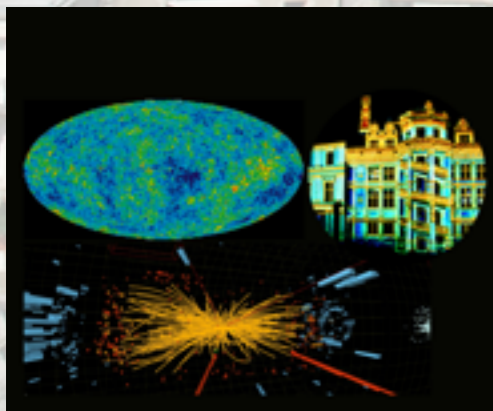


Implications of SUSY Searches for BSM

Nathaniel Craig
UC Santa Barbara

Rencontres de Blois 2015



Hierarchy Problem

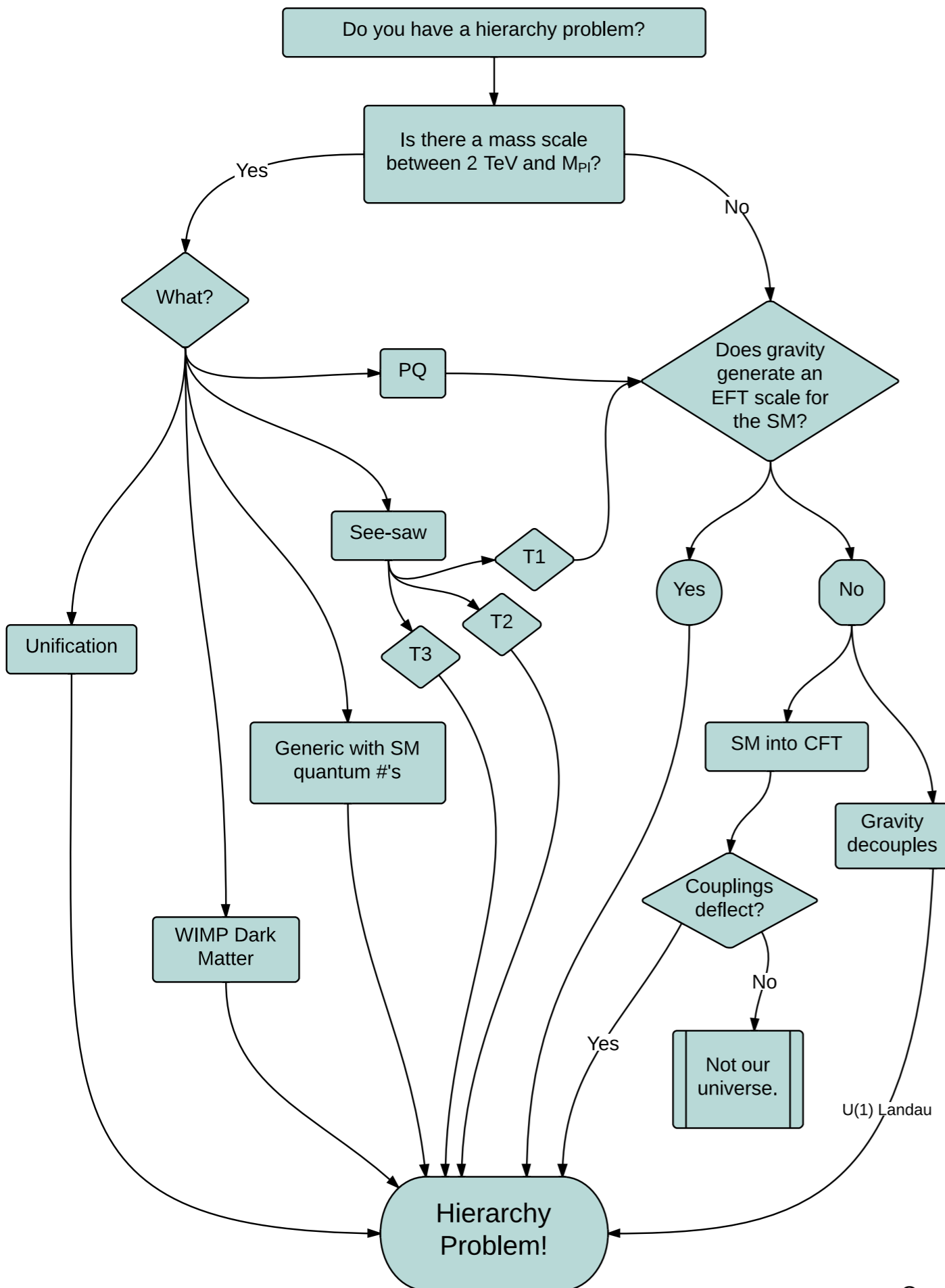
Elementary scalars are quadratically sensitive to physics at higher scales.

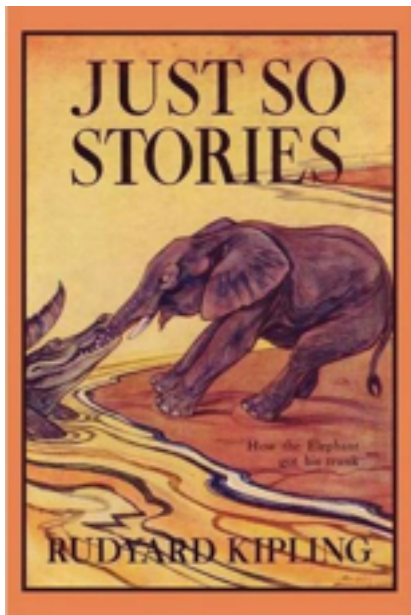
Independent of regularization scheme.

Model-building scales aside, gravity attests to presence of a higher scale.

No viable proposals for mitigating sensitivity to physics @ Planck scale *without* new physics @ weak scale.

Hierarchy problem only sharpened with the discovery of an elementary SM-like Higgs (+nothing else so far).





Natural vs. unnatural

Hierarchy problem is not a "just-so story"

Field Symmetry as $m \rightarrow 0$ Implication

Spin-1/2

$$m \Psi \bar{\Psi}$$

$$\begin{aligned} \Psi &\rightarrow e^{i\theta} \Psi \\ \bar{\Psi} &\rightarrow e^{-i\theta} \bar{\Psi} \end{aligned}$$

(chiral symmetry)

$\delta m \propto m$
Natural!

Spin-1

$$m^2 A_\mu A^\mu$$

$$A_\mu \rightarrow A_\mu + \partial_\mu \alpha$$

(gauge invariance)

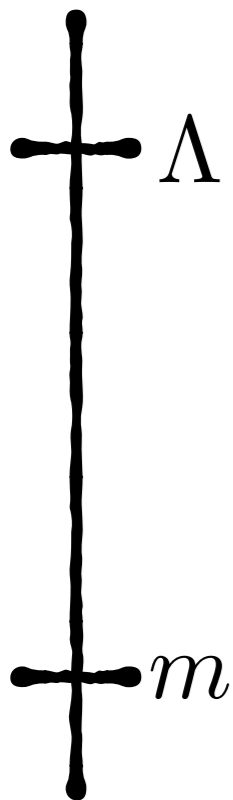
$\delta m \propto m$
Natural!

Spin-0

$$m^2 |H|^2$$

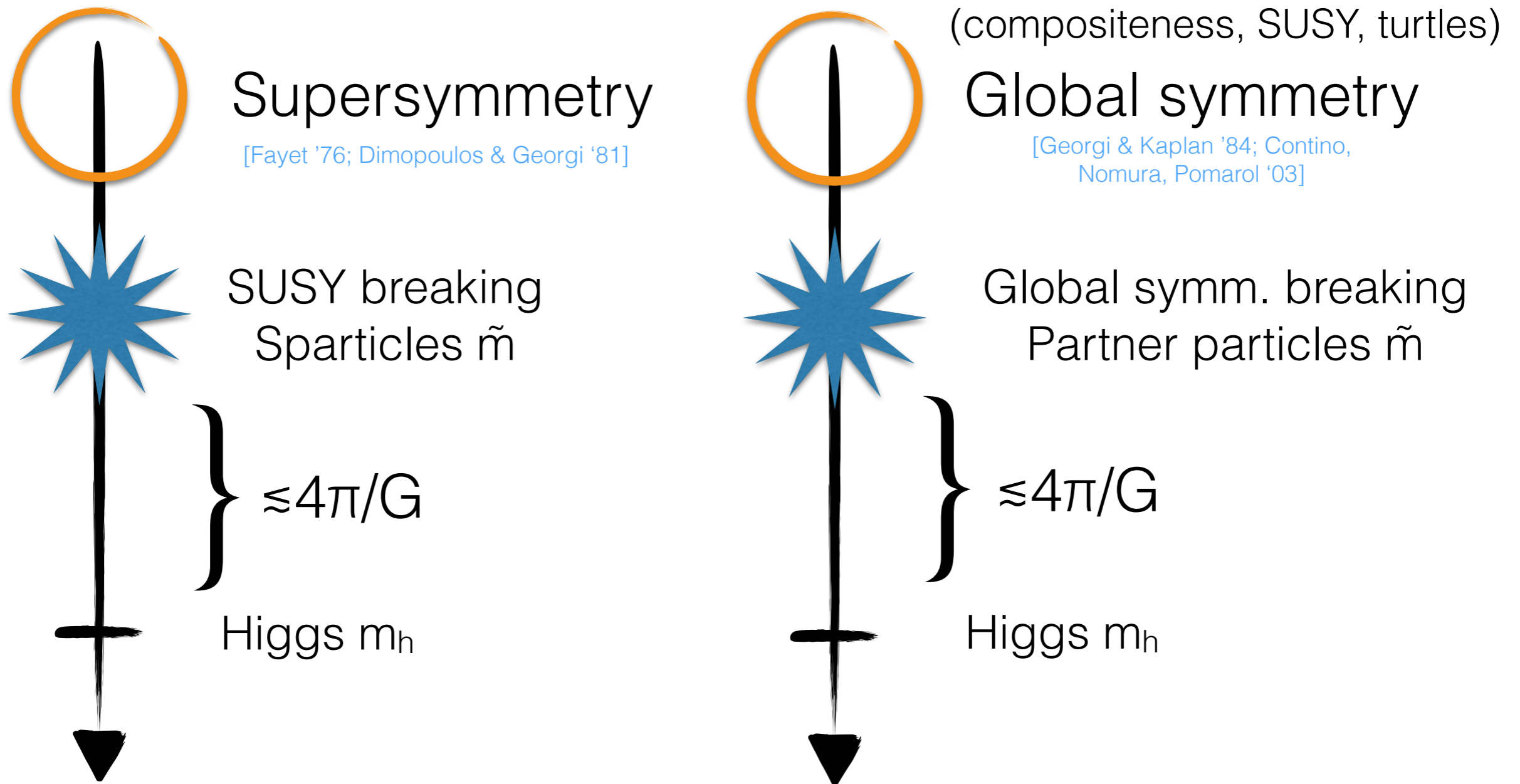
None

$\delta m \propto \Lambda$
Unnatural!



Electroweak naturalness

Make the Higgs mass technically natural by introducing symmetries



Continuous symmetries \rightarrow partner states w/ SM quantum #s

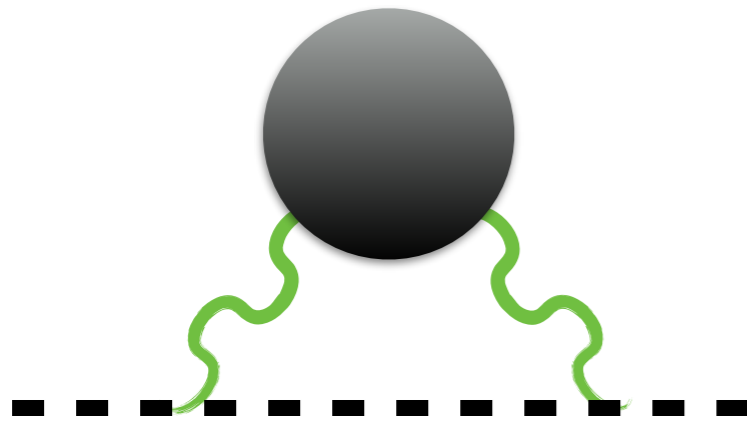
$$m_h^2 \sim \frac{3y_t^2}{4\pi^2} \tilde{m}^2 \log(\Lambda^2 / \tilde{m}^2) \quad \text{Totally natural: } \tilde{m} \lesssim 200 \text{ GeV}$$

The naturalness strategy

This is a *strategy* for new physics near m_h , not a *no-lose theorem*, because the theory does not break down if it is unnatural.

But naturalness has often been a very *successful* strategy.

E.g. charged pions



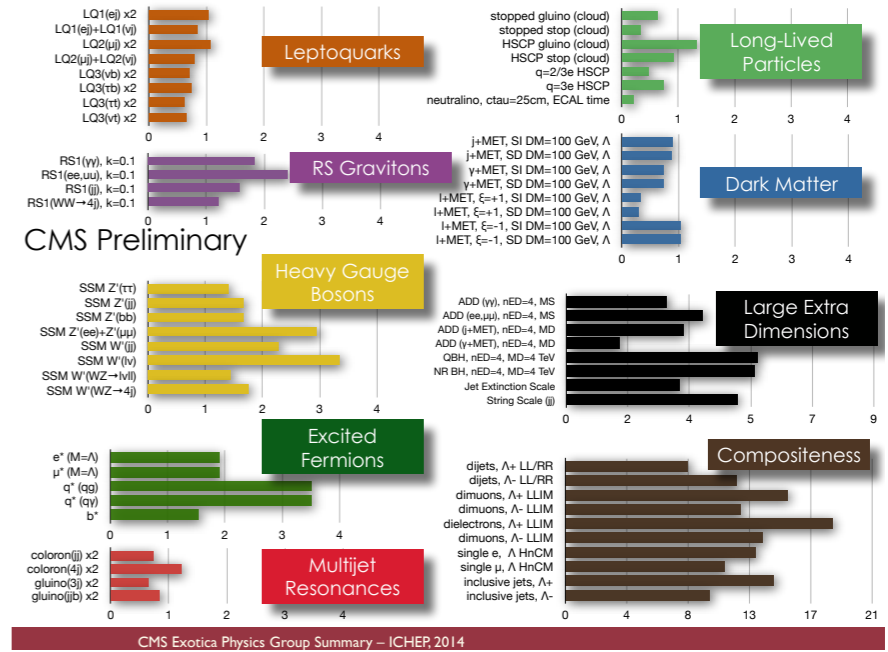
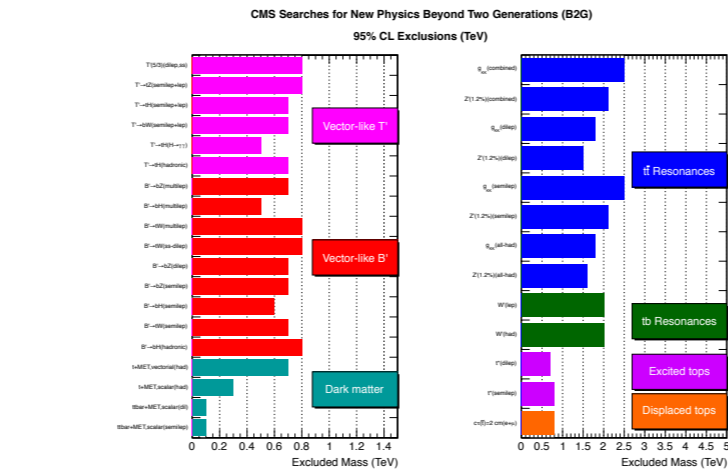
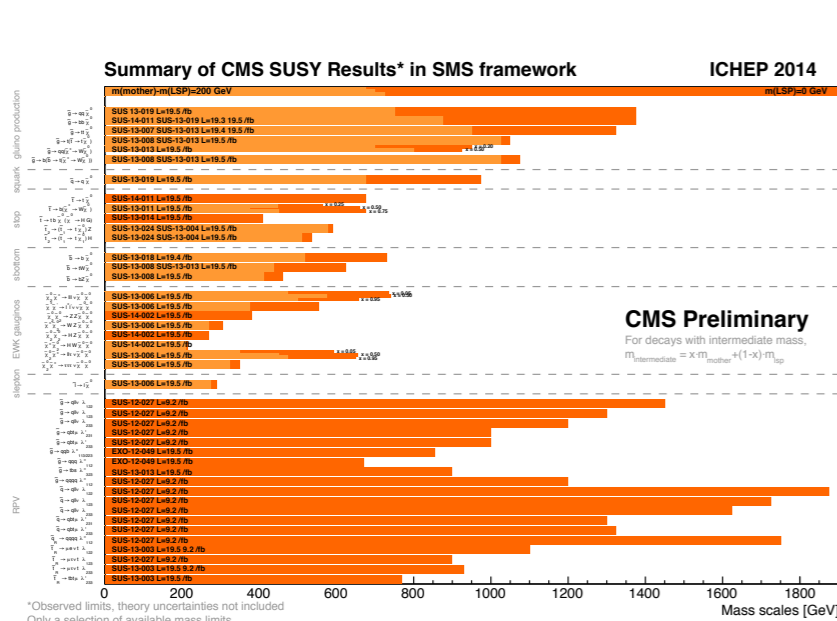
Electromagnetic contribution to the charged pion mass sensitive to the cutoff of the pion EFT.

$$\delta m^2 \sim \frac{3e^2}{16\pi^2} \Lambda^2$$

Naturalness suggests $\Lambda \sim 850$ MeV.

Rho meson (new physics!) enters at 770 MeV.

A physics driver @ LHC



170 of these 226 channels tied to naturalness

ATLAS SUSY Searches* - 95% CL Lower Limits
Status: Feb 2015

Model	e, μ, τ, γ	Jets	E_T^{miss}	$\int \mathcal{L} dt [fb^{-1}]$	Mass limit	Reference
MSUGRA/CMSSM	0	2-6 jets	Yes	20.3	850 GeV	1405.7875
$\tilde{q}\tilde{q}, \tilde{g}\tilde{g}$	0	2-6 jets	Yes	20.3	250 GeV	1411.7559
$\tilde{q}\tilde{q}, \tilde{g}\tilde{g}$ (compressed)	1 γ	0-1 jet	Yes	20.3	1.33 TeV	1405.7875
$\tilde{g}\tilde{g}, \tilde{q}\tilde{q}$	0	2-6 jets	Yes	20.3	1.2 TeV	1501.03555
$\tilde{g}\tilde{g}, \tilde{q}\tilde{q}$	1 e, μ	3-6 jets	Yes	20	1.32 TeV	1501.03555
$\tilde{g}\tilde{g}, \tilde{q}\tilde{q}$	2 e, μ	0-3 jets	-	20	1.6 TeV	1407.0603
GMSB (\tilde{g} NLSP)	1-2 $\tau + 0-1 \ell$	0-2 jets	Yes	20.3	1.28 TeV	ATLAS-CONF-2014-001
GGM (bino NLSP)	2 γ	-	Yes	20.3	619 GeV	ATLAS-CONF-2012-144
GGM (wino NLSP)	1 $e, \mu + \gamma$	-	Yes	4.8	590 GeV	1211.1167
GGM (higgsino-bino NLSP)	1 γ	1 b	Yes	4.8	690 GeV	ATLAS-CONF-2012-152
GGM (higgsino NLSP)	2 e, μ (Z)	0-3 jets	Yes	5.8	865 GeV	1502.01518
Gravitino LSP	0	mono-jet	Yes	20.3	1.25 TeV	1407.0600
$\tilde{g}\tilde{g}, \tilde{q}\tilde{q}$	0	3 b	Yes	20.1	1.1 TeV	1308.1841
$\tilde{g}\tilde{g}, \tilde{q}\tilde{q}$	0	7-10 jets	Yes	20.3	1.34 TeV	1407.0600
$\tilde{g}\tilde{g}, \tilde{q}\tilde{q}$	0	1-1 e, μ	Yes	20.1	1.3 TeV	1407.0600
$\tilde{g}\tilde{g}, \tilde{q}\tilde{q}$	0	2 b	Yes	20.1	100-620 GeV	1308.2631
$\tilde{g}\tilde{g}, \tilde{q}\tilde{q}$	2 e, μ (SS)	0-3 b	Yes	20.3	275-440 GeV	1404.2500
$\tilde{g}\tilde{g}, \tilde{q}\tilde{q}$	1-2 e, μ	1-2 b	Yes	4.7	230-160 GeV	1209.2102, 1407.0503
$\tilde{g}\tilde{g}, \tilde{q}\tilde{q}$	2 e, μ	0-2 jets	Yes	20.3	90-191 GeV	1403.4853, 1412.4742
$\tilde{g}\tilde{g}, \tilde{q}\tilde{q}$	0	1-1 e, μ	Yes	20.3	215-530 GeV	1407.0583, 1406.1122
$\tilde{g}\tilde{g}, \tilde{q}\tilde{q}$	0	1-2 b	Yes	20	210-640 GeV	
$\tilde{g}\tilde{g}, \tilde{q}\tilde{q}$	0	mono-jet+tag	Yes	20.3	90-240 GeV	
$\tilde{g}\tilde{g}, \tilde{q}\tilde{q}$	2 e, μ (Z)	1 b	Yes	20.3	150-580 GeV	
$\tilde{g}\tilde{g}, \tilde{q}\tilde{q}$	3 e, μ (Z)	1 b	Yes	20.3	290-600 GeV	
$\tilde{g}\tilde{g}, \tilde{q}\tilde{q}$	2 e, μ	0	Yes	20.3	90-325 GeV	1403.5294
$\tilde{g}\tilde{g}, \tilde{q}\tilde{q}$	2 e, μ	0	Yes	20.3	140-465 GeV	1403.5294
$\tilde{g}\tilde{g}, \tilde{q}\tilde{q}$	2 τ	-	Yes	20.3	100-350 GeV	1402.7050
$\tilde{g}\tilde{g}, \tilde{q}\tilde{q}$	3 e, μ	0	Yes	20.3	700 GeV	1402.7050
$\tilde{g}\tilde{g}, \tilde{q}\tilde{q}$	2-3 e, μ	0-2 jets	Yes	20.3	420 GeV	1403.5294, 1402.7029
$\tilde{g}\tilde{g}, \tilde{q}\tilde{q}$	e, μ, γ	0-2 b	Yes	20.3	250 GeV	1501.07110
$\tilde{g}\tilde{g}, \tilde{q}\tilde{q}$	4 e, μ	0	Yes	20.3	620 GeV	1405.5086
Direct $\tilde{g}\tilde{g}$ prod, long-lived \tilde{g}	Disapp. trk	1 jet	Yes	20.3	270 GeV	1310.3675
Stable, stopped \tilde{g} R-hadron	0	1-5 jets	Yes	27.9	832 GeV	1310.5884
Stable \tilde{g} R-hadron	trk	-	Yes	19.1	1.27 TeV	1411.6795
GMSB, stable \tilde{g} , long-lived \tilde{g}	1-2 μ	-	Yes	19.1	537 GeV	1411.6795
GMSB, \tilde{g} long-lived \tilde{g}	2 γ	-	Yes	20.3	435 GeV	1409.5542
$\tilde{g}\tilde{g}, \tilde{q}\tilde{q}$ (RPV)	1 μ , displ. vtx	-	Yes	20.3	1.0 TeV	ATLAS-CONF-2013-092
LFV $pp \rightarrow \tilde{\nu}_\tau + X, \tilde{\nu}_\tau \rightarrow e + \mu$	2 e, μ	-	-	4.6	1.61 TeV	1212.1272
LFV $pp \rightarrow \tilde{\nu}_\tau + X, \tilde{\nu}_\tau \rightarrow e + \mu + \tau$	1 $e, \mu + \tau$	-	-	4.6	1.1 TeV	1212.1272
Bilinear RPV CMSSM	2 e, μ (SS)	0-3 b	Yes	20.3	1.35 TeV	1404.2500
$\tilde{g}\tilde{g}, \tilde{q}\tilde{q}$	4 e, μ	-	Yes	20.3	750 GeV	1405.5086
$\tilde{g}\tilde{g}, \tilde{q}\tilde{q}$	3 $e, \mu + \tau$	-	Yes	20.3	450 GeV	1405.5086
$\tilde{g}\tilde{g}, \tilde{q}\tilde{q}$	3 $e, \mu + \tau$	-	Yes	20.3	916 GeV	ATLAS-CONF-2013-091
$\tilde{g}\tilde{g}, \tilde{q}\tilde{q}$	0-6-7 jets	-	Yes	20.3	850 GeV	1404.250
$\tilde{g}\tilde{g}, \tilde{q}\tilde{q}$	2 e, μ (SS)	0-3 b	Yes	20.3	490 GeV	1501.01325

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

ATLAS Exotics Searches* - 95% CL Exclusion
Status: ICHEP 2014

Model	ℓ, γ	Jets	E_T^{miss}	$\int \mathcal{L} dt [fb^{-1}]$	Mass limit	Reference
ADD $G_{KK} + g/q$	-	1-2 j	Yes	4.7	4.37 TeV	1210.4491
ADD non-resonant $\ell\ell$	2 e, μ	-	-	20.3	5.2 TeV	ATLAS-CONF-2014-030
ADD QBH $\rightarrow \ell q$	1 e, μ	1 j	-	20.3	5.2 TeV	1311.2006
ADD QBH	2 e, μ	2 j	-	20.3	5.82 TeV	to be submitted to PRD
ADD BH High N_{eff}	2 μ (SS)	-	-	20.3	5.7 TeV	1308.4075
ADD BH High Σp_T	$\geq 1 e, \mu$	$\geq 2 j$	-	20.3	6.2 TeV	1405.4254
RS1 $G_{KK} \rightarrow \ell\ell$	2 e, μ	-	-	20.3	2.98 TeV	1405.4123
RS1 $G_{KK} \rightarrow WW \rightarrow \ell\nu\ell$	2 e, μ	-	Yes	4.7	1.23 TeV	1208.2880
Bulk RS $G_{KK} \rightarrow ZZ \rightarrow \ell\nu\ell$	2 e, μ	2 j/1 j	-	20.3	730 GeV	ATLAS-CONF-2014-039
Bulk RS $G_{KK} \rightarrow HH \rightarrow b\bar{b}b\bar{b}$	2 e, μ	4 b	-	19.5	590-710 GeV	ATLAS-CONF-2014-005
Bulk RS $G_{KK} \rightarrow t\bar{t}$	1 e, μ	$\geq 1 b, \geq 1 j/2 j$	Yes	14.3	2.0 TeV	ATLAS-CONF-2013-052
$S^1/U(1)$ ED	2 e, μ	-	-	5.0	4.71 TeV	1209.2535
UED	2 γ	-	Yes	4.8	1.41 TeV	ATLAS-CONF-2012-072
SSM $Z' \rightarrow \ell\ell$	2 e, μ	-	-	20.3	2.9 TeV	1405.4123
SSM $Z' \rightarrow \tau\tau$	2 τ	-	-	19.5	1.9 TeV	ATLAS-CONF-2013-066
SSM $W' \rightarrow \ell\nu$	1 e, μ	-	Yes	20.3	3.28 TeV	ATLAS-CONF-2014-017
EGM $W' \rightarrow WZ \rightarrow \ell\nu\ell'$	3 e, μ	-	Yes	20.3	1.52 TeV	1406.4456
EGM $W' \rightarrow WZ \rightarrow qq\ell$	2 e, μ	2 j/1 j	-	20.3	1.59 TeV	ATLAS-CONF-2014-039
LRSM $W'_\mu \rightarrow \ell\nu$	1 e, μ	2 b, 0-1 j	Yes	14.3	1.84 TeV	ATLAS-CONF-2013-050
LRSM $W'_\mu \rightarrow t\bar{t}$	0 e, μ	$\geq 1 b, 1 j$	-	20.3	1.77 TeV	to be submitted to EPJ C
CI $q\bar{q}q\bar{q}$	-	2 j	-	4.8	7.6 TeV	1210.1718
CI $q\bar{q}\ell\ell$	2 e, μ	-	-	20.3	21.6 TeV	ATLAS-CONF-2014-030
CI $u\bar{u}t\bar{t}$	2 e, μ (SS) $\geq 1 b, \geq 1 j$	Yes	14.3	3.3 TeV	ATLAS-CONF-2013-051	
EFT D5 operator (Dirac)	0 e, μ	1-2 j	Yes	10.5	731 GeV	ATLAS-CONF-2012-147
EFT D9 operator (Dirac)	0 e, μ	1 j, $\geq 1 j$	Yes	20.3	2.4 TeV	at 90% CL for $m(\chi) < 80$ GeV at 90% CL for $m(\chi) < 100$ GeV
Scalar LQ 1 st gen	2 e	$\geq 2 j$	-	1.0	660 GeV	$\beta = 1$ 1112.4828
Scalar LQ 2 nd gen	2 μ	$\geq 2 j$	-	1.0	685 GeV	$\beta = 1$ 1203.3172
Scalar LQ 3 rd gen	1 $e, \mu, 1 \tau$	1 b, 1 j	-	4.7	534 GeV	$\beta = 1$ 1303.0526
Vector-like quark $TT \rightarrow Ht + X$	1 e, μ	$\geq 2 b, \geq 4 j$	Yes	14.3	790 GeV	T in (T,B) doublet ATLAS-CONF-2013-018
Vector-like quark $TT \rightarrow Wb + X$	1 e, μ	$\geq 1 b, \geq 3 j$	Yes	14.3	670 GeV	in (S,T) singlet ATLAS-CONF-2013-060
Vector-like quark $TT \rightarrow Zt + X$	2 $\geq 3 e, \mu$	$\geq 2 \geq 1 b$	-	20.3	735 GeV	T in (T,B) doublet ATLAS-CONF-2014-036
Vector-like quark $BB \rightarrow Zb + X$	2 $\geq 3 e, \mu$	$\geq 2 \geq 1 b$	-	20.3	755 GeV	B in (B,Y) doublet ATLAS-CONF-2014-036
Vector-like quark $BB \rightarrow Wt + X$	2 e, μ (SS) $\geq 1 b, \geq 1 j$	Yes	14.3	720 GeV	B in (T,B) doublet ATLAS-CONF-2013-051	
Excited quark $q^* \rightarrow q\gamma$	1 γ	1 j	-	20.3	3.5 TeV	only u^* and d^* , $A = m(q^*)$ 1309.3230
Excited quark $q^* \rightarrow qg$	-	2 j	-	20.3	4.09 TeV	to be submitted to PRD 1301.1583
Excited quark $b^* \rightarrow Wt$	1 τ 2 e, μ	1 b, 2 j or 1 τ	Yes	4.7	870 GeV	left-handed coupling $A = 2.2$ TeV 1308.1364
Excited lepton $\ell^* \rightarrow \ell\gamma$	2 $e, \mu, 1 \gamma$	-	-	13.0	2.2 TeV	to be submitted to PLB 1203.5420
LSTC $\Delta_T \rightarrow W\gamma$	1 $e, \mu, 1 \gamma$	-	Yes	20.3	960 GeV	$m(W\Delta) = 2$ TeV, no mixing 1203.5420
LFSM Majorana ν	2 e, μ	2 j	-	2.1	245 GeV	$ V_{cb} \geq 0.05, V_{cb} \geq 0.03, V_{cb} \geq 0$ ATLAS-CONF-2013-019
Type III Seesaw	2 e, μ	-	-	5.8	409 GeV	DY production, $BR(H^{\pm\pm} \rightarrow \ell\ell) = 1$ 1210.5070
Higgs triplet $H^{\pm\pm} \rightarrow \ell\ell$	2 e, μ (SS)	-	-	4.4	490 GeV	DY production, $ g = 4e$ 1301.5272
Multi-charged particles	-	-	-	4.4	490 GeV	DY production, $ g = 1_{E0}$ 1207.6411
Magnetic monopoles	-	-	-	2.0	862 GeV	

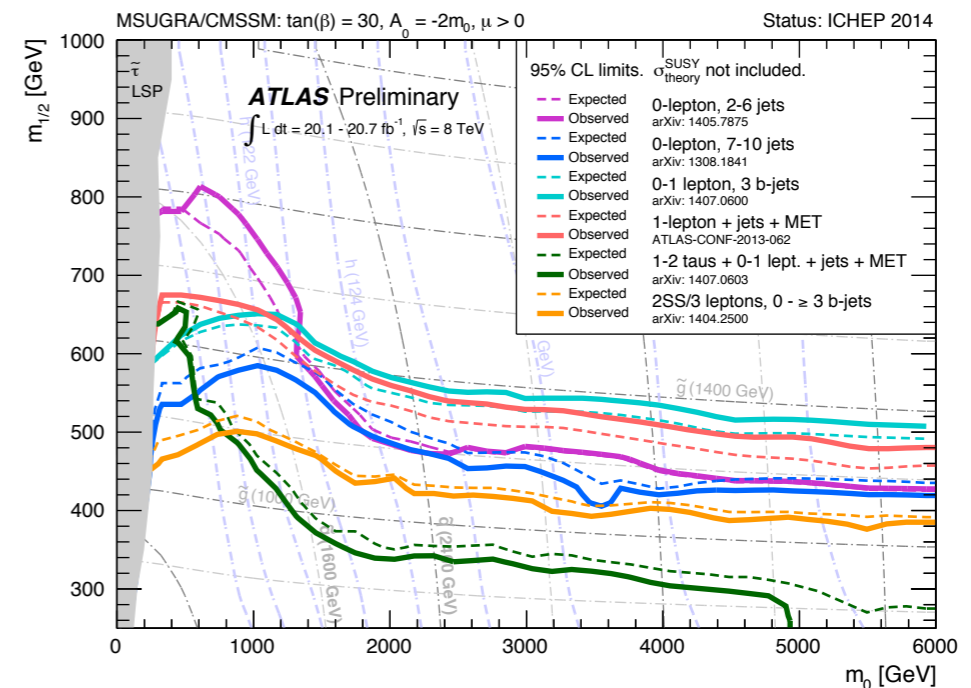
*Only a selection of the available mass limits on new states or phenomena is shown.

The case for SUSY

Why SUSY?

- ✓ Naturalness
- ✓ Dark matter
- ✓ Unification
- ✓ Higgs mass
- ✓ Decoupling

Why not?

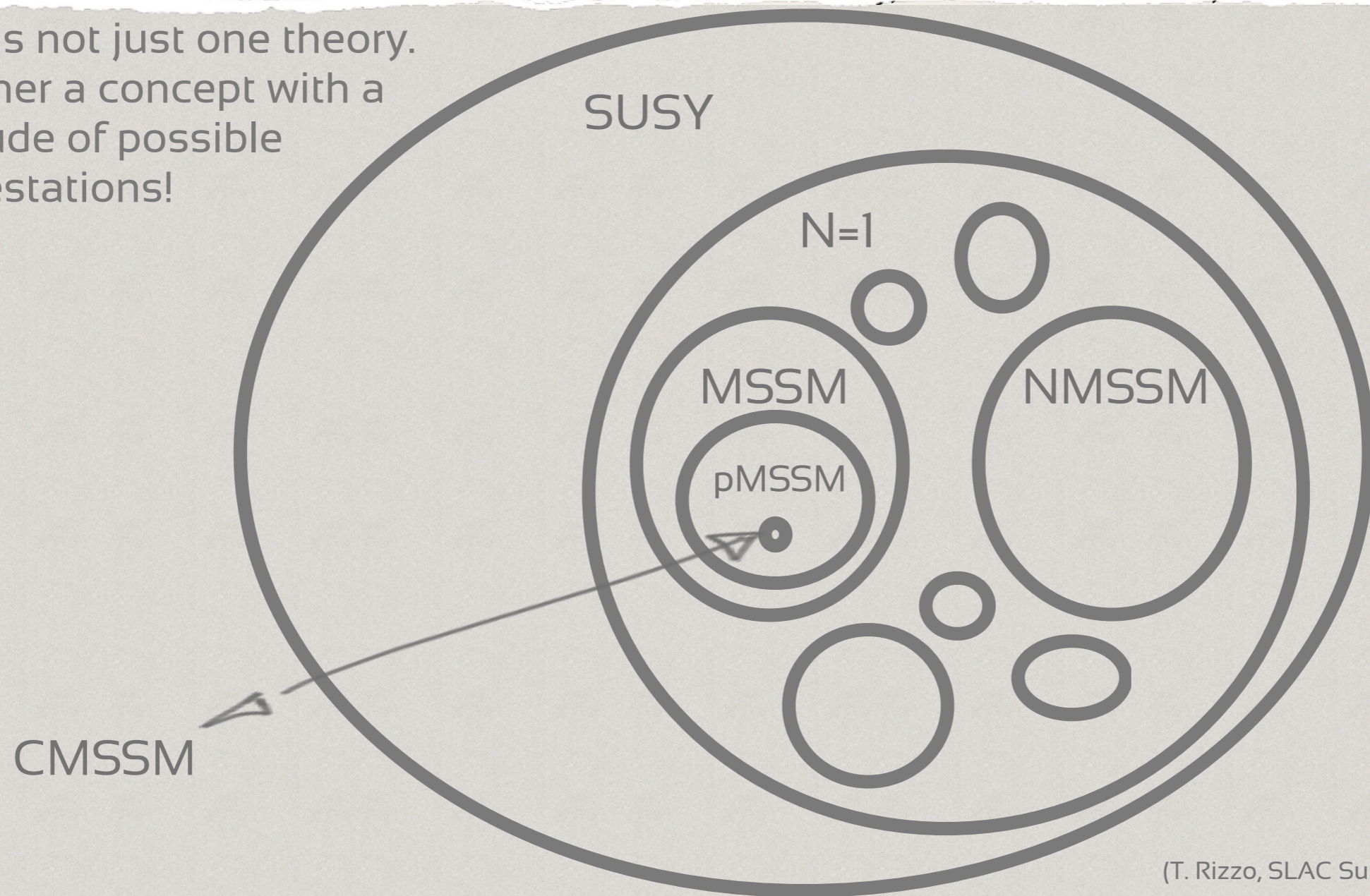


Mass reach for simplest versions out to 1.5 TeV

~1% tuning level

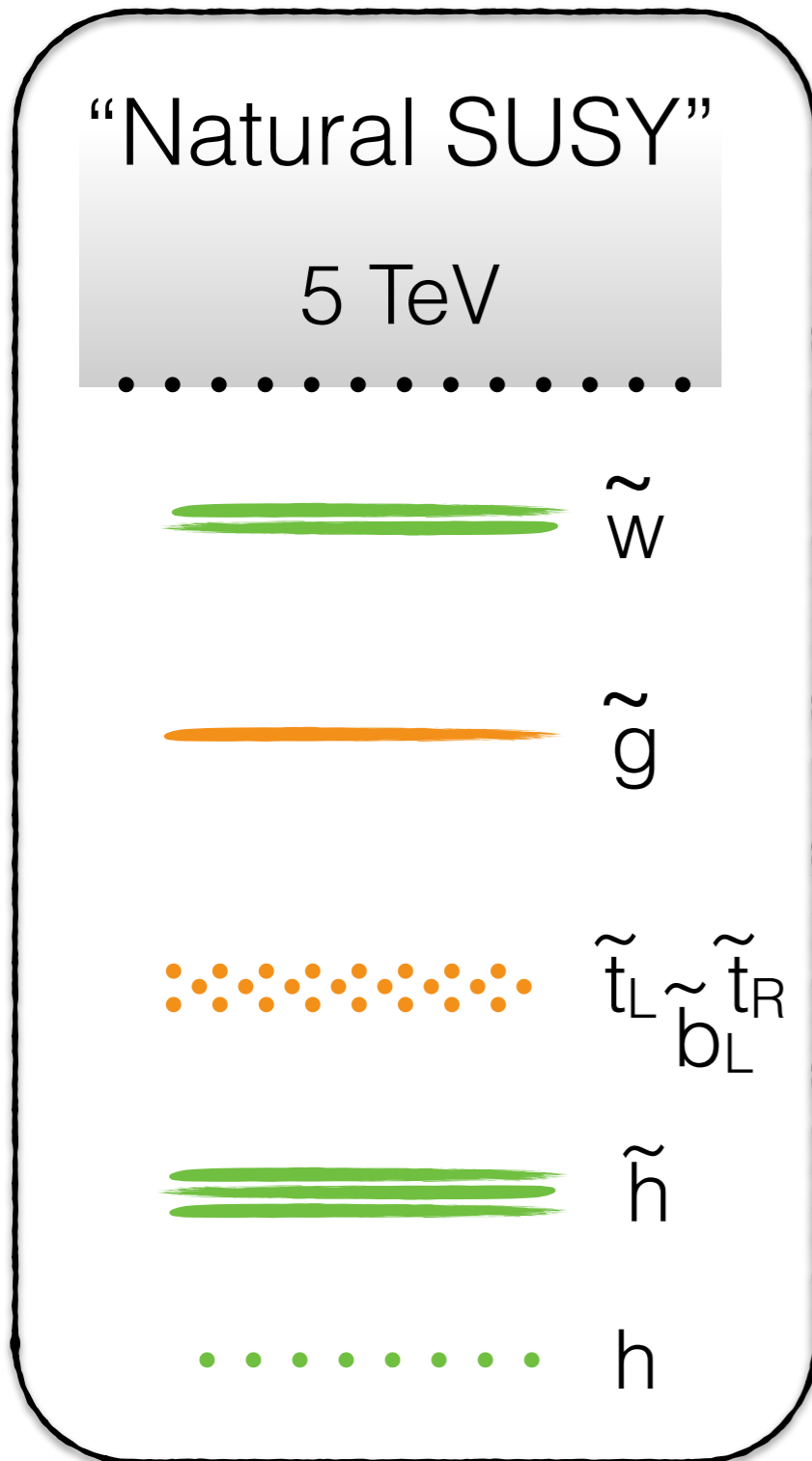
SUSY contains multitudes!

SUSY is not just one theory.
It's rather a concept with a
multitude of possible
manifestations!



(T. Rizzo, SLAC Summer Institute, 2012)

Minimal ingredients

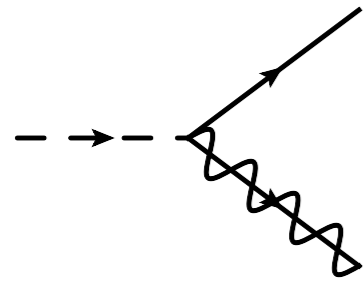


At the very least: organize minimal spectrum for naturalness by size of threshold corrections to Higgs

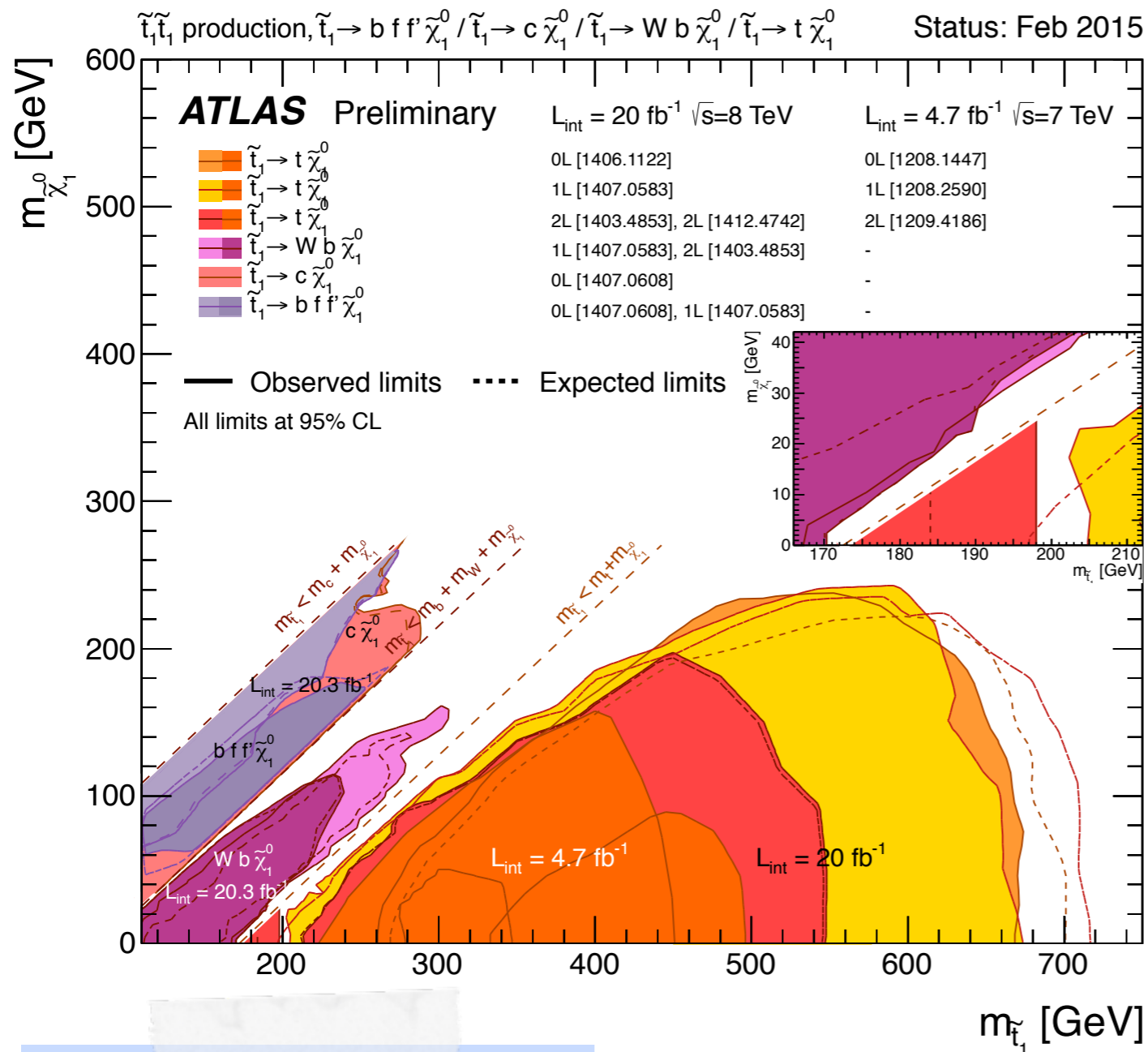
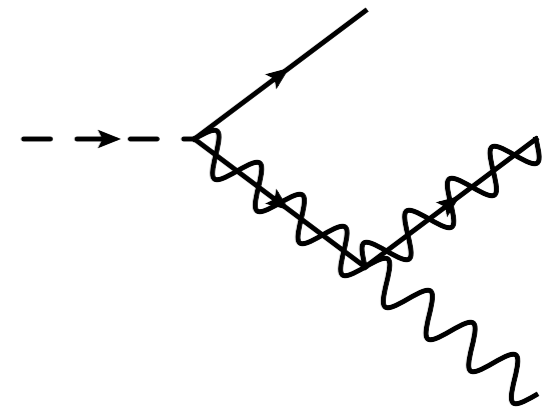
$$m_h^2 \sim \frac{3y_t^2}{4\pi^2} \tilde{m}^2 \log(\Lambda^2 / \tilde{m}^2)$$

QCD production of stops, gluinos makes natural target for LHC (but also look for electroweak physics @ electroweak scale)

[Dimopoulos, Giudice '95; Cohen, Kaplan, Nelson '96; Papucci, Ruderman, Weiler '11; Brust, Katz, Lawrence, Sundrum '11]



Direct limits



Scalar top searches:
greatest reach for
SUSY naturalness

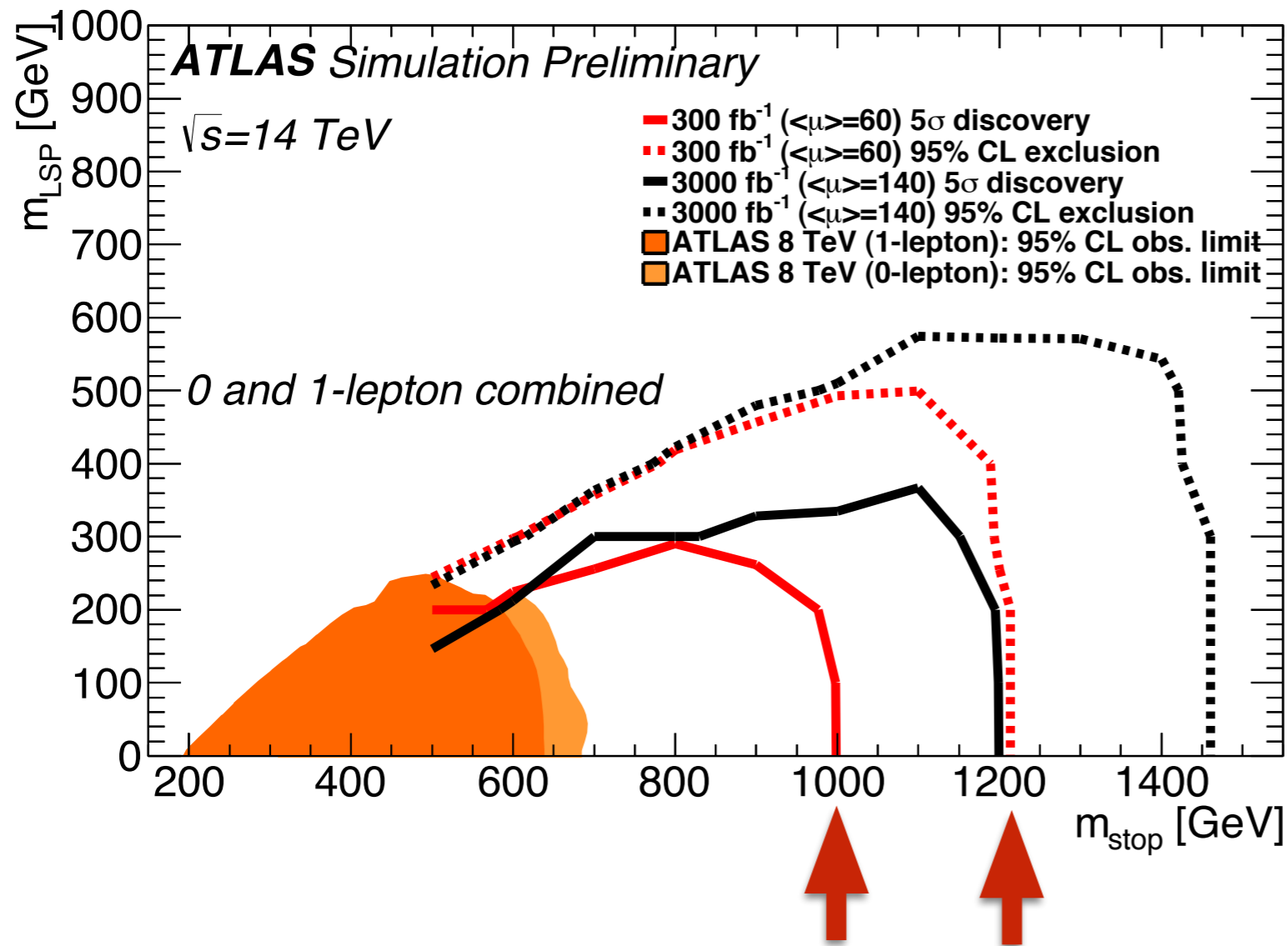
Where we are:
“generically”

$$m_h^2 \sim \frac{3y_t^2}{4\pi^2} \tilde{m}^2 \log(\Lambda^2 / \tilde{m}^2)$$

~7% tuning level

See also S. Asai's talk

Looking forward



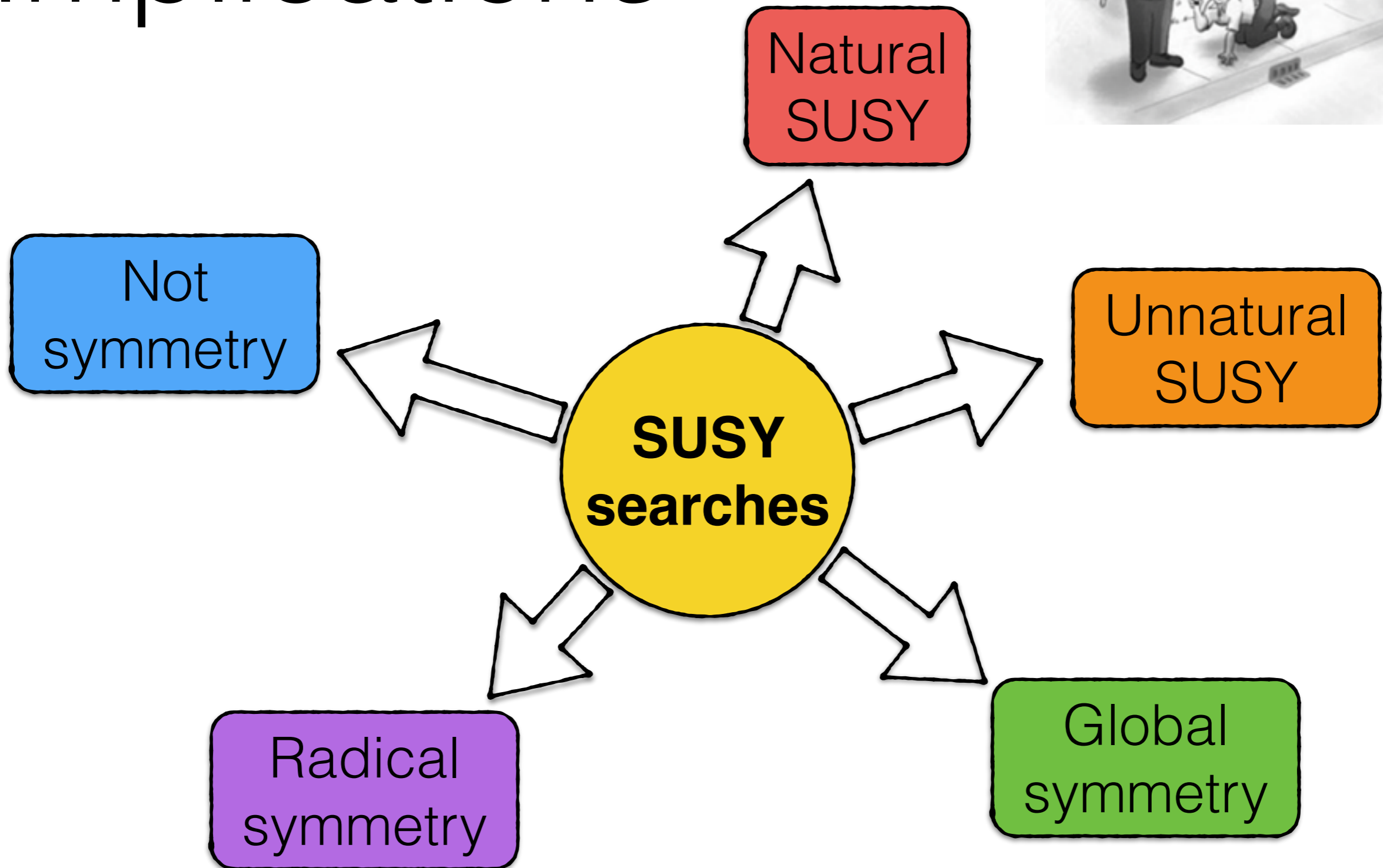
Reach doubles
by 300/fb

Where we'll be
@ end of LHC:
“generically”

~1% tuning level

If stops are just outside our current reach, an abundance of new physics awaits in Run 2. If not...

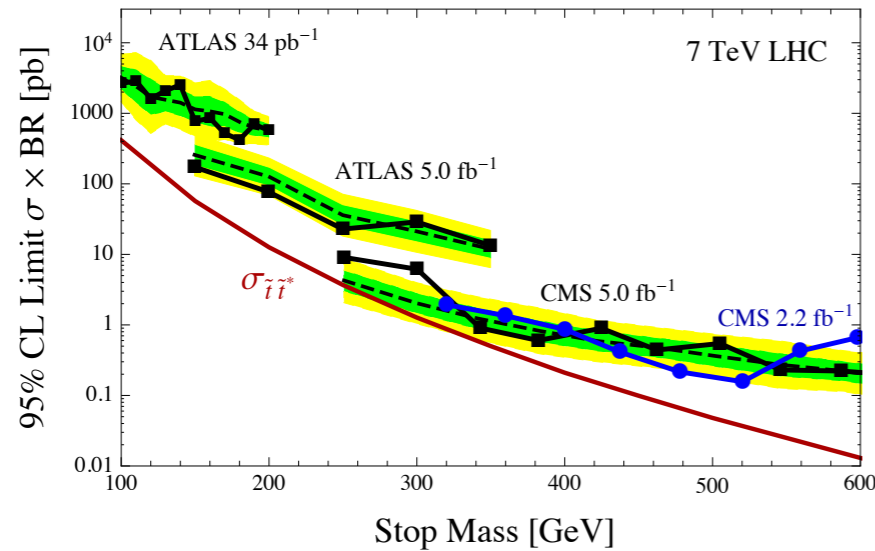
Implications



1. Natural SUSY?

Or: UDD RPV

[Bai, Katz, Tweedie '13]



Exclusions assume R parity is conserved; no sensitivity to stops with baryonic RPV

Mix your flavors

improving charm+MET with charm tagging

[Mahbubani, Perez, Papucci, Ruderman, Weiler '12]

Mix your decay modes

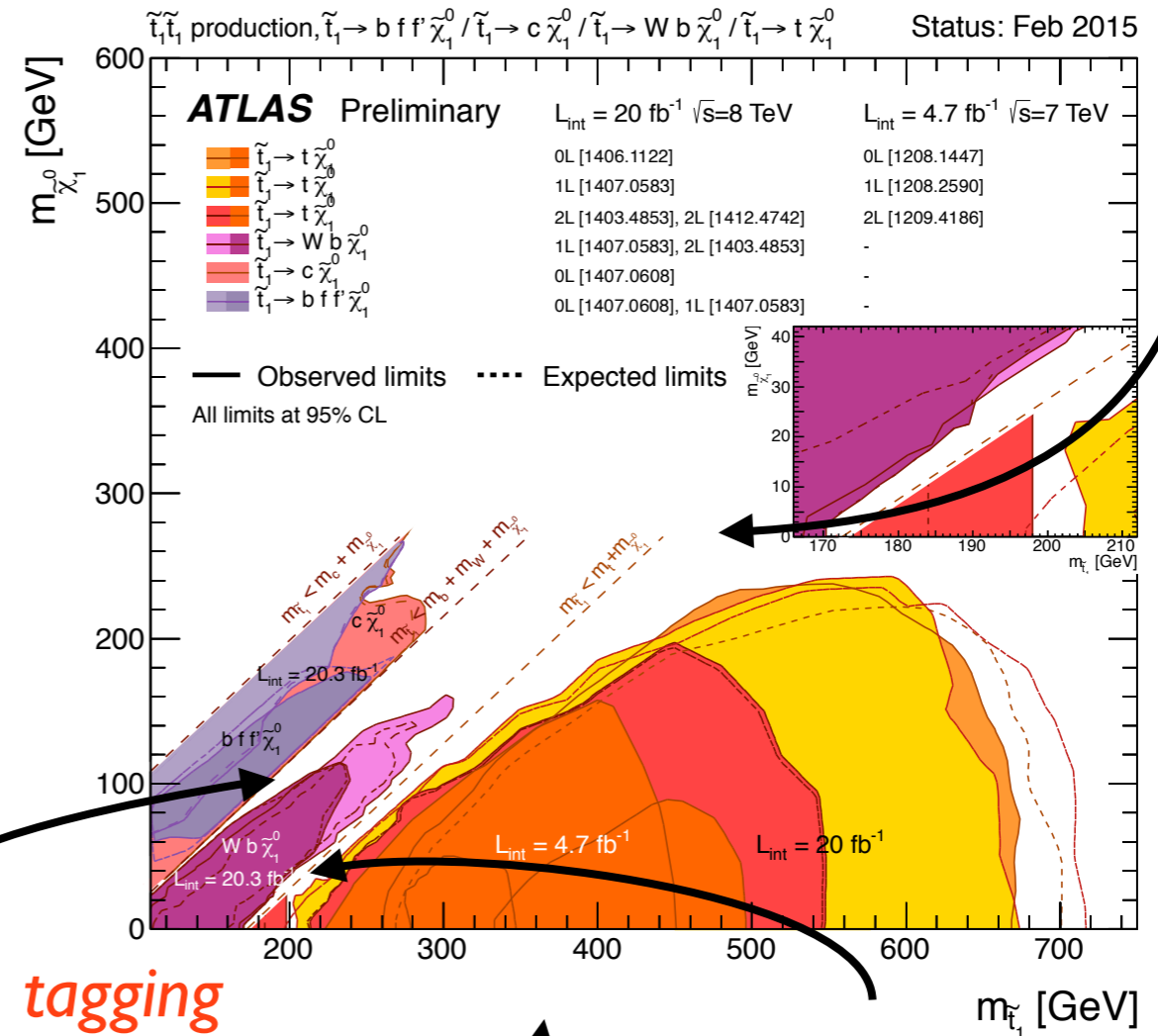
use topness & other dedicated variables

[Grasser, Shelton '12]

Be compressed

coverage improving with shape-based searches

[Martin '07; LeCompte & Martin '11]



Be stealthy

cascades; tt spin correlations; tt cross section limit

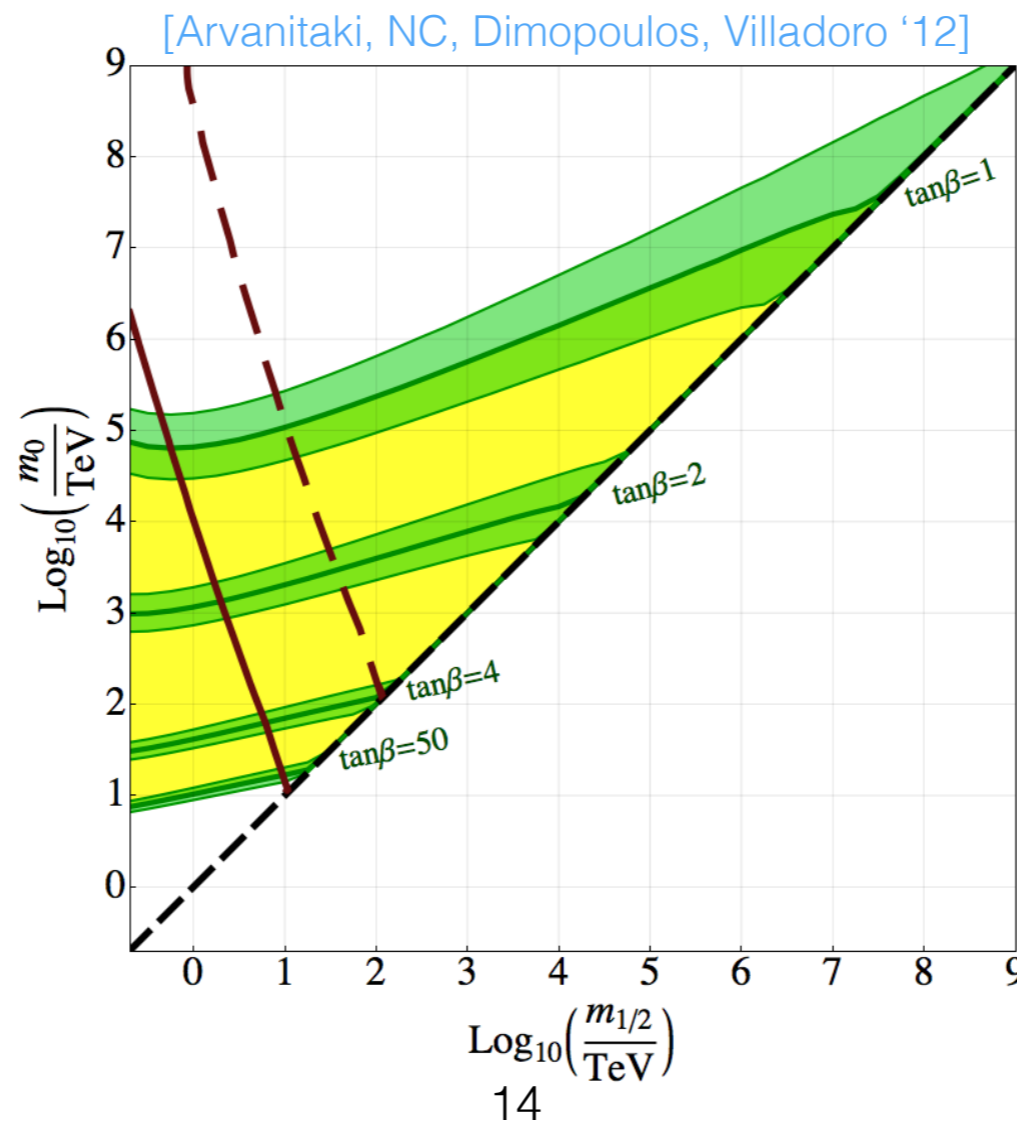
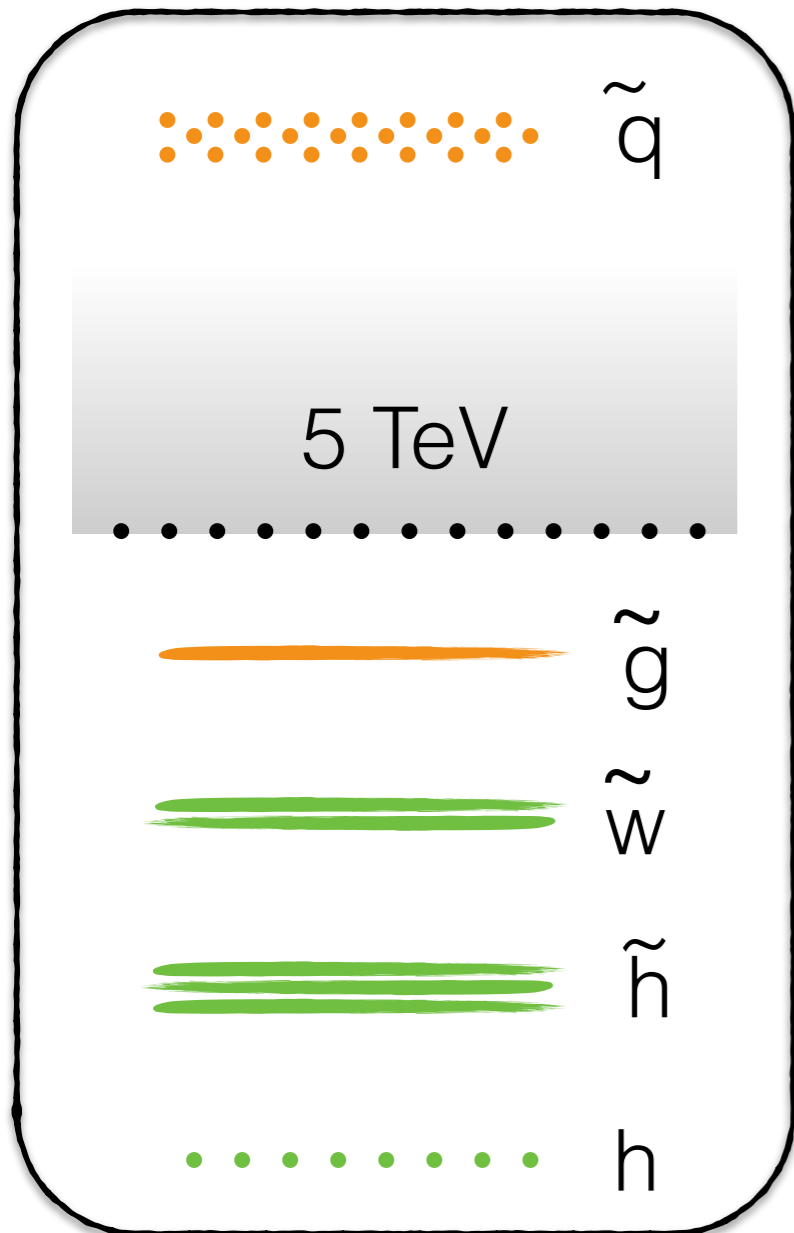
[Shelton '08; Fan, Reece, Ruderman '11; Han, Katz, Krohn, Reece '12; Czakon, Mitov, Papucci, Ruderman, Weiler '14]

2. Unnatural SUSY?

What if SUSY has nothing to do with stabilizing the weak scale?

“(mini-)Split SUSY”

- x Naturalness
- ✓ Dark matter
- ✓ Unification



Scalars decouple, fermions are light (unification/DM)

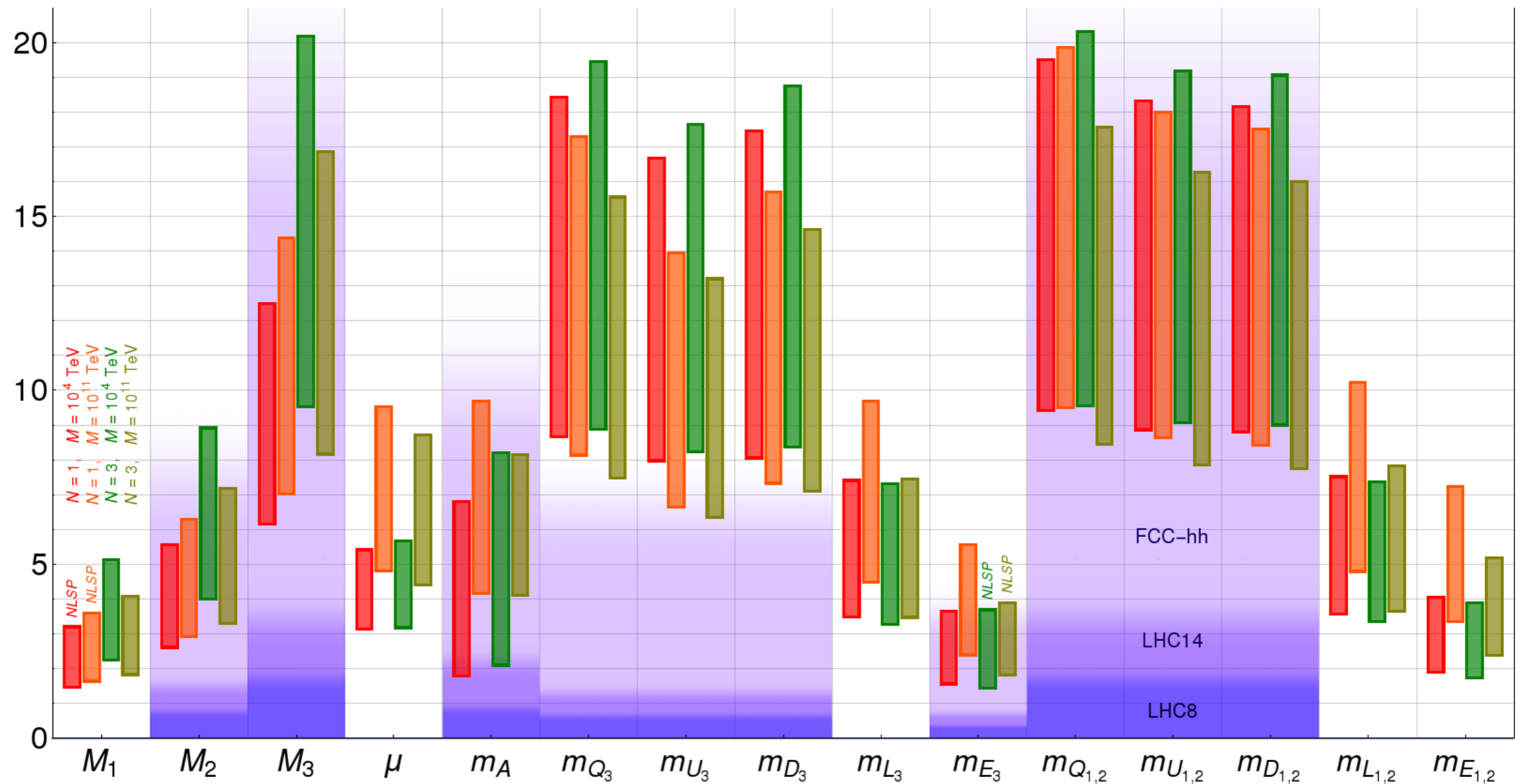
Gluino, higgsino signals @ LHC

Gluino decays prompt or displaced

Unnatural but simple

And still 28 orders of magnitude more natural than SM

[Vega, Villadoro '15]



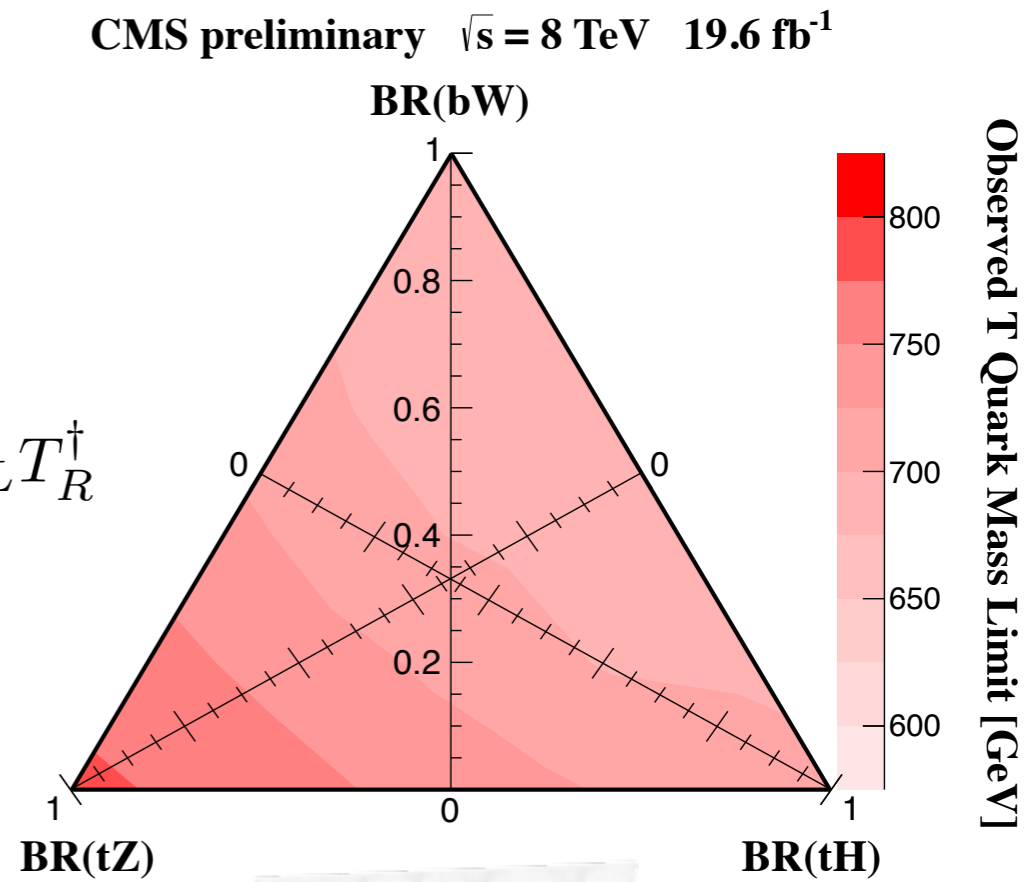
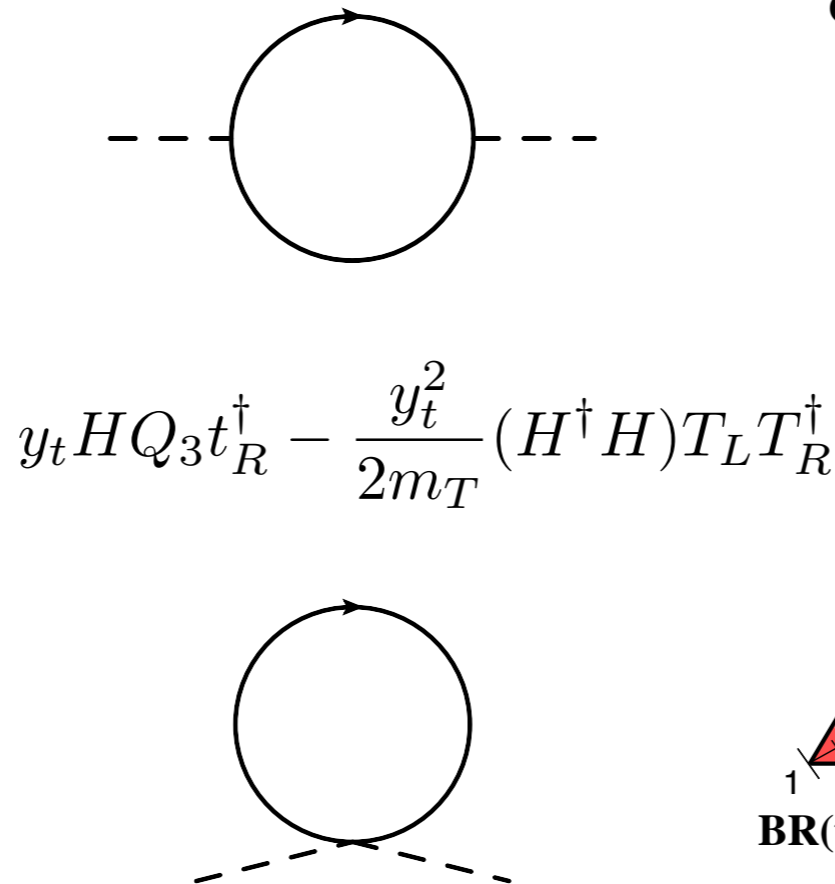
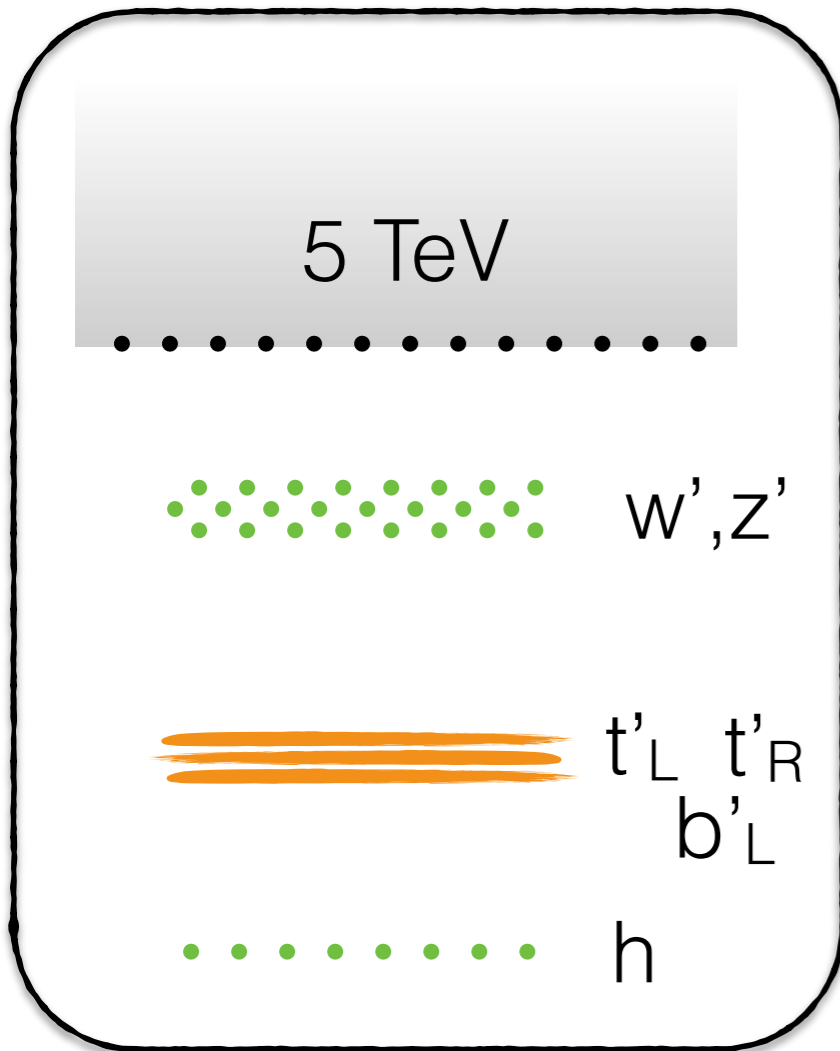
E.g., spectrum of minimal gauge mediation entirely fixed.

3. Global symmetries?

What about the “other” symmetry (global) for the Higgs mass?

“Composite Higgs/Little Higgs”

- ✓ Naturalness
- ✓ Dark matter
- ✗ Unification



See also P. Azzi's talk

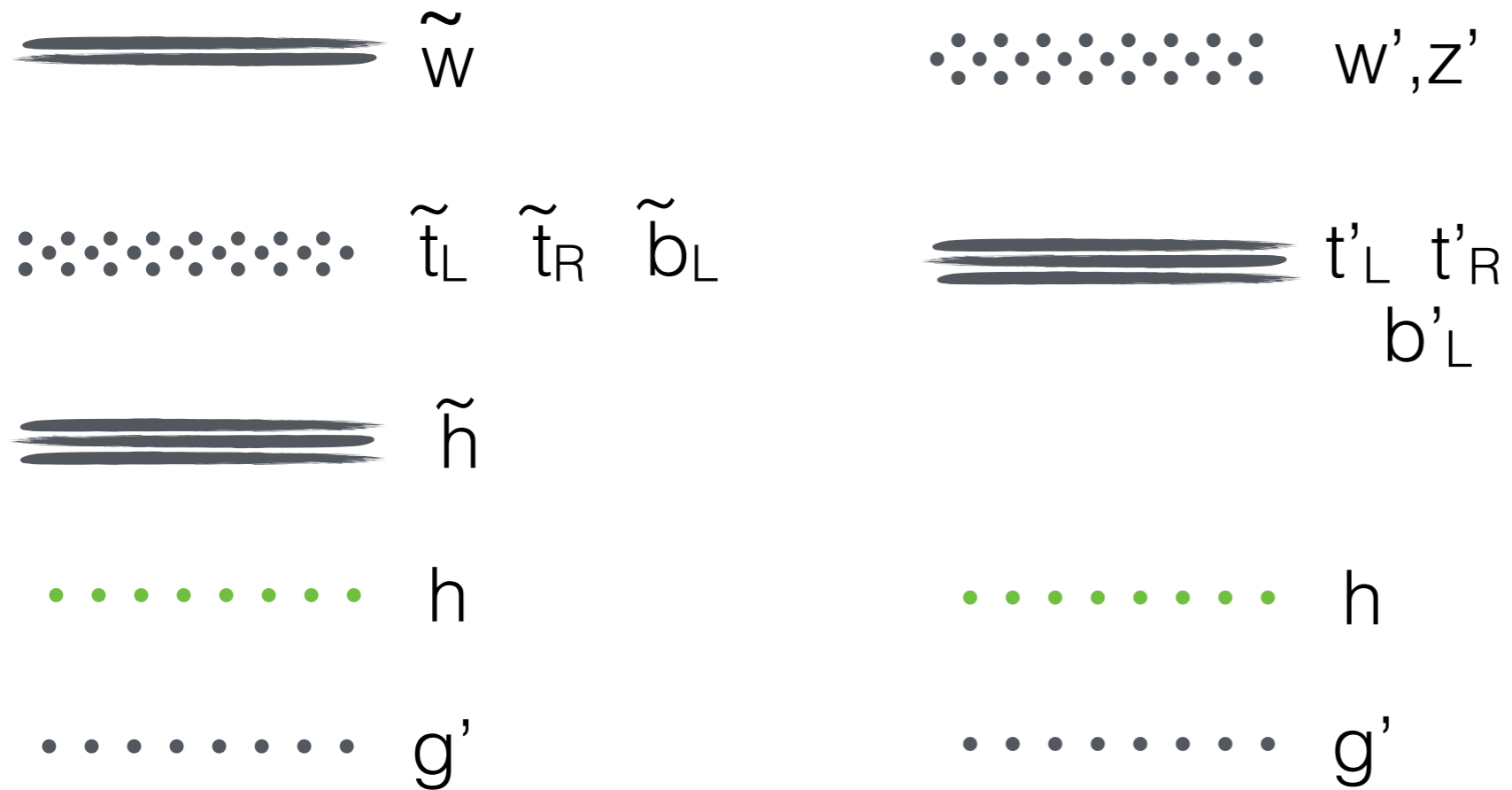
Need light QCD-charged top partners; bounds and tuning comparable to SUSY.

4. Radical symmmetries?

*What if the weak scale is natural,
but the new states are SM neutral?*

“Neutral naturalness”

- ✓ Naturalness
- ✓ Dark matter
- ✓ Unification



Strong SUSY bounds have nothing to do with couplings to Higgs.

Reach comes from QCD quantum #'s

Can we have natural theories without colored partner states?

Yes

An example: Twin Higgs

Standard Model $\xleftrightarrow{Z_2}$ **Standard Model**

E.g., weak gauge symmetry is $SU(2)_{\text{us}} \times SU(2)_{\text{twin}}$

Thanks to Z_2 , radiative corrections to the Higgs mass are $SU(4)$ symmetric:

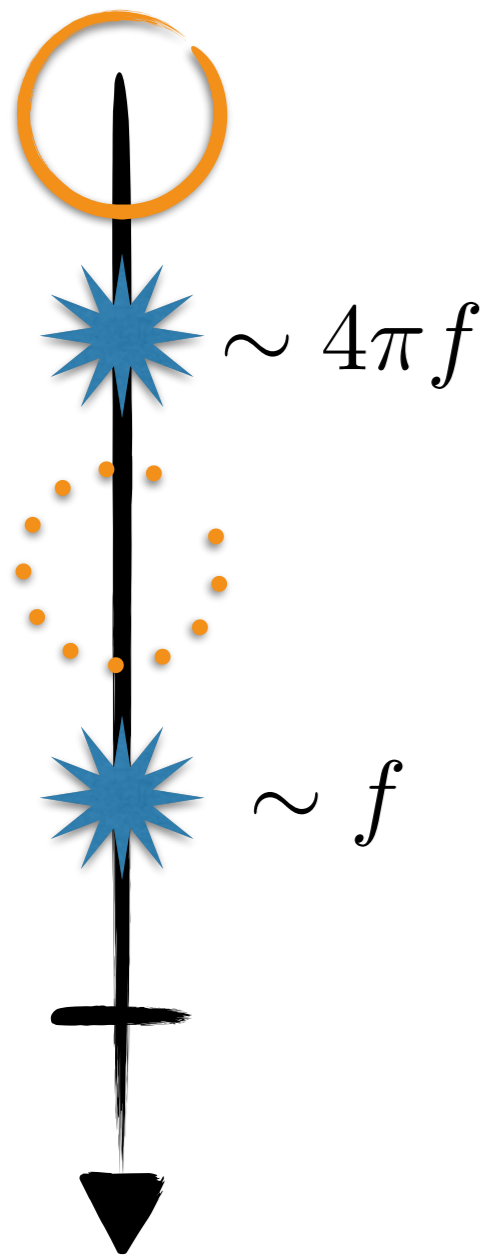
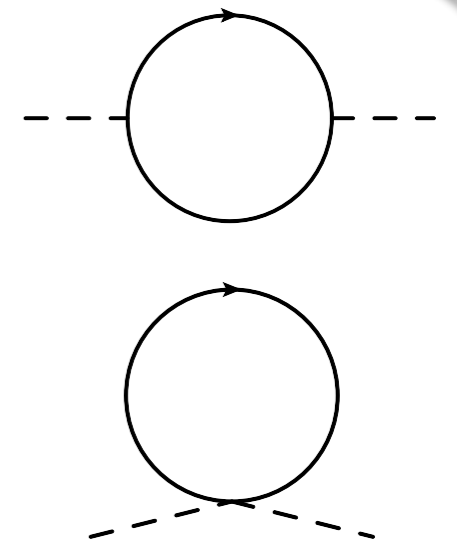
$$V(H) \supset \frac{9}{64\pi^2} g^2 \Lambda^2 (|H_A|^2 + |H_B|^2)$$

Higgs is a PNGB of $\sim SU(4)$, but partner states neutral under SM.

$$\mathcal{L} \supset -y_t H_A Q_3^A \bar{u}_3^A - y_t H_B Q_3^B \bar{u}_3^B$$

$$\downarrow \qquad \qquad \qquad \downarrow$$

$$h + \dots \qquad \qquad \qquad f - \frac{h^2}{2f} + \dots$$

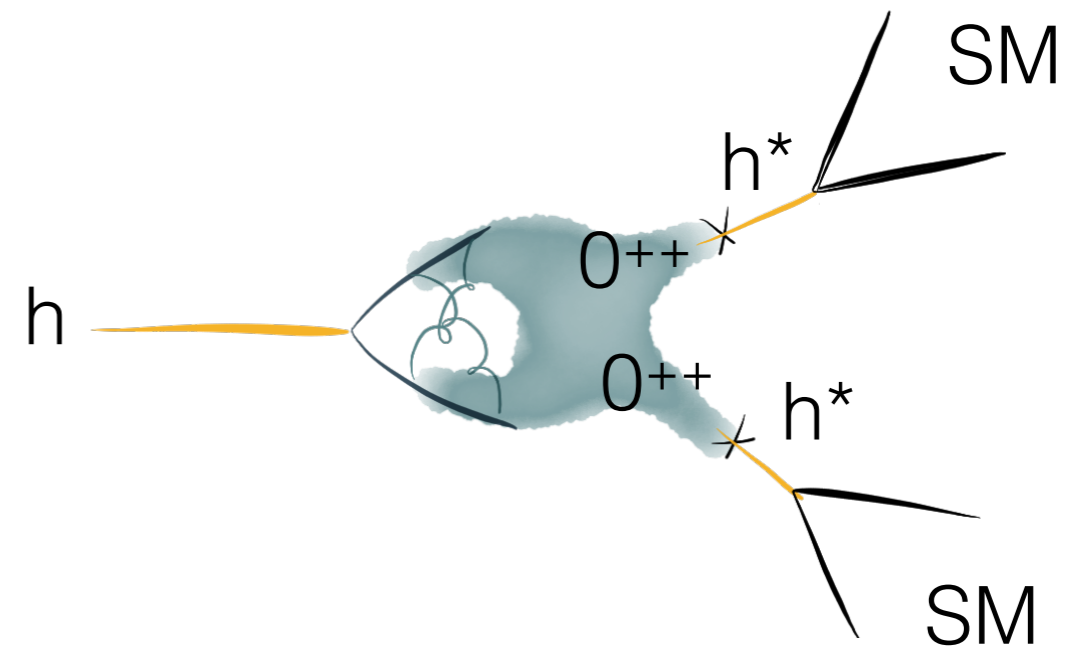
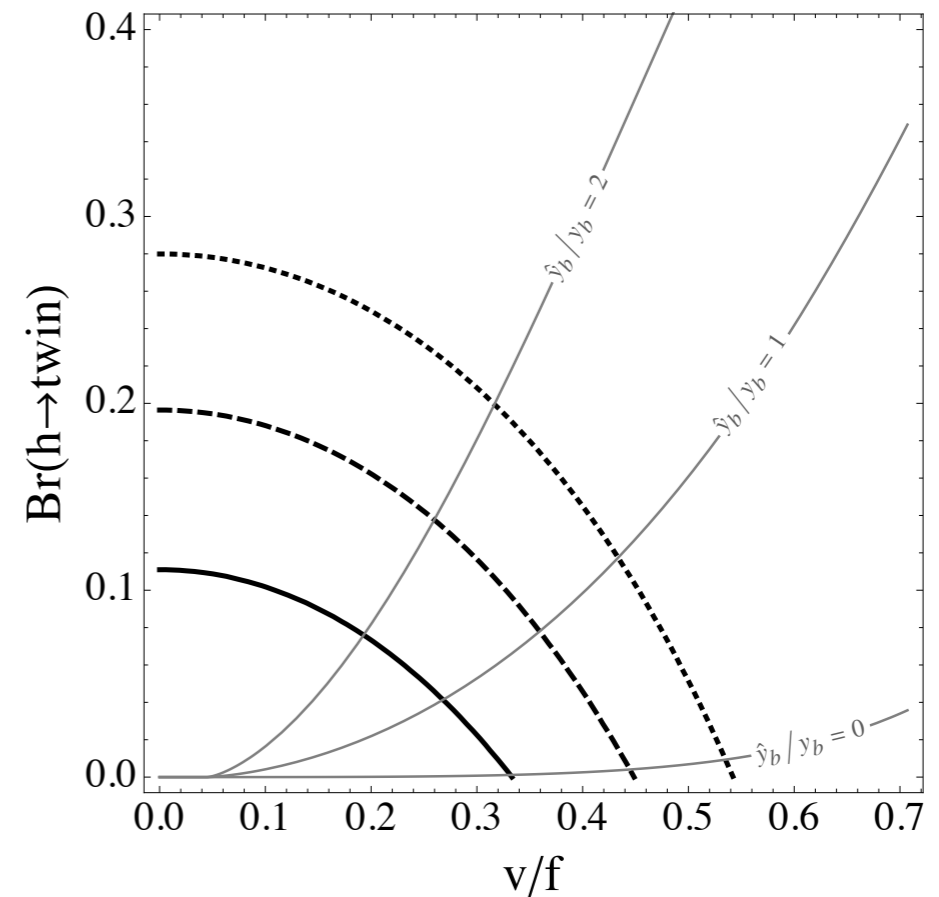


There are many more theories of this kind [NC, S Knapen, P Longhi '14]

See also J. Shelton's talk

Twin Signals

- Modest Higgs coupling deviations and invisible branching ratio ($\sim 5\text{-}10\%$).
- Displaced decays: Higgs into hidden sector, hidden sector confines (must have twin QCD!), displaced decays via off-shell Higgs.
- Singlet-like heavy Higgs decaying to hh , WW , ZZ , invisible.
- Abundant dark matter candidates (thermal, asymmetric, SIMP, ...)



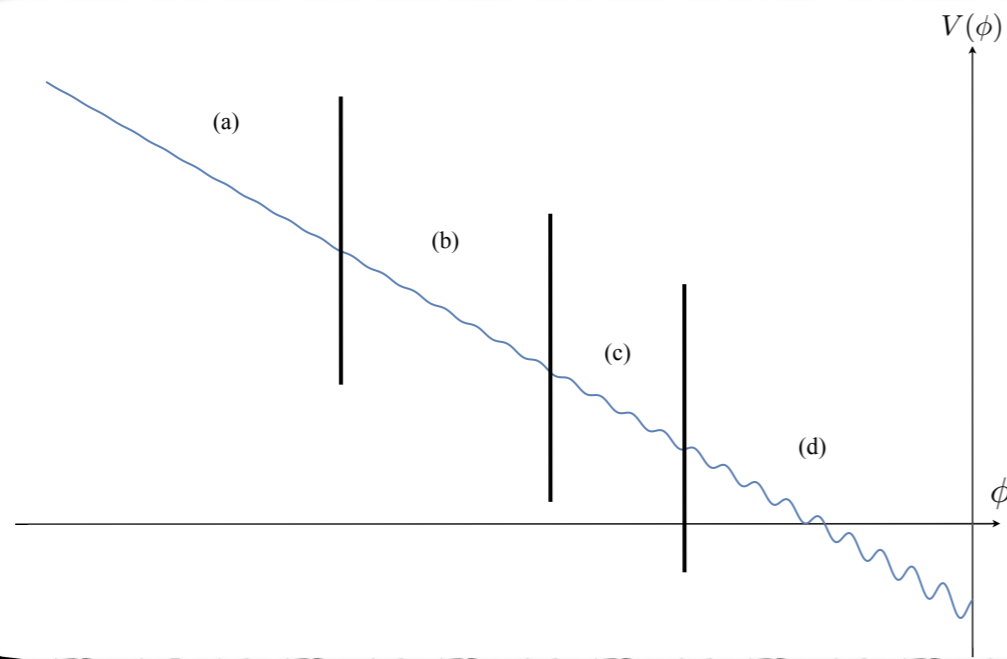
Not yet meaningfully constrained; naturalness potentially probed to $\sim 20\%$ level by end of LHC

5. Not symmmetries?

What if the weak scale is selected by dynamics, not symmmetries?

- ? Naturalness
- ✓ Dark matter
- ✓ Unification

Old idea: couple Higgs to field whose minimum sets $m_H=0$
 Old problem: How to make $m_H=0$ a special point of potential?



GKR solution: what turns on when m_H^2 goes negative?
Vev gives **quark masses** which give **axion potential!**

“Relaxion”

$$(-M^2 + g\phi)|H|^2 + V(g\phi) + \frac{1}{32\pi^2} \frac{\phi}{f} \tilde{G}^{\mu\nu} G_{\mu\nu}$$

$$\Rightarrow (-M^2 + g\phi)|H|^2 + V_{20}(g\phi) + \Lambda^4 \cos(\phi/f)$$

Just need Higgs + non-compact axion + inflation w/

- Very low Hubble scale ($\ll \Lambda_{\text{QCD}}$)
- 10 Giga-years of inflation

Minimal model: cutoff is $M < \left(\frac{\Lambda^4 M_P^3}{f}\right)^{1/6} \theta^{1/4} \sim 30 \text{ TeV} \times \left(\frac{10^9 \text{ GeV}}{f}\right)^{1/6} \left(\frac{\theta}{10^{-10}}\right)^{1/4}$



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Fix: make it someone else's QCD + axion

Field	$SU(3)_N$	$SU(3)_C$	$SU(2)_L$	$U(1)_Y$	
L	\square	—	\square	$-1/2$	I.e. axion of a different $SU(3)$; need to tie in Higgs vev
L^c	$\bar{\square}$	—	\square	$+1/2$	
N	\square	—	—	0	
N^c	$\bar{\square}$	—	—	0	

1. New quarks must get most of mass from Higgs:

$$\mathcal{L} \supset m_L L L^c + m_N N N^c + y H L N^c + y' H^\dagger L^c N$$

2. Must confine, but with light flavor $\Lambda^4 \simeq 4\pi f_\pi^3, m_N$

...still new physics @ weak scale

Now $m_N \geq yy'v^2/m_L$ (smallest see-saw mass from EWSB if L heavy)

But also $\begin{cases} m_N \geq \frac{yy'}{16\pi^2} m_L \log(M/m_L) & \text{(Radiative Dirac mass)} \\ m_N \geq yy' f_{\pi'}^2 / m_L & \text{(Higgs wiggles biggest)} \end{cases}$

These bounds imply $f_{\pi'} < v$ and $m_L < \frac{4\pi v}{\sqrt{\log(M/m_L)}}$

***Can't decouple new degrees of freedom.
New confining physics near weak scale!***

Couples to Higgs; hidden valley signatures

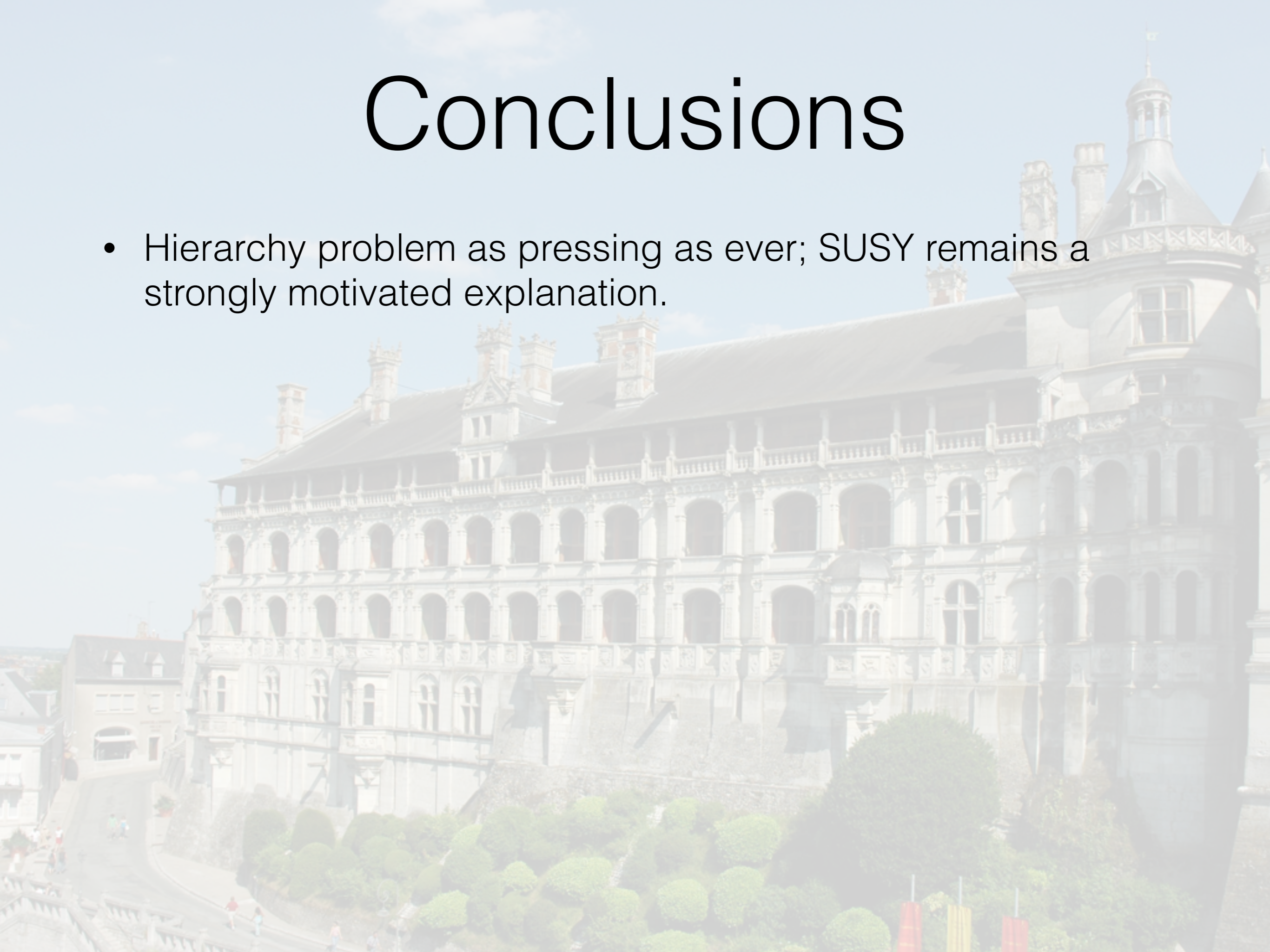
$$M < \left(\frac{\Lambda^4 M_P^3}{f}\right)^{1/6} \sim 3 \times 10^5 \text{ TeV} \times \left(\frac{10^9 \text{ GeV}}{f}\right)^{1/6} \left(\frac{f_{\pi'}}{30 \text{ GeV}}\right)^{1/2} \left(\frac{yy'}{10^{-2}}\right)^{1/6} \left(\frac{300 \text{ GeV}}{m_L}\right)^{1/6}$$

Conclusions



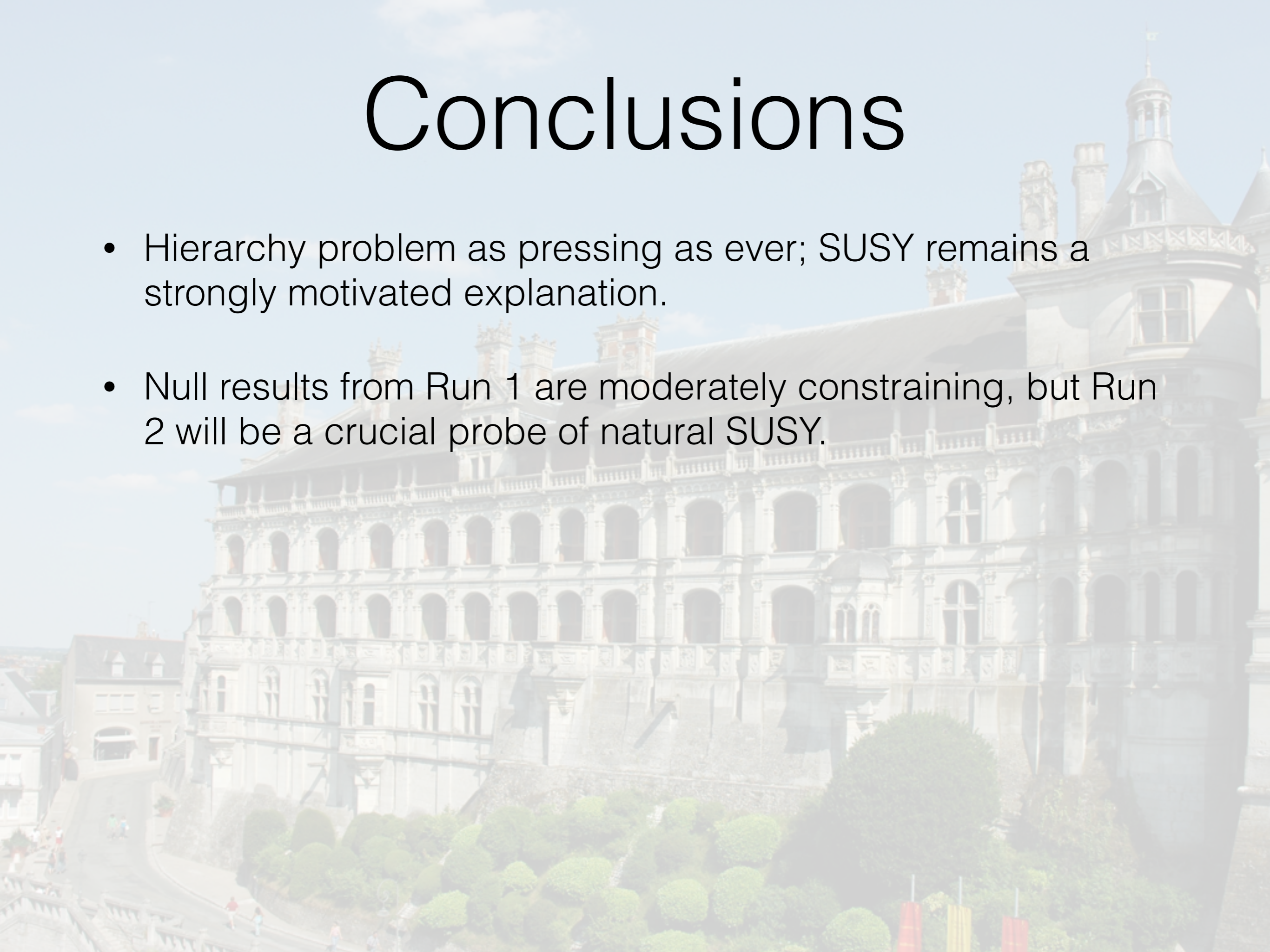
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- Many novel ideas being explored, with a range of new consequences for LHC *and other experiments*. Higgs-related physics and rich hidden sectors a common feature.
- Far more out there to explore!

Thank you!