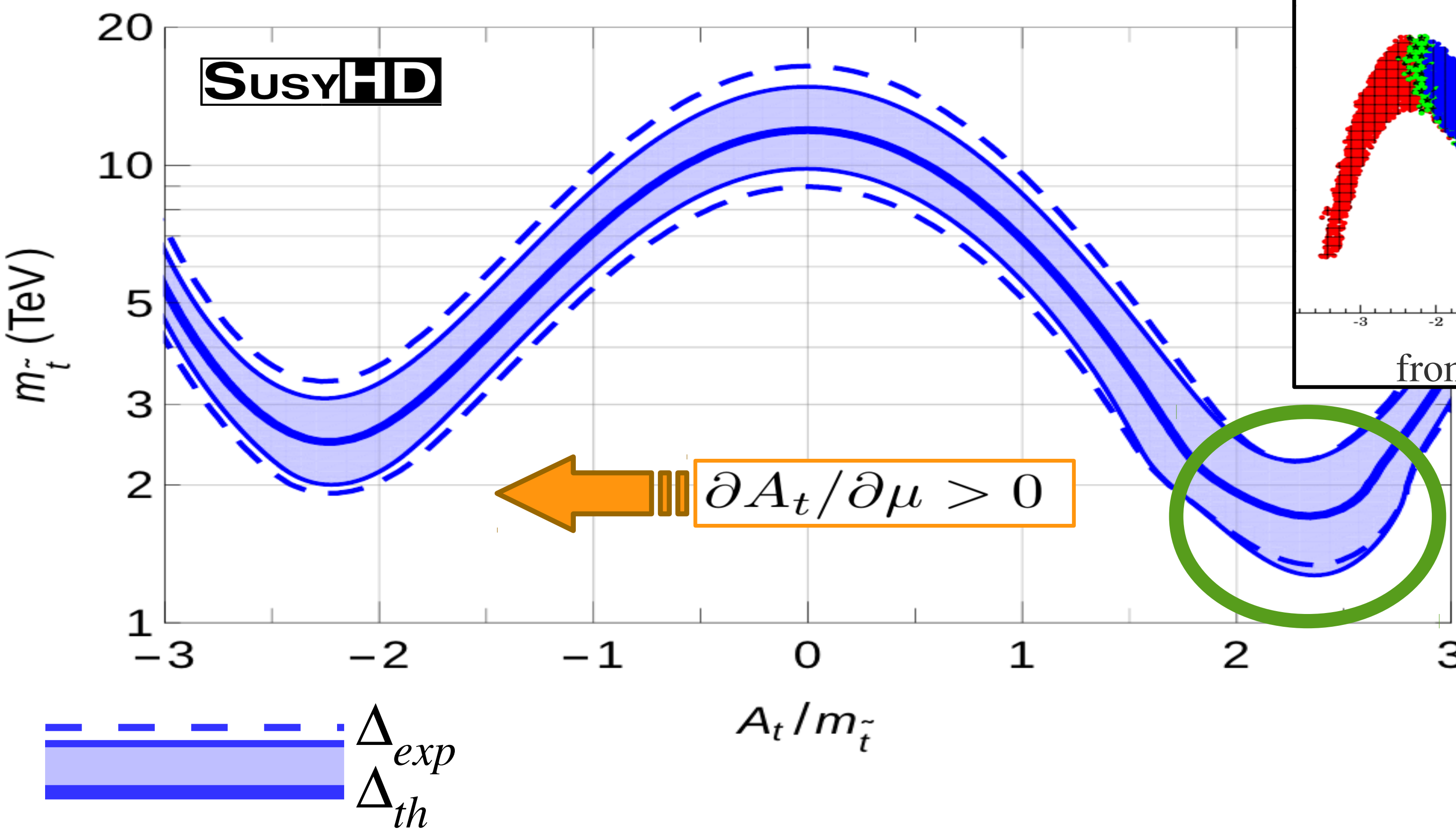
Effects from splitting fermions

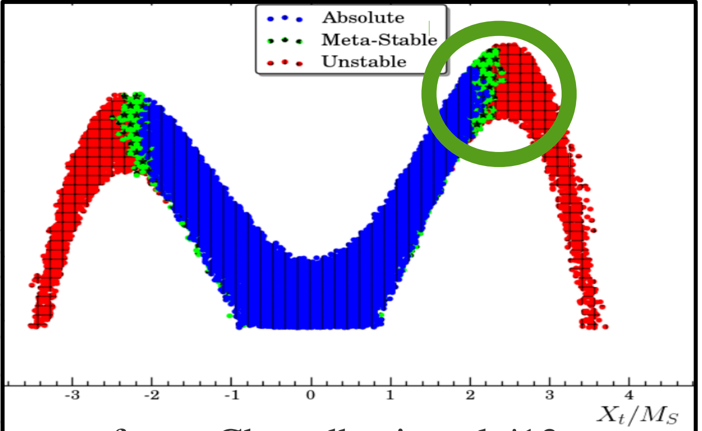



SusyHD
$\Delta\lambda_{\tilde{b}}^{(1)} = -\frac{\hat{y}_b^4}{32\pi^2}\frac{\mu^4}{m_{\tilde{b}}^4}$
$\hat{\alpha}_b = 0.1$
$\hat{\alpha}_b = 0.5$
$\hat{\alpha}_\tau = 0.1$
m_{SUSY} (GeV)
tan(β)
10^4
10^6
10^8
10^{10}
10^{12}
10^{14}
10^{16}
1
5
10
50
100

A “natural” SUSY-like spectrum:

$\tan\beta = 20$, $\mu = 300$ GeV ,





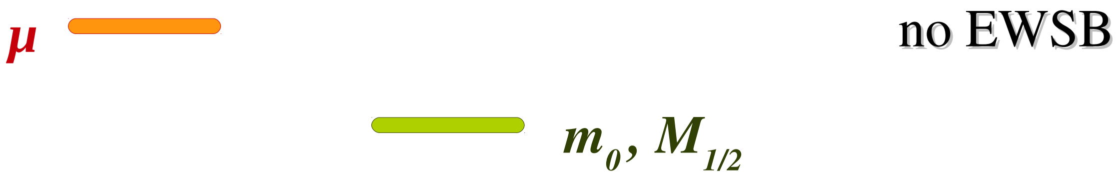
from: Chowdhuri et al. '13

No naturalness → no μ problem:

SUSY term

μ

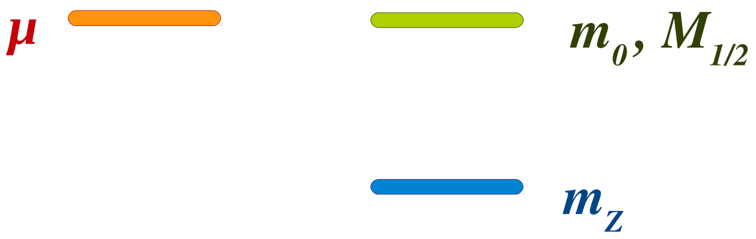
No naturalness → no μ problem:



No naturalness → no μ problem:

EWSB ~ m_0

No naturalness → no μ problem:



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

EWSB « m_0

No naturalness $\rightarrow$ 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, $M_{1/2}$ $|\mu|^2 \simeq -m_{H_u}^2 + \ldots$

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

m_Z EWSB « m_0

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

generated radiatively

$A_t \lesssim m_0$ *no maximal mixing*

$B_\mu \ll m_0^2$ tan(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 — 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 → no EDMs*