UV Complete Technicolor & Natural Low Scale Supersymmetry

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M. Antola, SD, F. Sannino, K. Tuominen: in preparation

CP^3 - Origins

Particle Physics & Origin of Mass

SUSY 2011, Chicago

Fine Tuning

Fine tuning (FT) in a theory with a fundamental scalar ϕ:

$$m_\phi^2 \equiv \left(m_\phi^2\right)_{tree} + k\Lambda_{UV}^2, \quad k \lesssim 1 \;\Rightarrow\quad \mathrm{FT} \sim \frac{k\,\Lambda_{UV}^2}{m_\phi^2}.$$

If the scalar breaks EW ($m_\phi \sim v_w$) and SUSY arises at a scale m_{SUSY}:

$$\mathrm{FT} \sim \frac{k\,m_{\mathsf{SUSY}}^2}{v_w^2}$$

also for $\Lambda_{UV} \gg m_{\mathsf{SUSY}}$; for MSSM, FT $\gtrsim 100$.

A solution to little hierarchy problem: $m_\phi \sim m_{\mathsf{SUSY}} \gg v_w$, but... how to break EW symmetry?

One can look at QCD for inspiration...

* Giudice, Barbieri '88

QCD & Dynamical EWSB

In QCD at Λ_{QCD} the interaction becomes strong and the quarks form a bound state with non-zero vev:

$$\langle 0|\, \bar{u}_L u_R + \bar{d}_L d_R \,|0\rangle \neq 0,\; T_L^3 + Y_L = Y_R = Q \;\Rightarrow\; SU(2)_L \times U(1)_Y \to U(1)_{EM}$$

M_Z and M_W determined by redefining currents in terms of composite pseudo-scalars (pions):

$$M_W^{QCD} = g f_{\pi^\pm}/2,\;\; \sqrt{\rho} = \frac{M_W^{QCD}}{M_Z^{QCD}} \cos^{-1}(\theta_W) = 1.$$

Given the experimental value for the pion decay constant

$$f_\pi = 93\,\mathrm{MeV} \quad \Rightarrow \quad M_W^{QCD} = 29\,\mathrm{MeV}!$$

Technicolor

The effective Lagrangian expansion breaks down at

$$\Lambda_{QCD} \simeq 4\pi f_\pi = 1.2\,\mathrm{GeV} \Rightarrow \Lambda_{TC} \simeq 4\pi v = 3\,\mathrm{TeV},\ v = 246\ \mathrm{GeV}\,.$$

A Technicolor (TC) model able to give the right masses to the EW gauge bosons is simply "scaled up" QCD (no fundamental scalar $\Rightarrow$ no fine-tuning!):

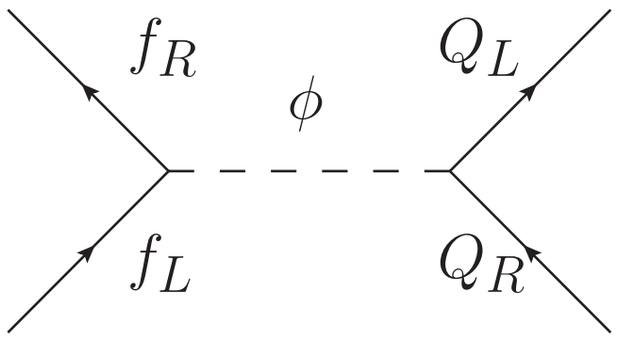
$$SU(N)_{TC} \times SU(3)_C \times SU(2)_L \times U(1)_Y\,.$$

To generate the fermion masses additional interactions are necessary.

* Susskind '79

Bosonic Technicolor

Scalars ϕ with Yukawa couplings to both technifermions & SM fermions, $m_\phi \gg \Lambda_{TC} \quad \Rightarrow$



$$\rightarrow \frac{y_f y_U}{m_\phi^2}(\bar{Q}_L Q_R)(\bar{f}_R f_L) \Rightarrow m_f \approx \frac{y_f y_U}{m_\phi^2}\Lambda_{TC}^3$$

By supersymmetrizing the theory and taking $m_\phi \sim m_{\text{SUSY}}$ the theory becomes natural (no FT). Moreover since $m_{\text{SUSY}} \gg \Lambda_{TC}$ the FCNC generated by scalars are suppressed.

The fermion masses can be generated also by Extended TC (ETC) gauge interactions. No viable model of gauge ETC has ever been written (either FCNC too large, or m_t too small).

* Simmons '89; Dine, Kagan, Samuel '90

Pheno Viable TC

The S parameter for a TC model is estimated by:

$$S_{th} = \frac{1}{6\pi}\frac{N_f}{2}d(\mathrm{R}), \quad S_{exp} \leq (6\pi)^{-1} \text{ @ } 95\%$$

Phenomenological viability requires:

- Small N_f and N_{TC}: $N_f d(R) \lesssim 6$
- Walking TC: $\beta(\alpha_*) = 0 \Rightarrow \langle \overline{Q}Q \rangle_{ETC} \simeq \langle \overline{Q}Q \rangle_{TC} \left(\frac{\Lambda_{ETC}}{\Lambda_{TC}}\right)^{\gamma}$

Walking behavior boosts m_f w/o increasing FCNC.

* Yamawaki et al. '86, Appelquist et al '86

Minimal Walking Technicolor

TC-fermions in the $SU(2)_{TC}$ adjoint representation: $a = 1, 2, 3$;

$$Q_L^a = \begin{pmatrix} U_L^a \\ D_L^a \end{pmatrix},\ U_R^a,\ D_R^a\ .$$

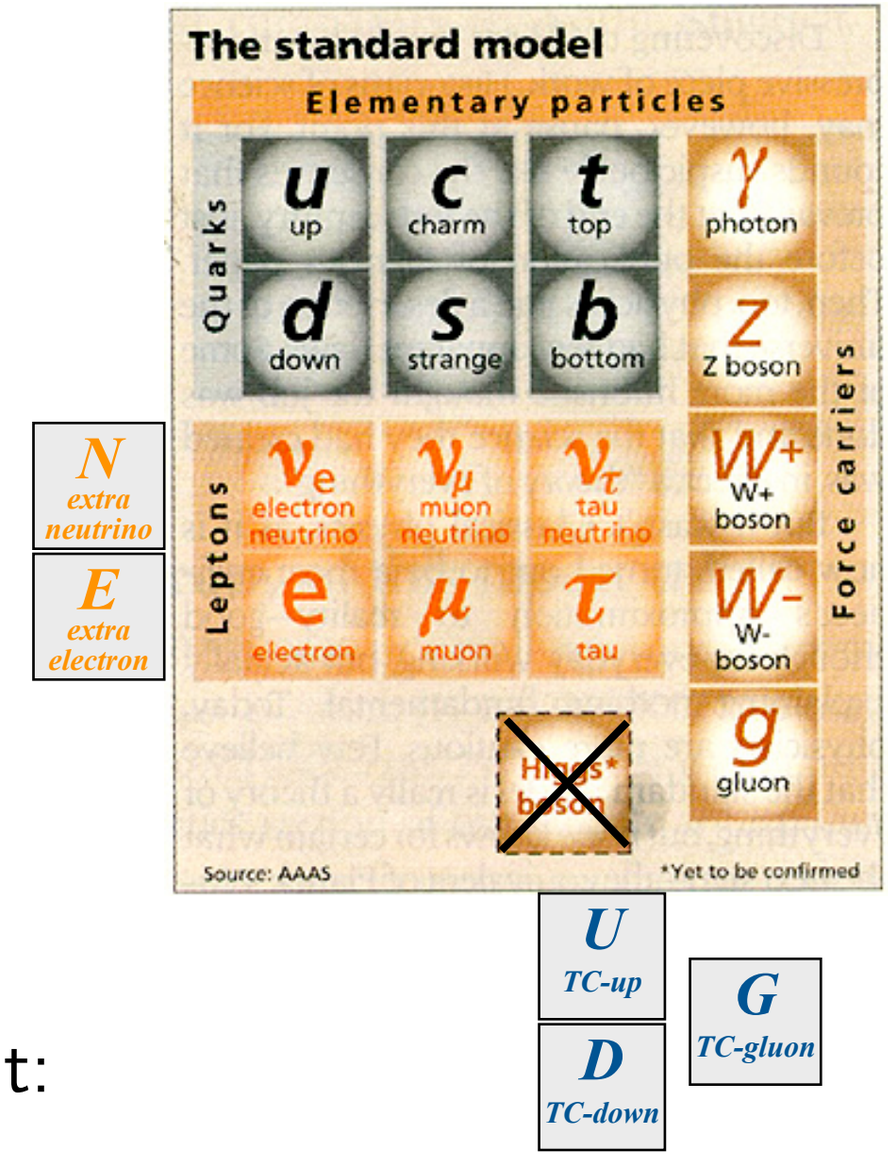
Heavy leptons to cancel Witten anomaly:

$$L_L = \begin{pmatrix} N_L \\ E_L \end{pmatrix},\ N_R,\ E_R\ .$$

Anomalies free hypercharge assignment:

$$Y(Q_L) = \frac{1}{2}, \qquad Y(U_R, D_R) = (1, 0)\ ,$$

$$Y(L_L) = -\frac{3}{2}, \qquad Y(N_R, E_R) = (-1, -2)\ .$$



* Sannino, Tuominen '04

MWT Lagrangian

The MWT Lagrangian is

$$\begin{aligned}
\mathcal{L}_{MWT} &= \mathcal{L}_{SM} - \mathcal{L}_H + \mathcal{L}_{TC}, \\
\mathcal{L}_{TC} &= -\frac{1}{4}\mathcal{F}^a_{\mu\nu}\mathcal{F}^{a\mu\nu} + i\bar{Q}_L\gamma^\mu D_\mu Q_L + i\bar{U}_R\gamma^\mu D_\mu U_R + i\bar{D}_R\gamma^\mu D_\mu D_R \\
&\quad + i\bar{L}_L\gamma^\mu D_\mu L_L + i\bar{E}_R\gamma^\mu D_\mu E_R + i\bar{N}_R\gamma^\mu D_\mu N_R,
\end{aligned}$$

with the covariant derivatives defined by the fields' quantum numbers.

The techniquarks condense and break EW:

$$\langle \eta_i^\alpha \eta_j^\beta \epsilon_{\alpha\beta} E^{ij} \rangle = -2\,\langle \overline{U}_R U_L + \overline{D}_R D_L \rangle,\ \eta = \begin{pmatrix} U_L \\ D_L \\ -i\sigma^2 U_R^* \\ -i\sigma^2 D_R^* \end{pmatrix},\ E = \begin{pmatrix} 0 & \mathbb{I} \\ \mathbb{I} & 0 \end{pmatrix}$$

$$\langle \eta_i^\alpha \eta_j^\beta \epsilon_{\alpha\beta} E^{ij} \rangle \neq 0 \qquad \Rightarrow \qquad SU(2)_L \times U(1)_Y \to U(1)_{EM}$$

* Foadi, Frandsen, Ryttov, Sannino '07

Low Energy TC Lagrangian

Low energy ($\Lambda \ll \Lambda_{TC}$) Lagrangian:

$$\mathcal{L}_{\rm Higgs} \;=\; \frac{1}{2}{\rm Tr}\left[D_\mu M D^\mu M^\dagger\right] - \mathcal{V}(M) + \mathcal{L}_{\rm ETC}\ ,$$

where the potential reads

$$\begin{aligned}\mathcal{V}(M) \;&=\; -\frac{m_M^2}{2}{\rm Tr}[MM^\dagger] + \frac{\lambda}{4}{\rm Tr}\left[MM^\dagger\right]^2 + \lambda'{\rm Tr}\left[MM^\dagger MM^\dagger\right] \\ &-\; 2\lambda''\left[{\rm Det}(M) + {\rm Det}(M^\dagger)\right]\ ,\end{aligned}$$

$$M_{ij} \sim \eta_i\eta_j \text{ with } i,j = 1\ldots 4,\ \langle M\rangle = \frac{v}{2}E.$$

M transforms under the full $SU(4)$ group according to

$$M \to uMu^T\ , \qquad \text{with} \qquad u \in SU(4)\,.$$

Global $SU(4) \to SO(4)$ $\Rightarrow$ 6 uneaten Nambu-Goldstone Bosons (NGB)

Minimal Super Conformal Technicolor

MWT	Minimal S-partners	N=1 : Multiplets : N=4
G_μ	G_μ	V
$\bar{D}_R$	$\bar{D}_R$	Φ_3
$\bar{U}_R$	$\bar{U}_R \quad \tilde{\bar{U}}_R$	Φ_1
U_L	$U_L \quad \tilde{U}_L$	Φ_2
D_L	$D_L \quad \tilde{D}_L$	

V Φ_3 Φ_1 Φ_2

Particle spectrum: 4SYM + Lepton 4th superfamily + MSSM.

$$
\begin{aligned}
f(\Phi)_{TC} &= -\frac{g_{TC}}{3\sqrt{2}}\epsilon_{ijk}\epsilon^{abc}\Phi_i^a\Phi_j^b\Phi_k^c + y_U\epsilon_{ij3}\Phi_i^a H_j \Phi_3^a \\
&+ y_N\epsilon_{ij3}\Lambda_i H_j N + y_E\epsilon_{ij3}\Lambda_i H'_j E + y_R\Phi_3^a\Phi_3^a E
\end{aligned}
$$

MSCT represents a possible UV completion of MWT.

* Antola, SD, Sannino, Tuominen '10

Effective 4-Fermion Lagrangian

By assuming

- $m_{\tilde{H}}, m_{\tilde{g}}, m_{\tilde{W}}, m_{\tilde{B}} \sim m_{\mathsf{SUSY}}$
- $m_\phi^2 \sim m_{\mathsf{SUSY}}^2 > 0$, for any soft squared scalar mass term m_ϕ^2

the effective $\mathcal{L}$ at scale $\Lambda < m_{\mathsf{SUSY}}$ determined from $f(\Phi)_{\mathsf{TC}}$ is

$$
\begin{aligned}
\mathcal{L}_{\text{4-f}} &= \frac{c_\theta^2}{m_s^2}\left(F_u^\dagger F_u + F_d^\dagger F_d\right) + \frac{c_\theta s_\theta}{m_s^2}\left(F_u \cdot F_d + \text{h.c.}\right) \\
&- \frac{1}{2} M_D \left(D_R D_R + \text{h.c.}\right) + \frac{g_{\mathsf{TC}}^2}{m_{\text{SUSY}}^2} \bar{\eta}_b \cdot \eta_d \bar{\eta}_c \cdot \eta_e \epsilon^{a,b,c} \epsilon^{a,d,e} \ , \\
F_u &= q_{Lu}^i Y_u^i \bar{u}_R^i + y_U Q_L \bar{U}_R + y_N L_L \bar{N}_R \ , \\
F_d &= q_{Ld}^i Y_d^i \bar{d}_R^i + l_L^i Y_l^i \bar{e}_R^i + y_E L_L \bar{E}_R \ ,
\end{aligned}
$$

where $m_s \sim m_{\mathsf{SUSY}}$ and $\tan(\theta) = b\left(\mu^2 + m_{\mathsf{SUSY}}^2\right)^{-1}$.

Low Energy MSCT Lagrangian

Low energy ($\Lambda \ll \Lambda_{\mathsf{TC}}$) $\mathcal{L}$ for MSCT with strong g_{TC} coupling:

$$
\begin{aligned}
\mathcal{L}'_{MSCT} &= \mathcal{L}_{SMkin} + \mathcal{L}_{MWT} + \mathcal{L}_{ETC}, \\
-\mathcal{L}_{ETC} &= c_1 \Lambda_{TC}^2 \mathsf{Tr}\left[M\Delta\right] + c_2 \Lambda_{TC}^2 \mathsf{Tr}\left[MZ\right] + c_3 \Lambda_{TC}^4 W_{ijkl} M_{ij} M^*_{kl} + cc.
\end{aligned}
$$

The spurion fields' vevs are given by:

$$
\begin{aligned}
W_{ijkl} &= \frac{y_U^2 c_\theta^2}{m_s^2} \omega^2 \left(\delta_{ij1} + \delta_{ij2}\right) \delta_{kl3}\,, \text{ with } \omega = \frac{\langle U_L \bar{U}_R \rangle_{m_s}}{\langle U_L \bar{U}_R \rangle_{\Lambda_{TC}}} = \left(\frac{m_s}{\Lambda_{TC}}\right)^\gamma, \\
\Delta_{ij} &= \delta_{ij4} \frac{M_D}{2}\,, \\
Z_{ij} &= \frac{c_\theta y_U \omega}{m_s^2} \delta_{j3} \Big(c_\theta \delta_{ik} \left(y_u u_R \bar{q}^k_{Lu} + y_N N_R \bar{\Lambda}^k_L \right) \\
&- s_\theta \epsilon_{ik} \left(y_d \bar{d}_R q^k_{Ld} + y_e \bar{e}_R l^k_L + y_E \bar{E}_R \Lambda^k_L \right) \Big).
\end{aligned}
$$

EW Symmetry Breaking in MSCT

For $M_D \neq 0$ the potential is minimized by the composite scalar vev

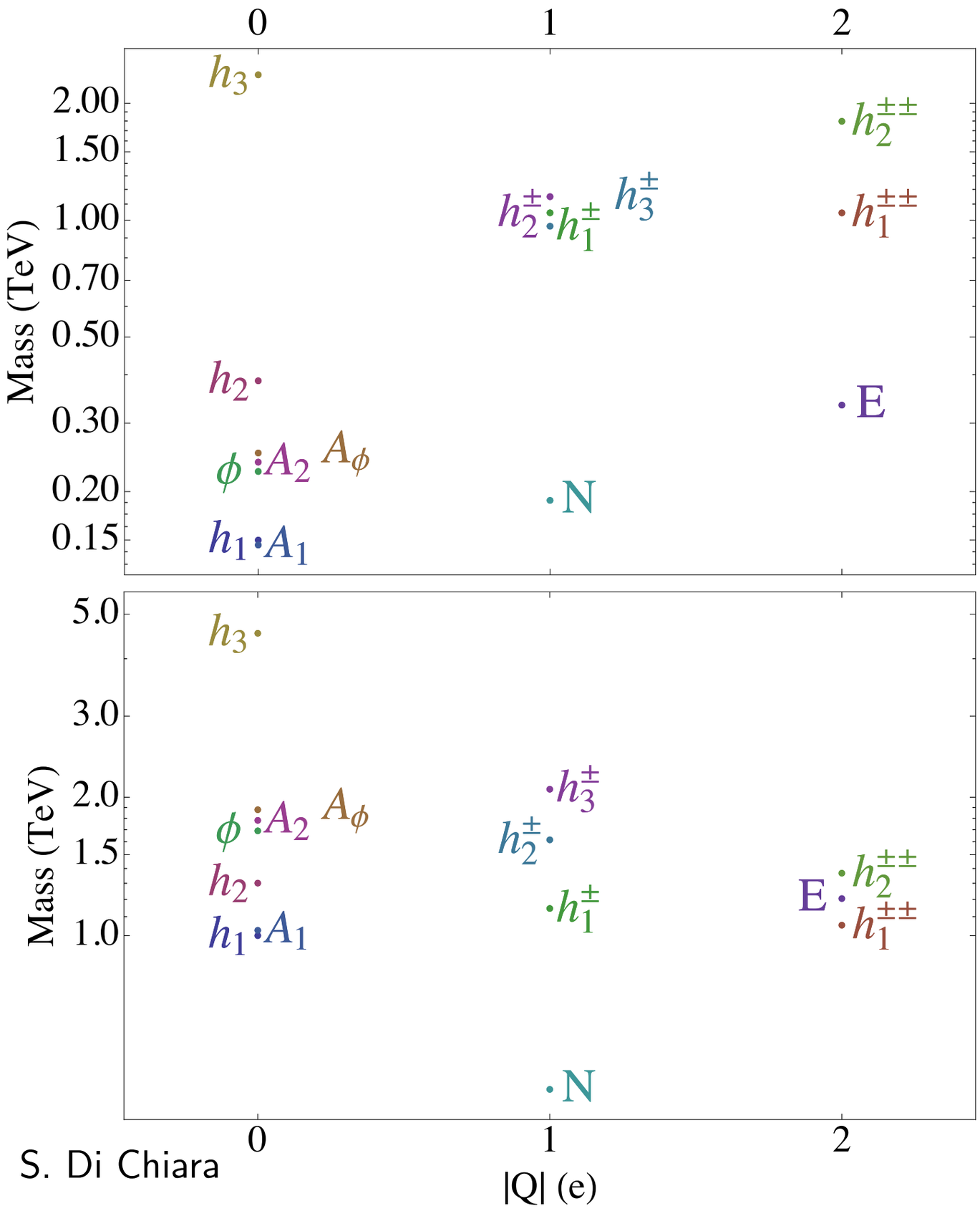
$$\langle M \rangle = \frac{1}{\sqrt{2}} \begin{pmatrix} 0 & 0 & v_1 & 0 \\ 0 & \sqrt{2}v_2 & 0 & 0 \\ v_1 & 0 & 0 & 0 \\ 0 & 0 & 0 & \sqrt{2}v_4 \end{pmatrix} .$$

All SM fermions, 4th family leptons, NGB get non-zero mass.

We performed parameter space scan around values suggested by naive dimensional analysis with $\gamma = 1.5$ and imposed/required:

- Yukawa couplings $< 2\pi$ ($\simeq$ value of UV fixed point)
- $m_\phi^2 > (120\mathrm{GeV})^2$ for $\forall\phi,\ m_{E,N} > 100$ GeV, $m_{\mathsf{SUSY}} > 5$ TeV
- Stable potential
- S and T EW parameters within exp. limits

Viable Mass Spectrum



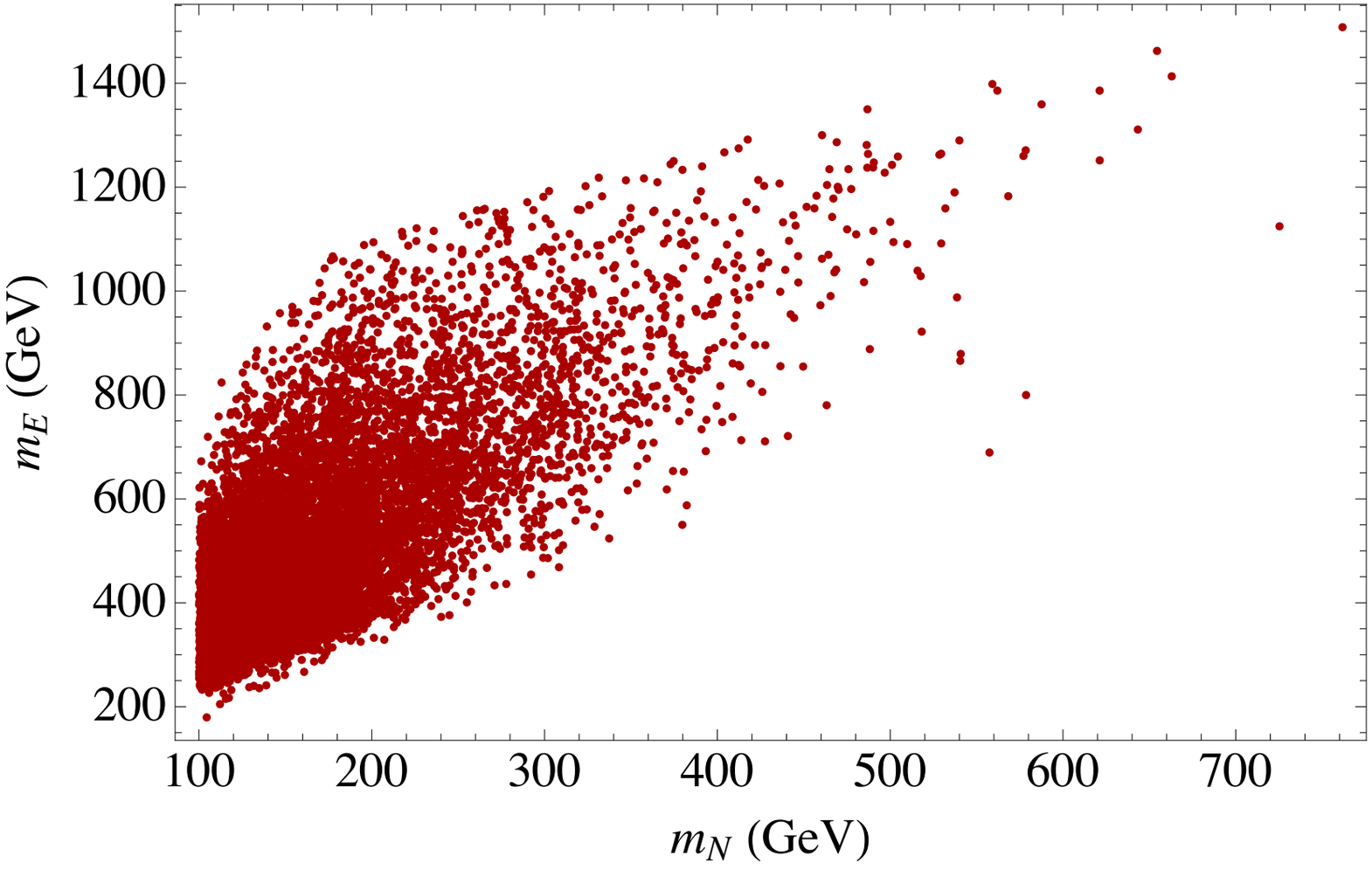
Viable mass spectrum for a light (top) and heavy (bottom) composite Higgs scalar.

- ϕ and A_ϕ don't couple linearly to fermions or gauge bosons
- h_1 has in general weaker SM Higgs-like couplings
- N and E are also gauge eigenstates

Chargino Masses

The plot below shows 10^4 viable points:

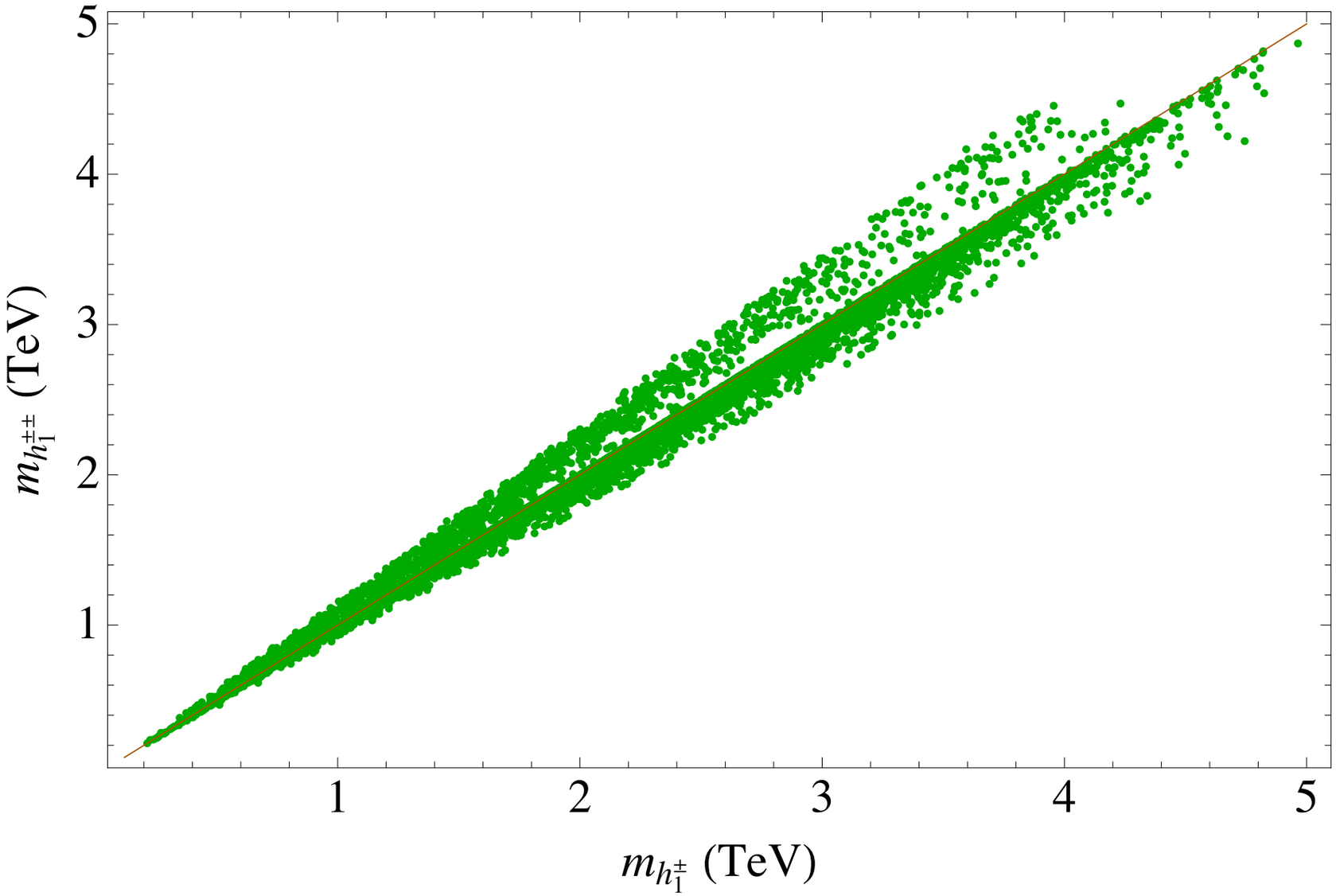
- $m_N < m_E$ gives $S_L < 0$ needed to offset the technifermion's $S_{TC} > 0$
- Only 1% of viable points has $m_N > 400$ GeV



Charged Higgs Masses

Plot of the masses of the charged lightest scalars $h_1^{\pm}$ and $h_1^{\pm\pm}$:

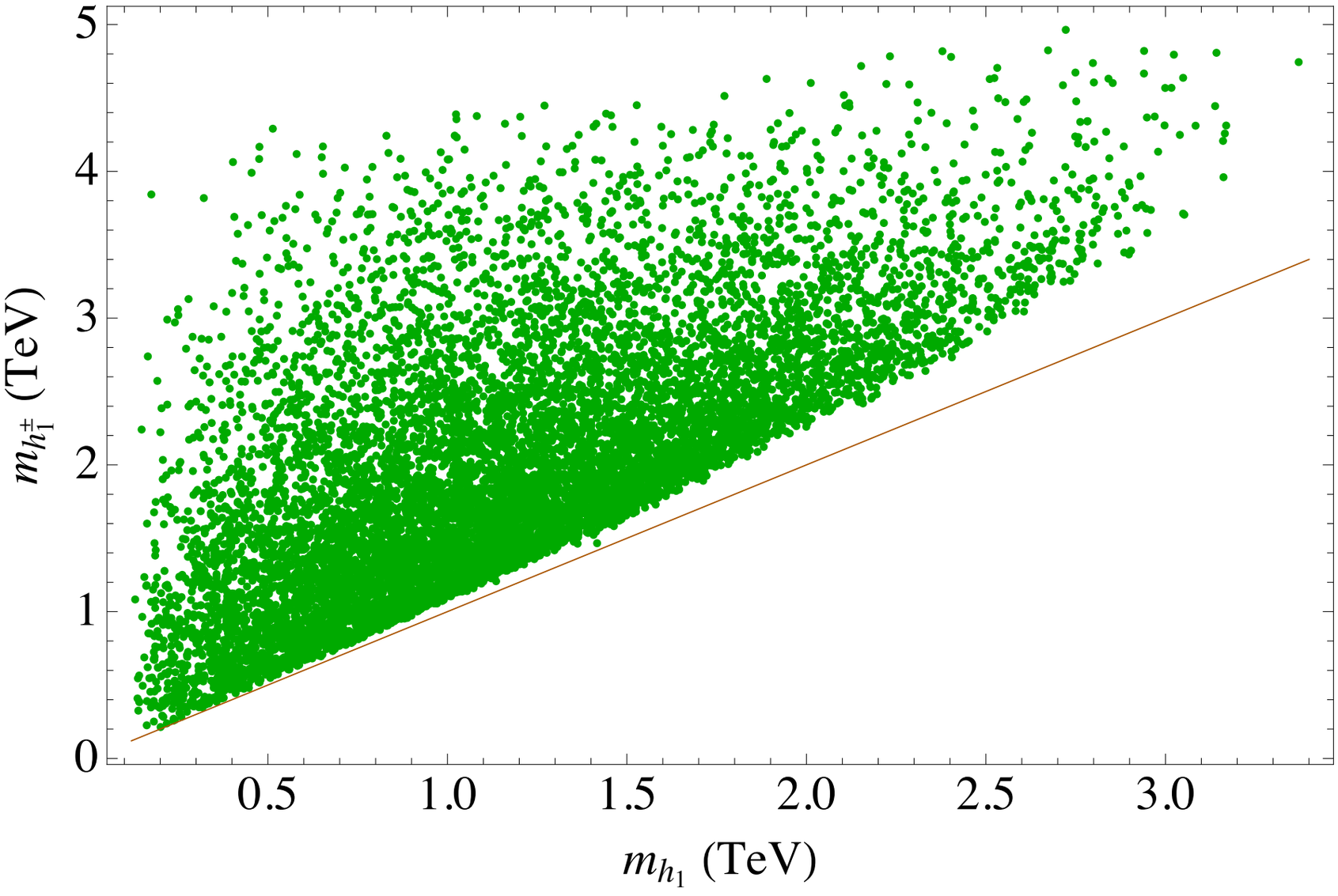
- $h_1^{\pm}$ and $h_1^{\pm\pm}$ are nearly degenerate and very heavy



Neutral vs Charged Higgs Masses

Plot of the lightest Higgs h_1 vs lightest charged scalar $h_1^\pm$ masses:

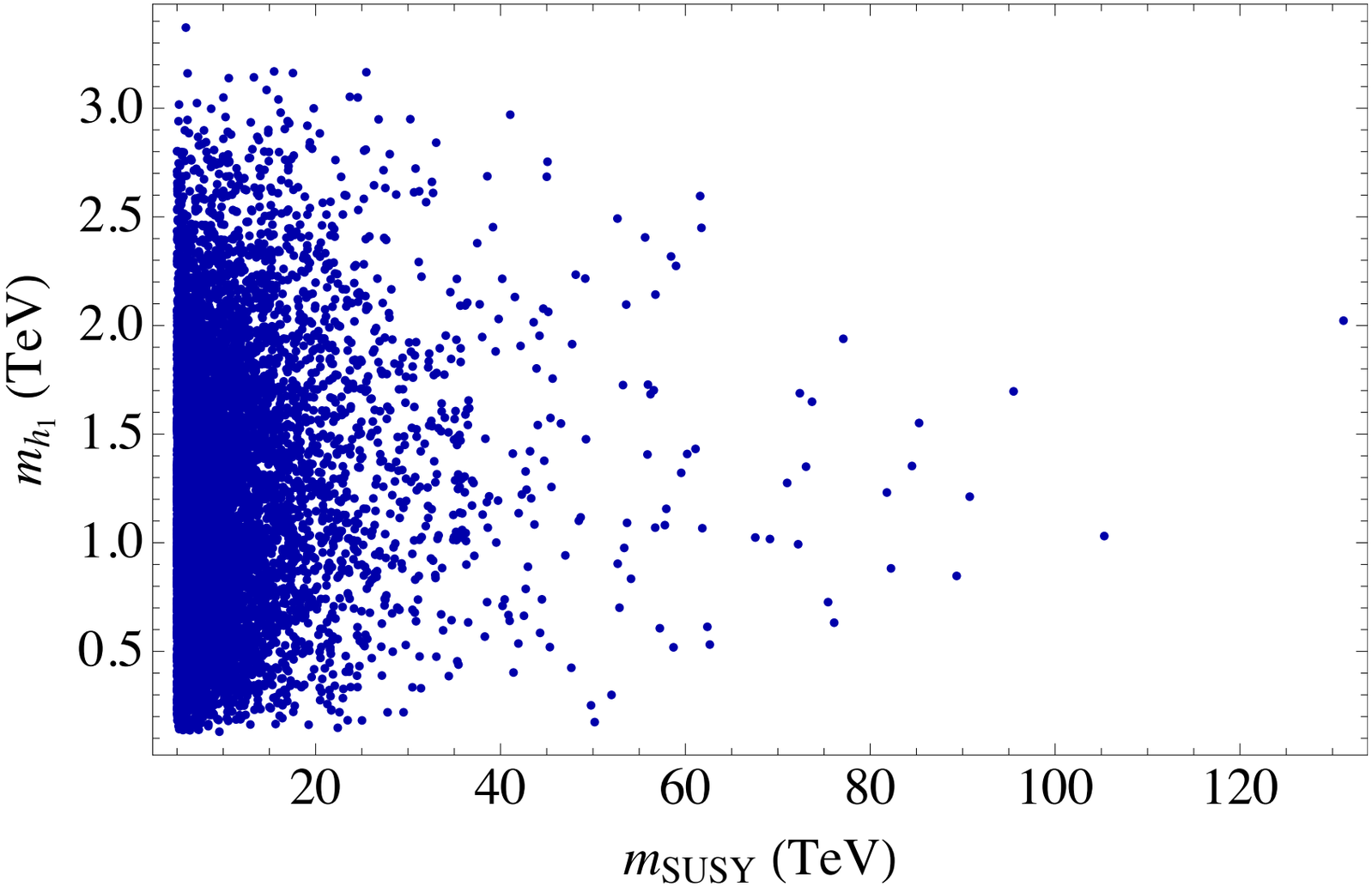
- $h_1^\pm$ is always heavier than h_1



Higgs Mass vs m_{SUSY}

Lightest Higgs mass vs m_{SUSY} plot for 10^4 viable points:

- The lightest Higgs can be very heavy: 50% of viable points has $m_{h_1} > 1.1$ TeV
- Low scale SUSY is highly favored: 50% of viable points has $5\ \mathrm{TeV} < m_{\mathsf{SUSY}} < 7.3$ TeV; $m_{\mathsf{SUSY}} \leqslant 131$ TeV



Light Fundamental Higgses

By allowing the fundamental Higgses to be light one gets:

$$\mathcal{L}''_{ETC} = -c_1 \Lambda_{TC}^2 \mathrm{Tr}\left[M\Delta\right] - c_5 \Lambda_{TC}^2 \mathrm{Tr}\left[MX\right] + h.c.,$$

where the matrix field X is

$$X = \frac{y_U}{\sqrt{2}} \begin{pmatrix} 0 & 0 & H^0 & 0 \\ 0 & 0 & -H^+ & 0 \\ H^0 & -H^+ & 0 & 0 \\ 0 & 0 & 0 & 0 \end{pmatrix}.$$

The complete Lagrangian is defined by

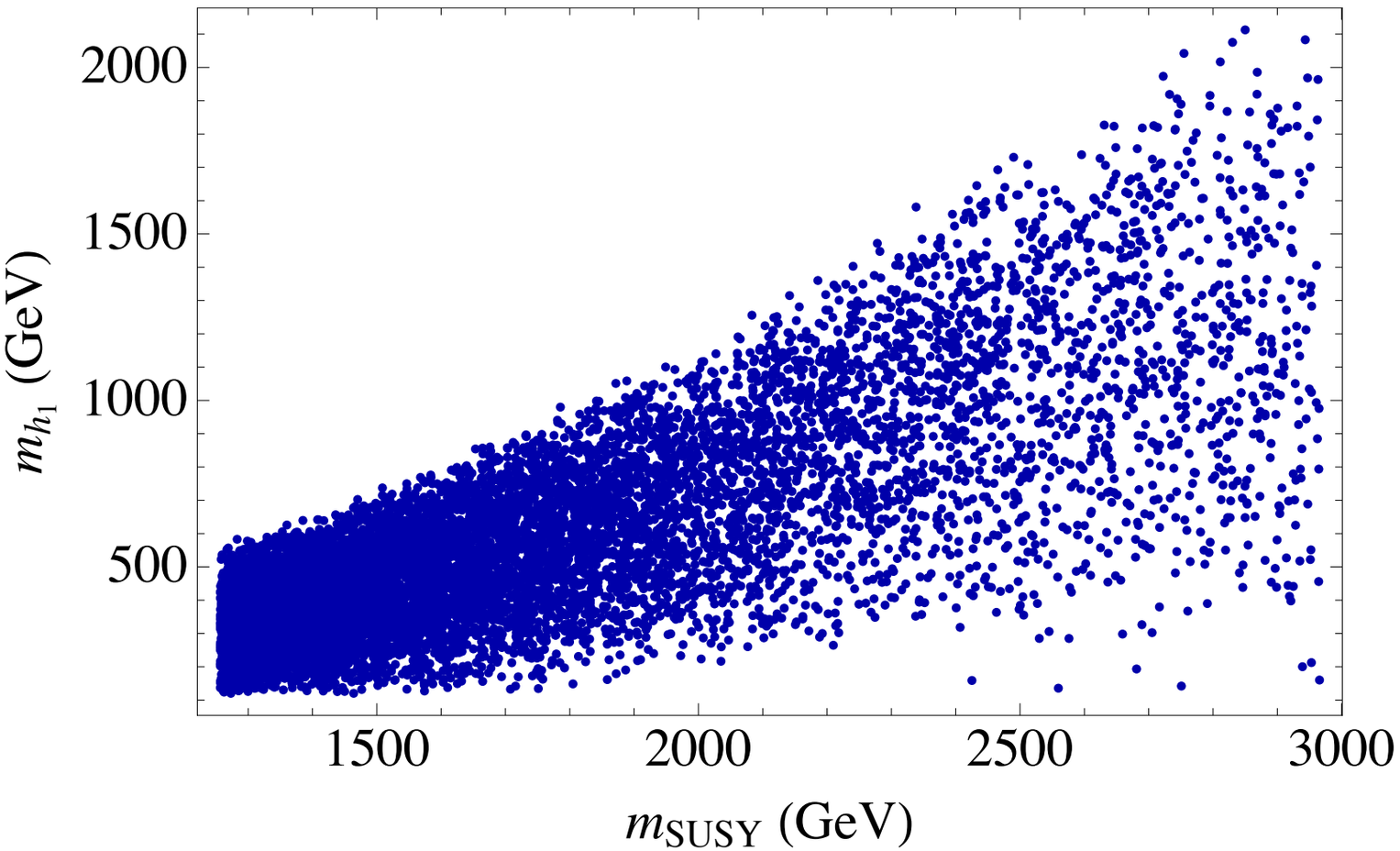
$$\mathcal{L}''_{MSCT} = \mathcal{L}_{SMkin} + \mathcal{L}'_{TC} + \mathcal{L}''_{ETC} \ .$$

EW symmetry broken by composite Higgs field $\Rightarrow MX$ induces a non-zero vev for $H \Rightarrow$ SM fermions and 4th family leptons become massive.

$$v_H > 0 \Rightarrow v_1 < 246\mathrm{GeV}$$

Low Scale SUSY

We take $m_{\mathsf{SUSY}} = \Lambda_{TC}$ (which can be justified), with g_{TC} strong at Λ_{TC}, and require positive squared mass terms for the fundamental Higgses H_u, H_d.



We limit $\Lambda_{TC} \geq 1.2$ TeV, because of exp. constraints on heavy resonances.

$m_{\mathsf{SUSY}} = 1.2$ TeV $\Rightarrow$
$m_{h_1} < 500$ GeV.

LHC Pheno & Conclusions

- Because of the weaker SM-like couplings h_1 has a wider viable range of masses
- New heavy leptons must be observed below 400 GeV: either chargino or neutralino
- Well defined hierarchies in the particle mass spectrum
- Low scale supersymmetry favored by experiment: possibility to observe superpartners together with TC composite resonances

A Technicolor model with a SUSY UV completion is natural and able to generate viable mass spectrum while satisfying EW constraints.

Backup Slides

Dynamical EWSB

In QCD at a Λ_{QCD} the interaction becomes strong and the quarks form a bound state with non-zero vev:

$$\langle 0|\, \bar{u}_L u_R + \bar{d}_L d_R \,|0\rangle \neq 0\,,\; T^3_L + Y_L = Y_R = Q \;\Rightarrow\; SU(2)_L \times U(1)_Y \to U(1)_{EM}$$

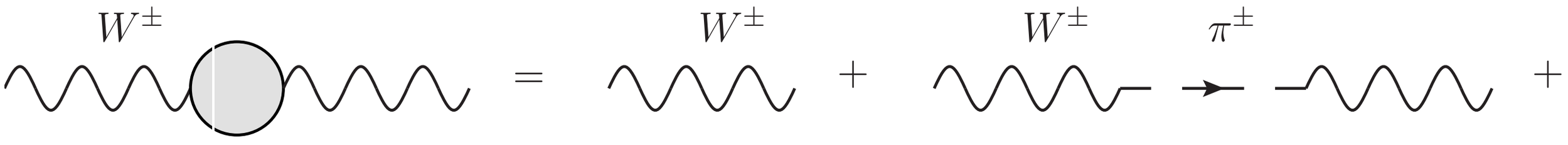
Redefine fields in terms of composite pseudo-scalars

$$q = (u, d)\,,\; j^\mu_{5a} = \bar{q}\gamma^\mu\gamma^5 \frac{\tau_a}{2} q = f_\pi \partial^\mu \pi_a$$

and plug in $\mathcal{L}_{k-f}$

$$\mathcal{L}_{k-f} \supset \frac{g}{2} f_{\pi^+} W^+_\mu \partial^\mu \pi^+ + \frac{g}{2} f_{\pi^-} W^-_\mu \partial^\mu \pi^- + \frac{g}{2} f_{\pi^0} W^0_\mu \partial^\mu \pi^0 + \frac{g'}{2} f_{\pi^0} B^+_\mu \partial^\mu \pi^0$$

QCD



$$= \frac{1}{p^2} + \frac{1}{p^2}(g f_{\pi^\pm}/2)^2 \frac{1}{p^2} + \ldots = \frac{1}{p^2 - (g f_{\pi^\pm}/2)^2}$$

The EW bosons have acquired masses:

$$M_W^{QCD} = g f_{\pi^\pm}/2, \;\; \rho = \frac{M_W^{QCD}}{M_Z^{QCD}} \cos^{-1}(\theta_W) = 1,$$

Given the experimental value for the pion decay constant

$$f_\pi = 93\,\mathrm{MeV} \quad \Rightarrow \quad M_W^{QCD} = 29\,\mathrm{MeV}!$$

Walking TC

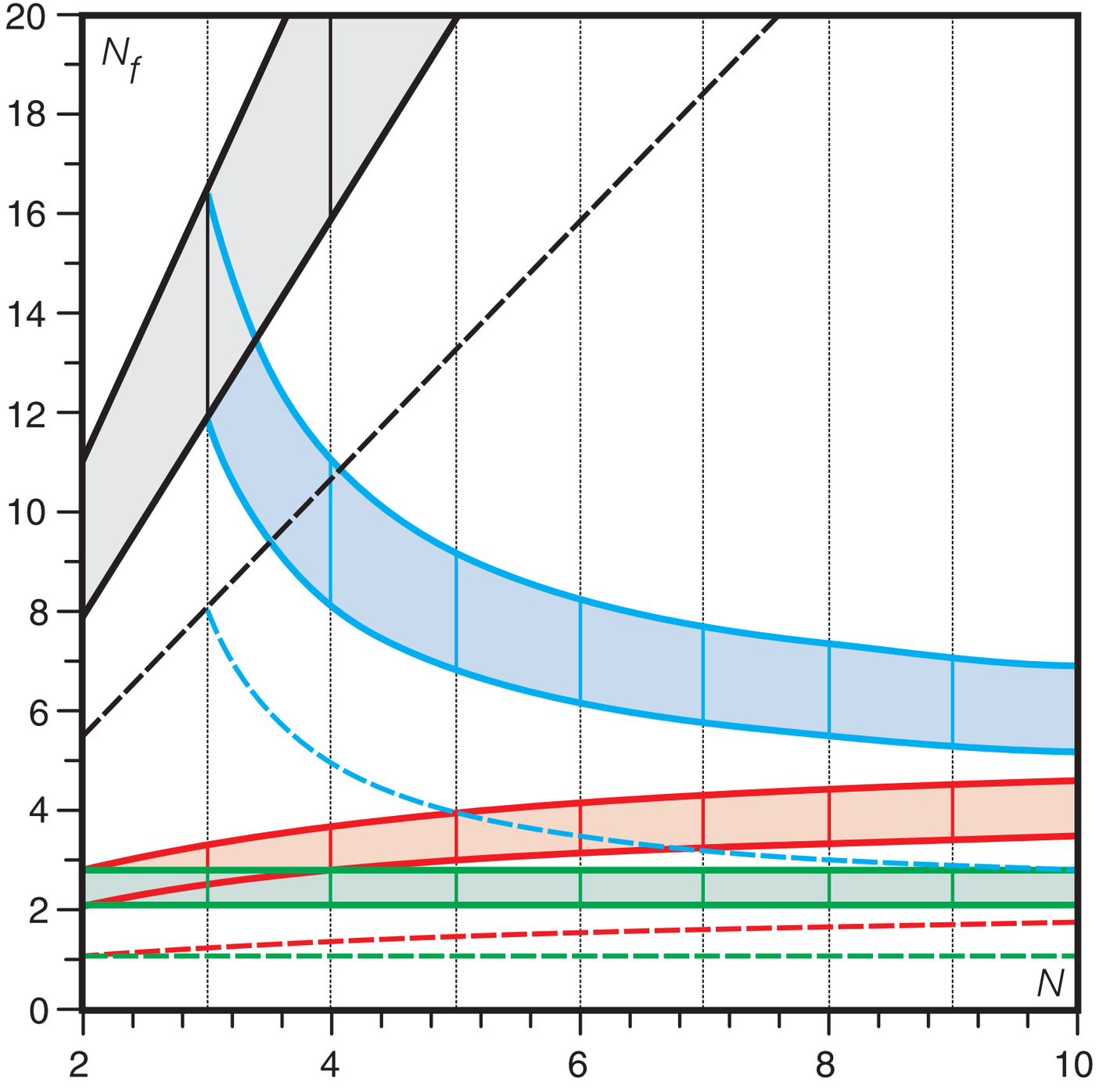
Look for Walking TC ($\beta(\alpha_*) = 0$) in theory space (Representation (R), Number of colors (N), Number of flavors (N_f)) by studying

$$\begin{aligned}
\beta(g) &= -\beta_0 \frac{\alpha^2}{4\pi} - \beta_1 \frac{\alpha^3}{(4\pi)^2},\ \alpha_* = -4\pi \frac{\beta_0}{\beta_1},\ \beta_0 = \frac{11}{3} C_2(\mathrm{G}) - \frac{4}{3} T(\mathrm{R}), \\
\beta_1 &= \frac{34}{3} {C_2}^2(\mathrm{G}) - \frac{20}{3} C_2(\mathrm{G}) T(\mathrm{R}) - 4 C_2(\mathrm{R}) T(\mathrm{R}).
\end{aligned}$$

The conformal window is defined by requiring asymptotic freedom, existence of a Banks-Zaks fixed point, and conformality to arise before chiral symmetry breaking:

$$\begin{aligned}
\beta_0 > 0 &\Rightarrow N_f > \frac{11}{4} \frac{d(\mathrm{G}) C_2(\mathrm{G})}{d(\mathrm{R}) C_2(\mathrm{R})}, \\
\beta_1 < 0 &\Rightarrow N_f < \frac{d(\mathrm{G}) C_2(\mathrm{G})}{d(\mathrm{R}) C_2(\mathrm{R})} \frac{17 C_2(\mathrm{G})}{10 C_2(\mathrm{G}) + 6 C_2(\mathrm{R})} \\
\alpha_* < \alpha_c &\Rightarrow N_f > \frac{d(\mathrm{G}) C_2(\mathrm{G})}{d(\mathrm{R}) C_2(\mathrm{R})} \frac{17 C_2(\mathrm{G}) + 66 C_2(\mathrm{R})}{10 C_2(\mathrm{G}) + 30 C_2(\mathrm{R})}.
\end{aligned}$$

Walking in the SU(N)



* Dietrich, Sannino '06

Phase diagram for theories with fermions in the:

- fundamental representation (grey)
- two-index antisymmetric (blue)
- two-index symmetric (red)
- adjoint representation (green)

The S parameter for a TC model is estimated by:

$$S_{th} = \frac{1}{6\pi}\frac{N_f}{2}d(\mathrm{R}),$$

$$12\pi\, S_{ex} \leq 6 \ @\ 95\%$$

TC Models

Walking Technicolor candidate models:

- Fundamental:
  $12\pi S(N=3, N_f=12) = 36,$
  $12\pi S(N=2, N_f=8) = 16$
- Adjoint:
  $12\pi S(N=2, N_f=2) = 6,$
  $12\pi S(N=3, N_f=2) = 16$
- 2 I. Symmetric:
  $12\pi S(N=2, N_f=2) = 6,$
  $12\pi S(N=3, N_f=2) = 12$
- 2 I. Antisymmetric:
  $12\pi S(N=3, N_f=12) = 36$

Alternatives to reduce S:

- Custodial TC ($S=0$)
- Partially Gauged TC
- Split TC

The best (fully gauged) Walking TC candidates are:

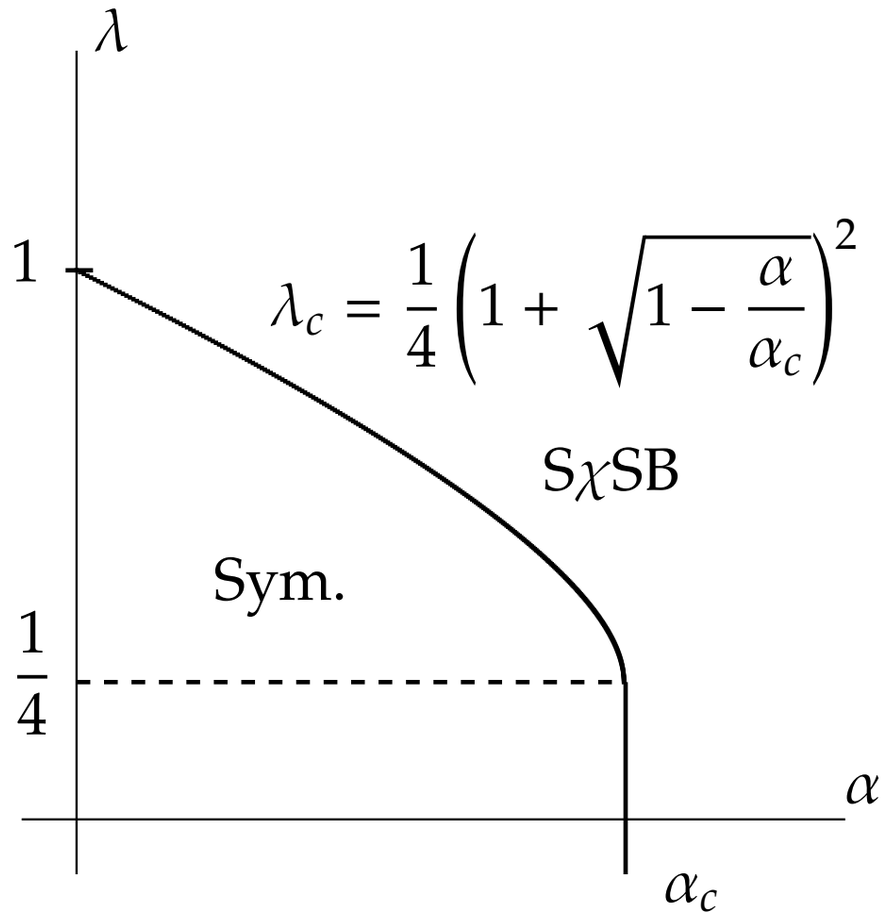
- $\mathrm{Adj}, N=2, N_f=2$
- 2-IS, $N=3, N_f=2$

Ideal Walking

A strong ETC sector increases the value of the fermion mass anomalous dimension. In gauged Nambu-Jona-Lasinio (gNJL):

$$\mathcal{L}_{gNJL} = \mathcal{L}_{TC} + \frac{16\pi^2\lambda}{d[r]N_f\Lambda^2_{ETC}}\bar{\psi}_L\psi_R\bar{\psi}_R\psi_L \Rightarrow$$

$$\gamma_m(\lambda) = 1 - \omega + 2\omega\frac{\lambda}{\lambda_c},\ \omega \equiv \sqrt{1 - \frac{\alpha}{\alpha_c}}$$



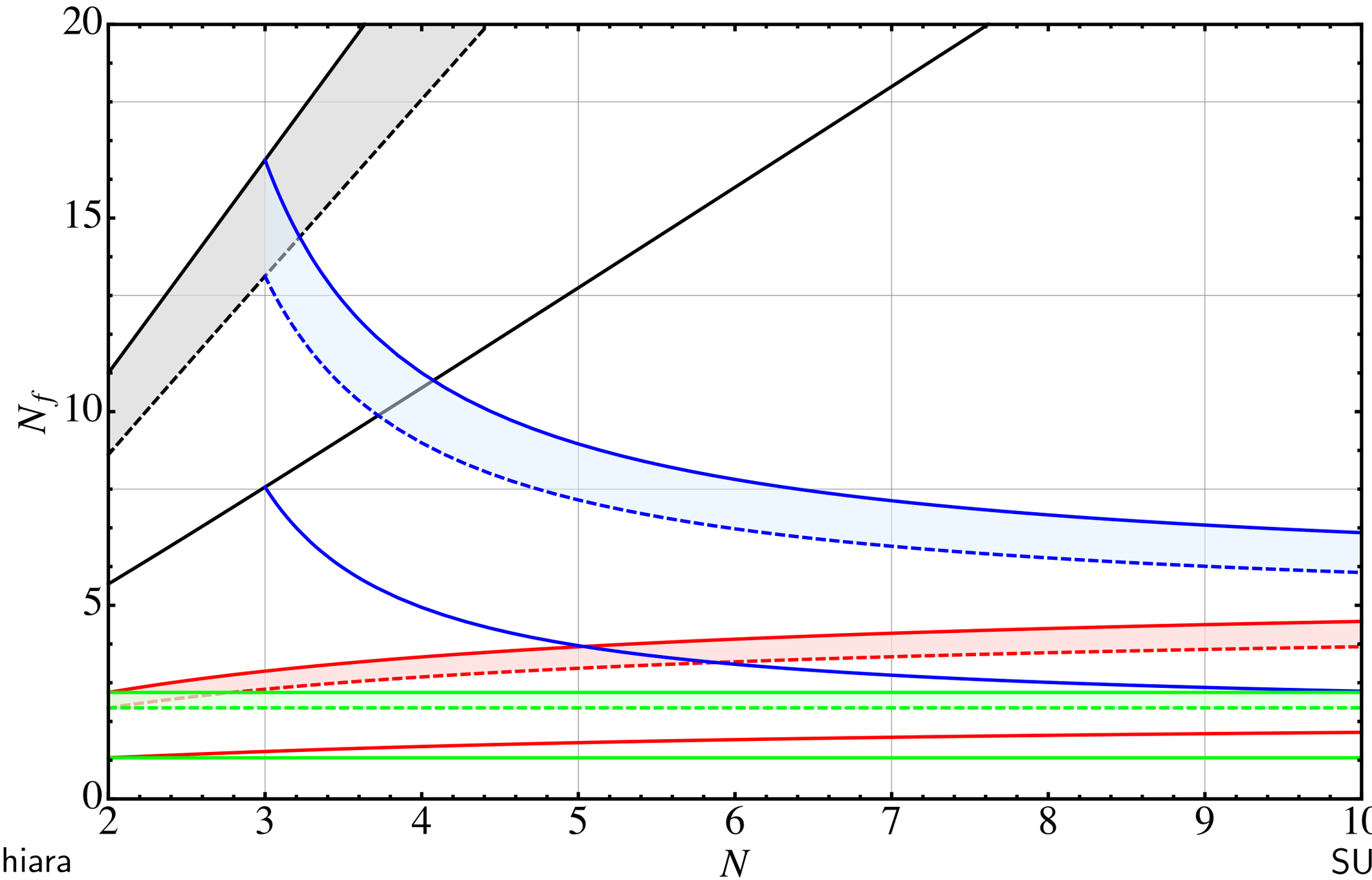
Assuming $\lambda = \lambda_c = 0.75$ one gets $\gamma_m(\lambda = \lambda_c) = 1 + \omega = 1.73 \Rightarrow$
By using dimensional analysis $m_t = 172\,\mathrm{GeV}$ for $\Lambda_{ETC} \approx 10^7\,\mathrm{TeV}$!

An accurate estimate of Λ_{TC} and $\langle\bar{T}T\rangle_{\mathrm{TC}}$ is needed to determine Λ_{ETC}.

* Fukano, Sannino '10

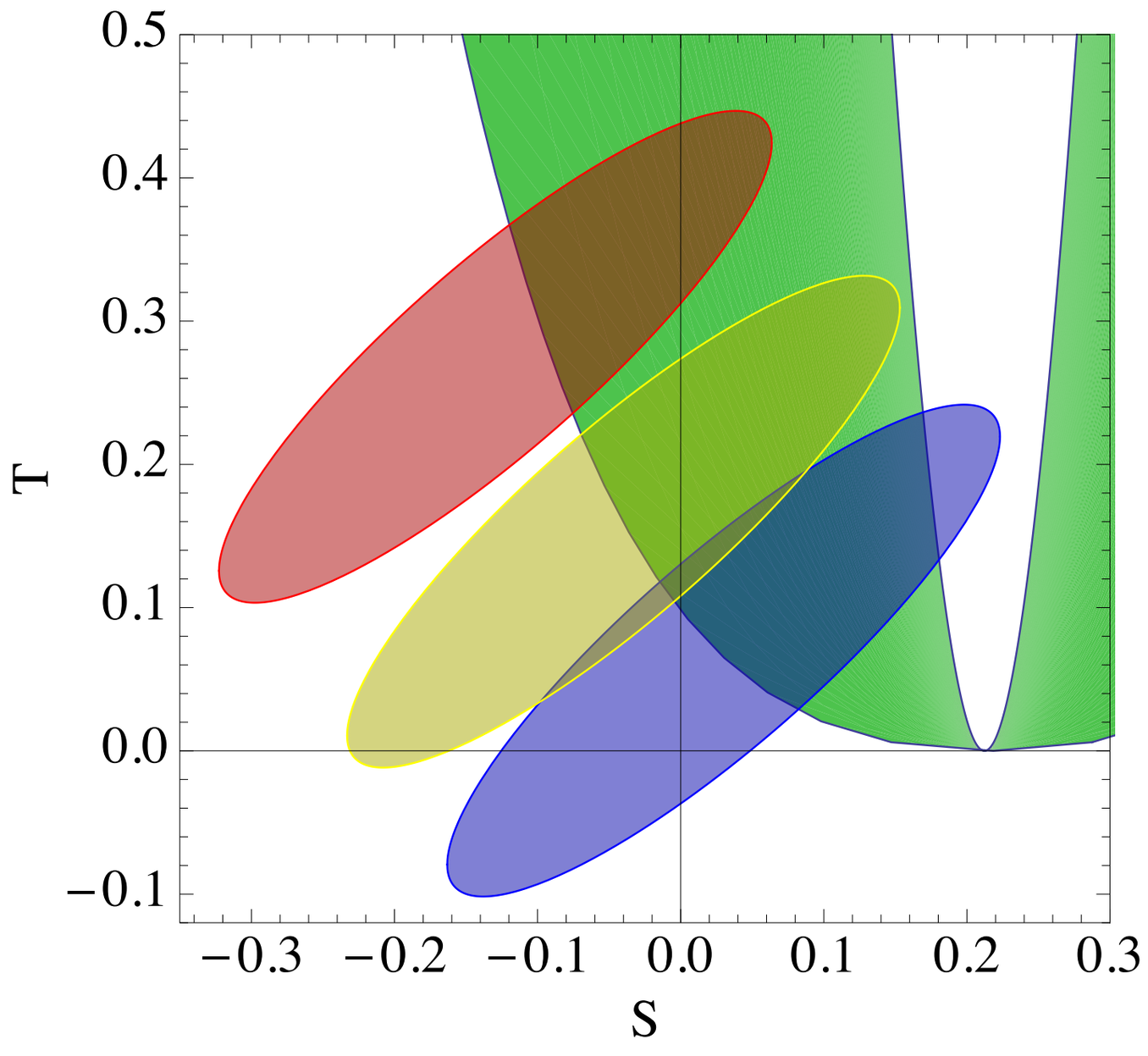
Phase Diagram with 4F Interaction

Phase diagram for $SU(N)$ representations with chiral symmetry breaking (dashed) line determined for $\lambda_c = 0.75$



S & T in MWT

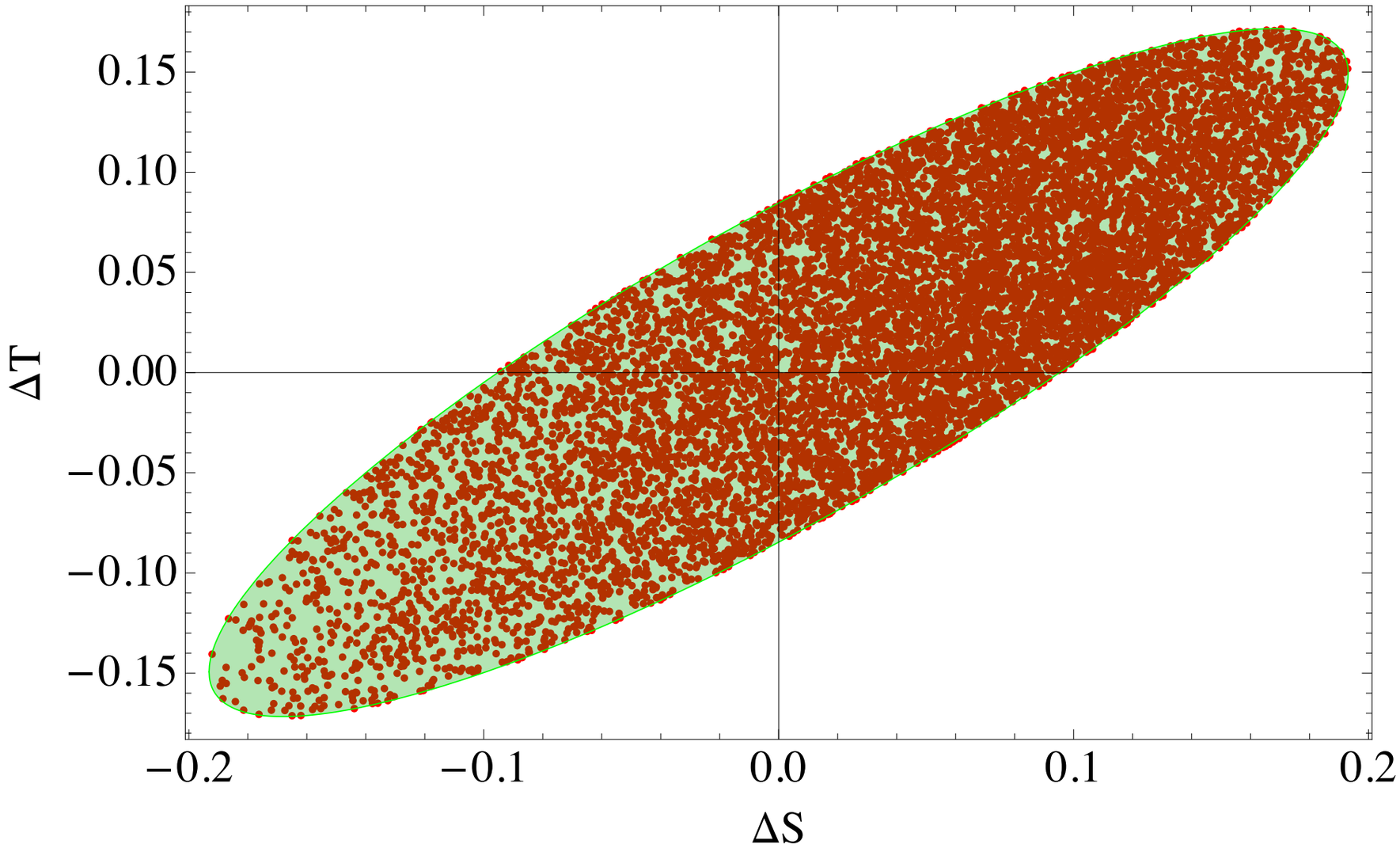
The ellipses give the S and T 90% CL region for $M_H =$ 117 GeV (blue), 300 GeV (yellow), 1 TeV (red). MWT's S and T region (green) calculated for $M_Z \leqslant m_{E,N} \leqslant 10\ M_Z$.



S & T Parameters

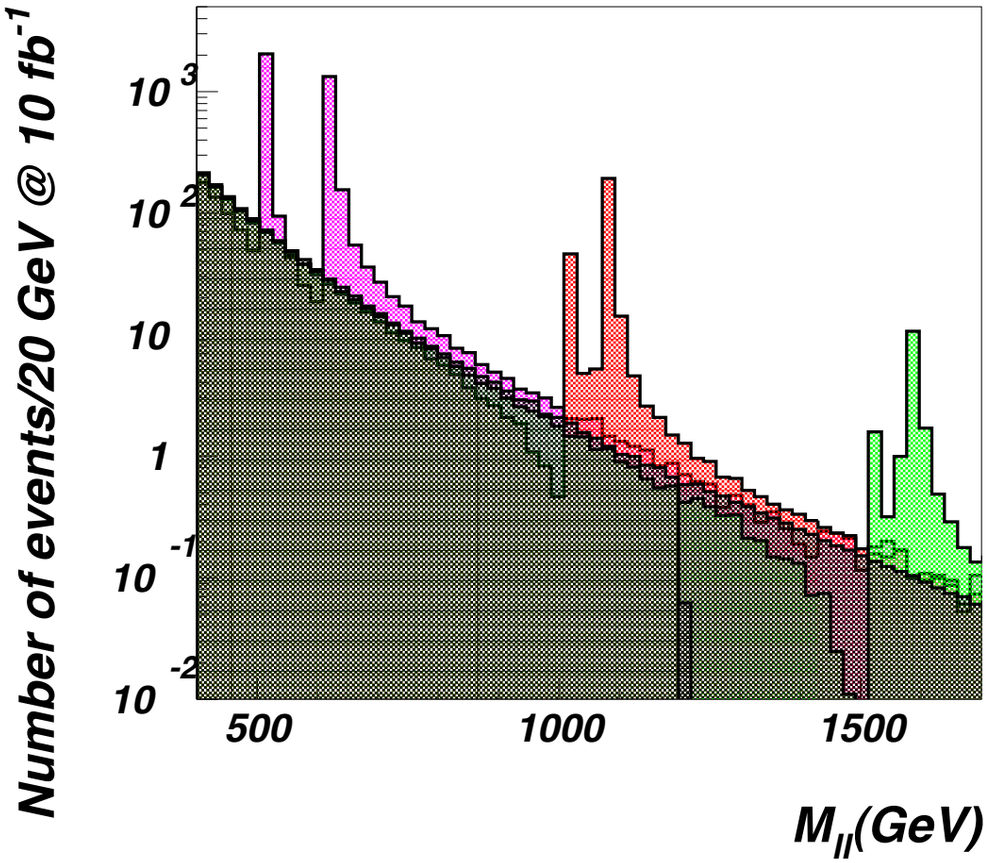
Plot of the $\Delta S = S - S_{min}$ and $\Delta T = T - T_{min}$ MSCT prediction for 10^4 viable points, with the 90% CL experimentally viable region:

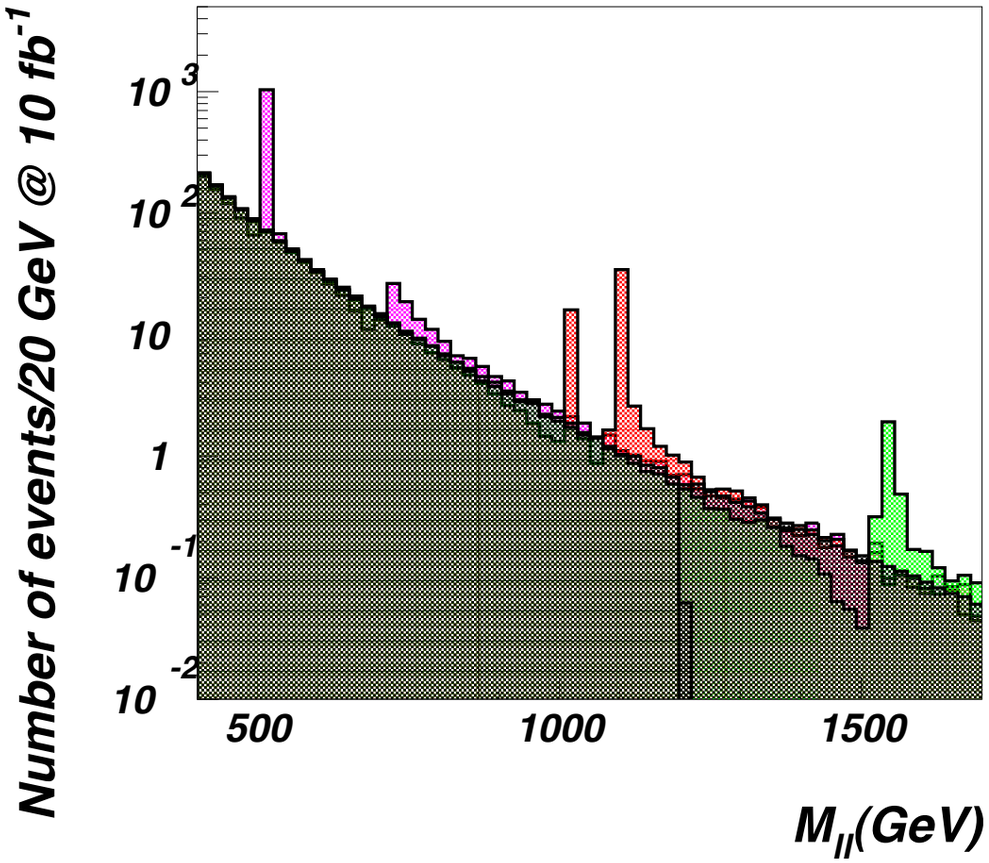
- $S_{th} = S_L + S_{\mathsf{TC}}$, $T_{th} = T_L + T_{M_D}$



MWT Phenomenology

Invariant mass distribution $M_{\ell\ell}$ for $pp \to R_{1,2} \to \ell^+\ell^-$ signal and background processes given by $\tilde{g} = 2$ (left), $\tilde{g} = 3$ (right) and $M_A = 0.5$ TeV (purple), 1 TeV (red), 1.5 TeV (green). $R_1(R_2)$ is the lighter (heavier) vector meson.





* Sannino, SD, et al. '10

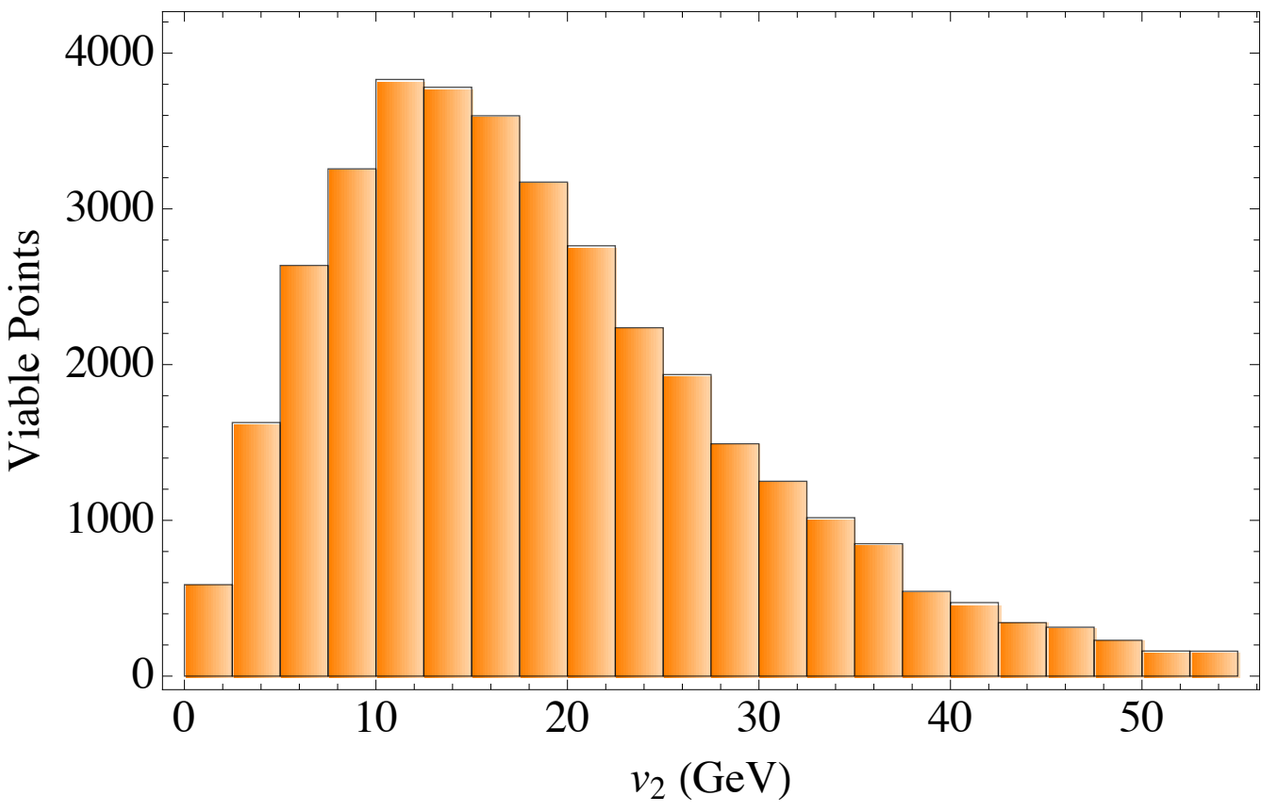
Vector Resonance Signals

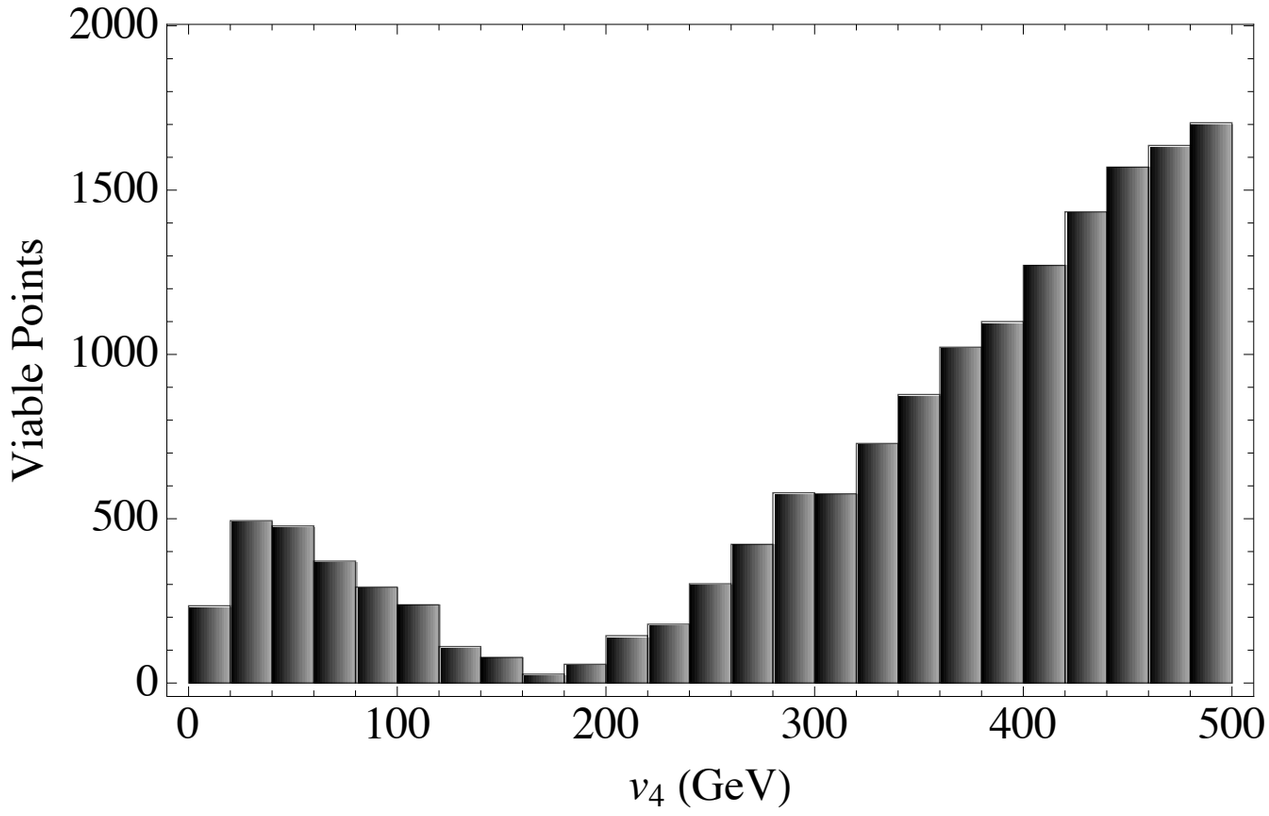
$pp \to R_{1,2} \to \ell^+\ell^-$. Signal and background cross sections for $\tilde{g} = 2, 3, 4$, and required luminosity for 3σ and 5σ signals.

$\tilde{g}$	M_A	$M_{R_{1,2}}$	σ_S (fb)	σ_B (fb)	$\mathscr{L}(\text{fb}^{-1})$ for 3σ	$\mathscr{L}(\text{fb}^{-1})$ for 5σ
2	500	$M_1 = 517$	194	3.43	0.012	0.038
2	500	$M_2 = 623$	118	1.34	0.019	0.056
2	1000	$M_1 = 1027$	4.57	$9.17 \cdot 10^{-2}$	0.53	1.8
2	1000	$M_2 = 1083$	16.4	$5.60 \cdot 10^{-2}$	0.13	0.39
2	1500	$M_1 = 1526$	0.133	$5.91 \cdot 10^{-3}$	26	67
2	1500	$M_2 = 1546$	0.776	$2.81 \cdot 10^{-3}$	2.7	8.2
3	500	$M_1 = 507$	93.5	3.71	0.037	0.090
3	500	$M_2 = 715$	0.447	0.649	39	81
3	1000	$M_1 = 1013$	1.32	$8.81 \cdot 10^{-2}$	2.7	7.4
3	1000	$M_2 = 1097$	2.94	$5.15 \cdot 10^{-2}$	0.79	2.5
3	1500	$M_1 = 1514$	$3.19 \cdot 10^{-3}$	$5.63 \cdot 10^{-3}$	6300	14000
3	1500	$M_2 = 1586$	0.120	$3.94 \cdot 10^{-3}$	29	68
4	500	$M_1 = 504$	34.6	3.85	0.12	0.34
4	500	$M_2 = 836$	0.0	0.649	-	-
4	1000	$M_1 = 1007$	0.234	$8.98 \cdot 10^{-2}$	30	85
4	1000	$M_2 = 1148$	0.0	$5.15 \cdot 10^{-2}$	-	-
4	1500	$M_1 = 1509$	$1.31 \cdot 10^{-3}$	$3.94 \cdot 10^{-3}$	25000	57000
4	1500	$M_2 = 1533$	$1.43 \cdot 10^{-2}$	$3.94 \cdot 10^{-3}$	435	1200

Composite Scalar VEVs

The distribution of the v_2 and v_4 vevs is given by:





Low Scale SUSY

Even by requiring the mass terms of the elementary fields H_u and H_d to be positive

$$\text{if } v_1 \neq 0 \Rightarrow \langle H \rangle = \frac{v_H s_\beta}{\sqrt{2}} \neq 0, \ \langle H' \rangle = \frac{v_H c_\beta}{\sqrt{2}} \neq 0,$$

and by that the SM fermions and the 4th family leptons acquire mass.

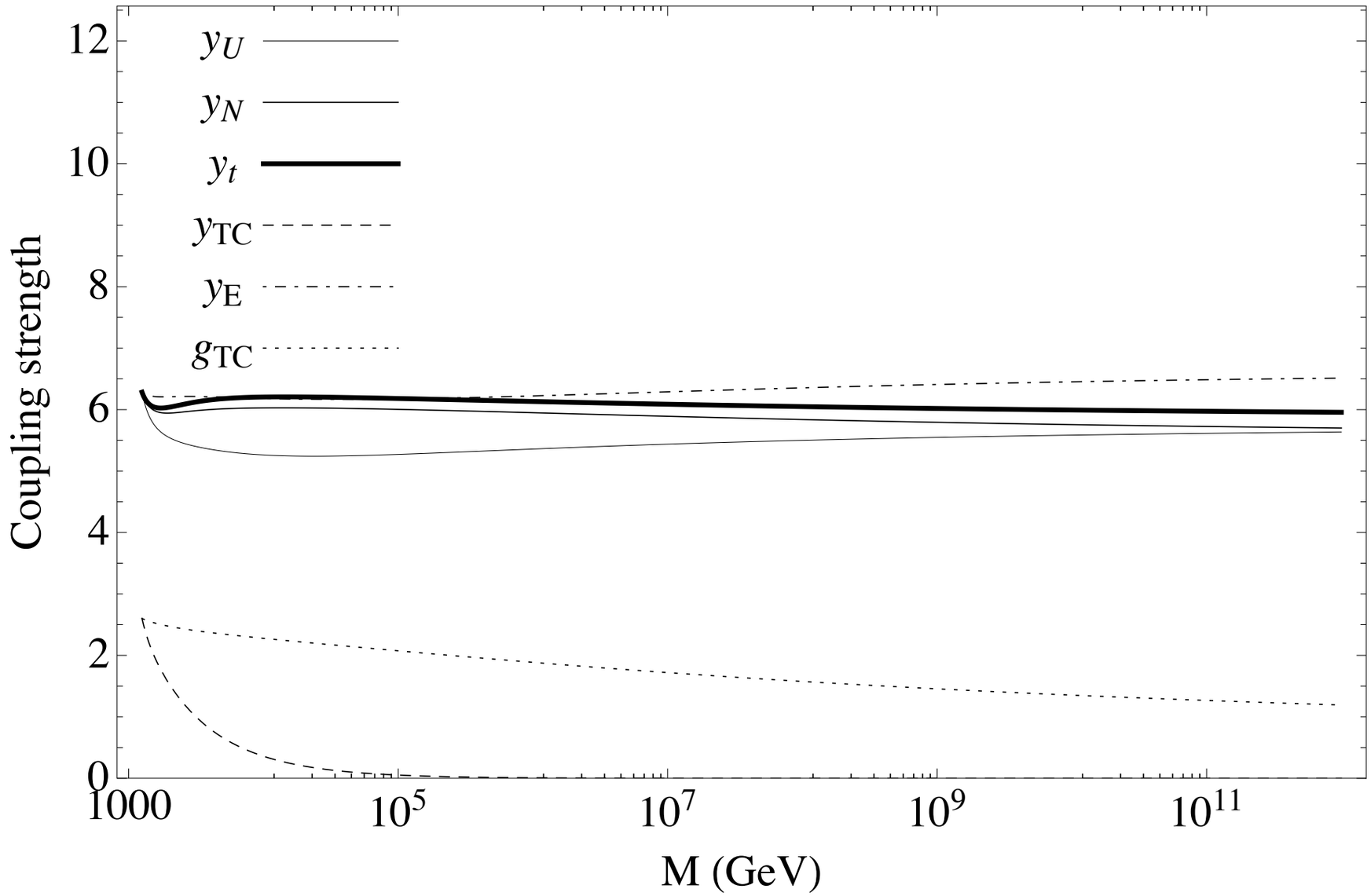
Since

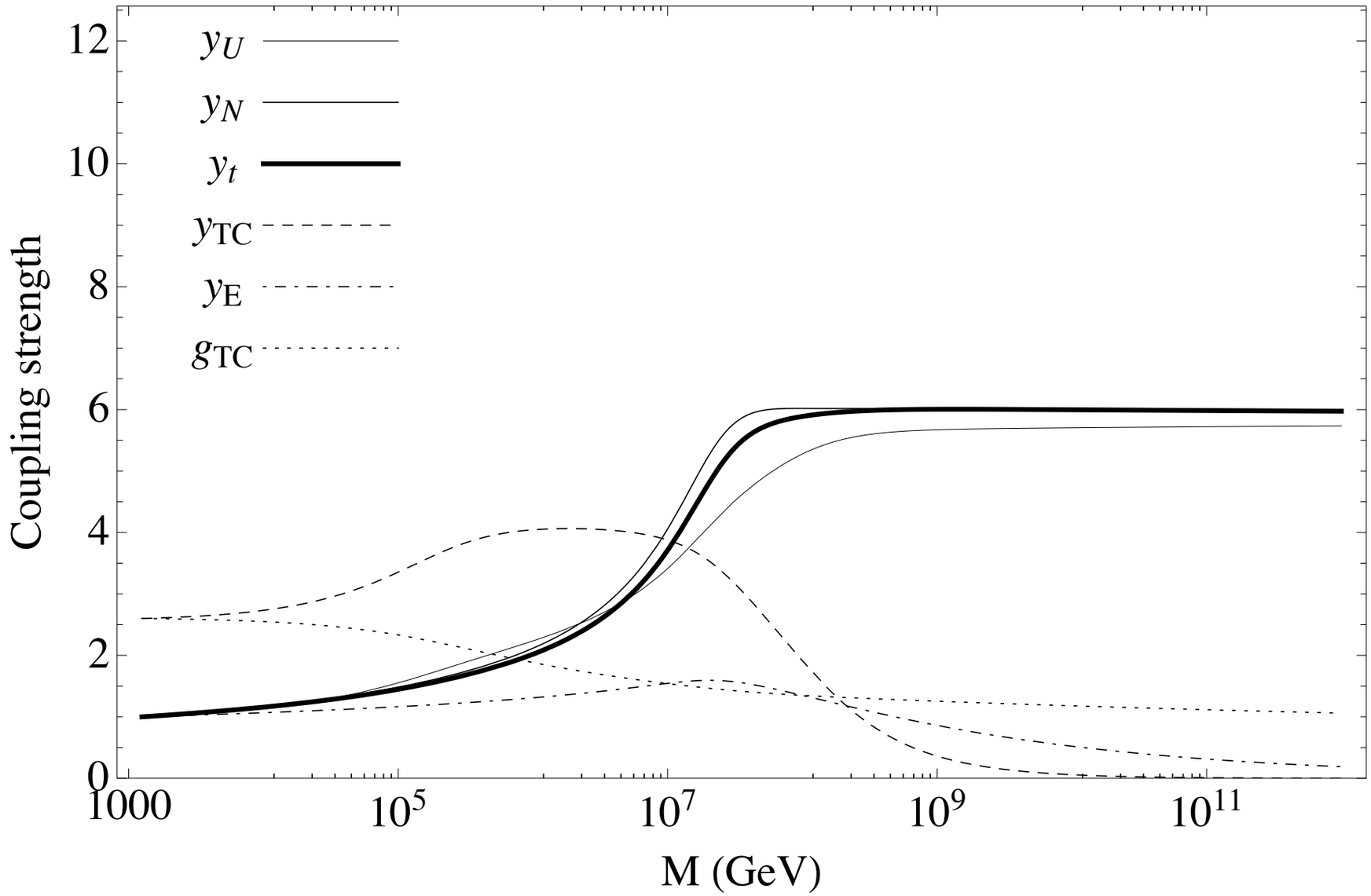
$$m_Z^2 = \frac{1}{4}\left(g_L^2 + g_Y^2\right)\left(v_1^2 + v_H^2\right), \ m_{W^\pm}^2 = \frac{1}{4} g_L^2 \left(v_1^2 + v_H^2\right).$$

the TC scale is lowered for increasing values of v_H. Viable EWSB by a composite field can be achieved for $m_{\text{SUSY}} \gtrsim \Lambda_{TC}$.

RGE @ 2 Loops and UV Fixed Point

The RGE show that the upper weak component Yukawa couplings have a UV fixed point independent of the initial conditions.



RGE @ 2 Loops and UV Fixed Point

The RGE show that the upper weak component Yukawa couplings have a UV fixed point independent of the initial conditions.