Minimal Super Conformal Technicolor

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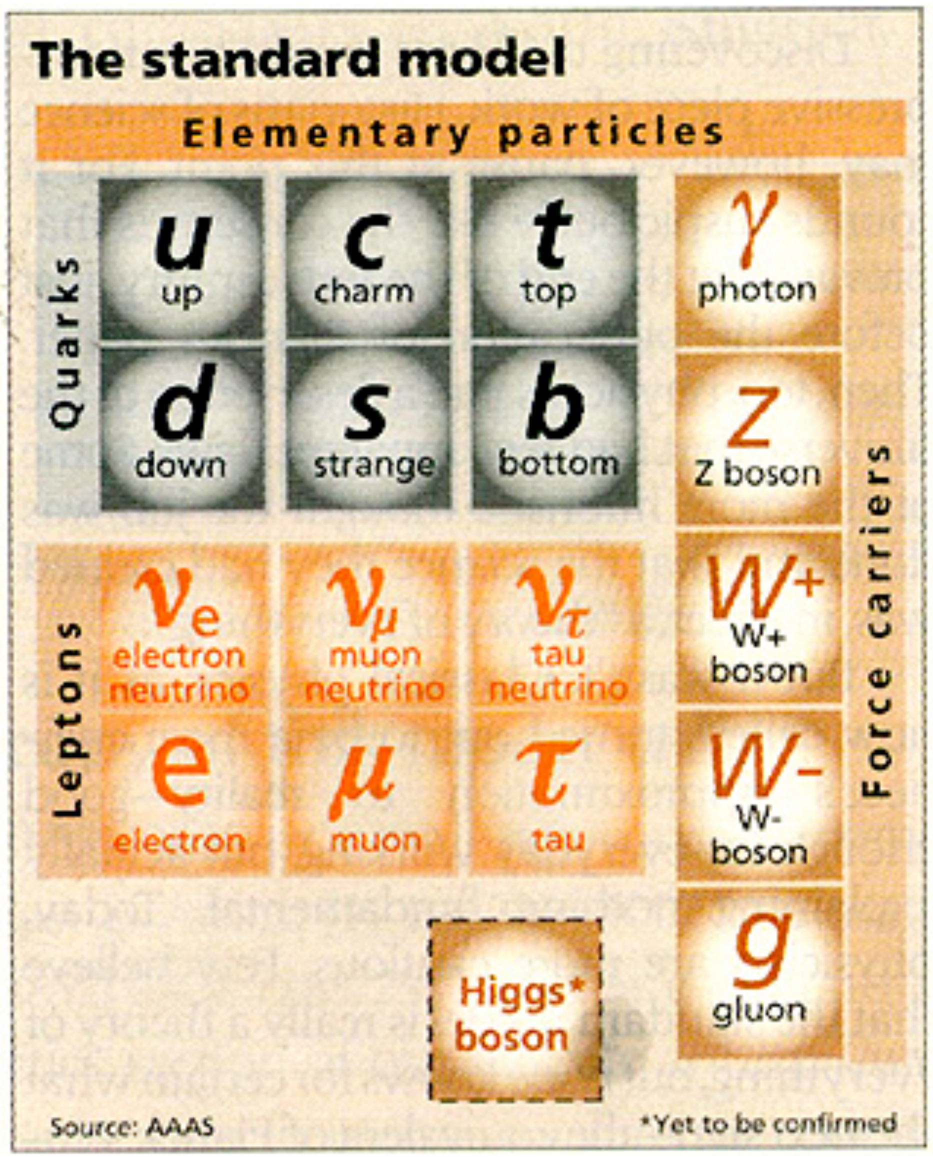
M. Antola, SD, F. Sannino, K. Tuominen: arXiv:1001.2040

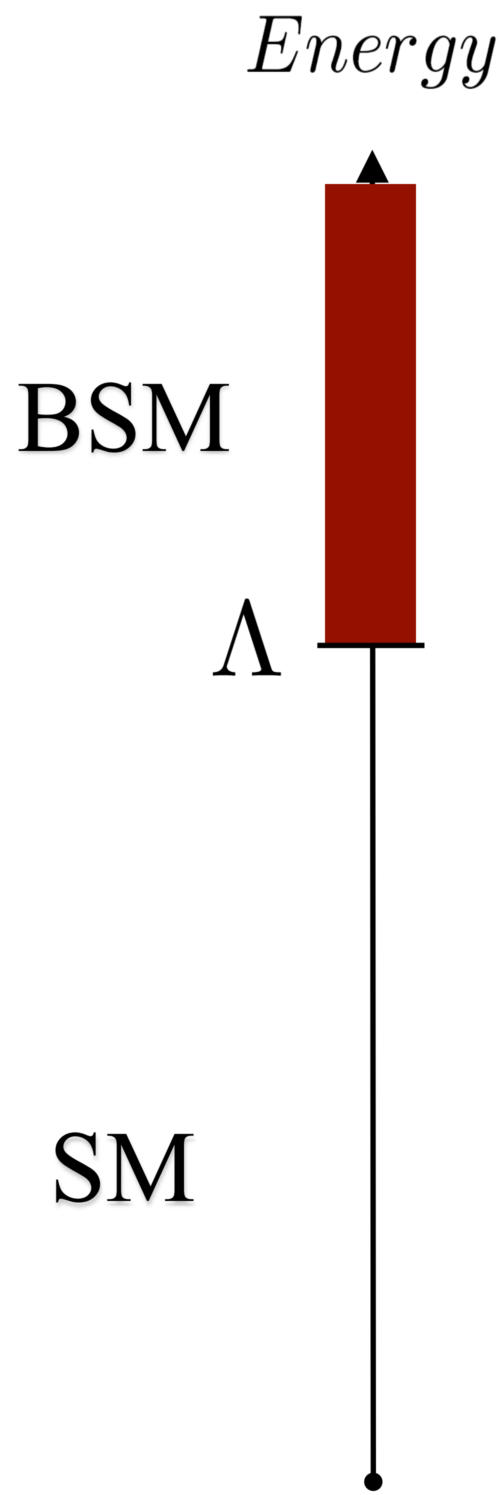
CP^3 - Origins

Particle Physics & Origin of Mass

Planck 2010, CERN

Low Energy Theory

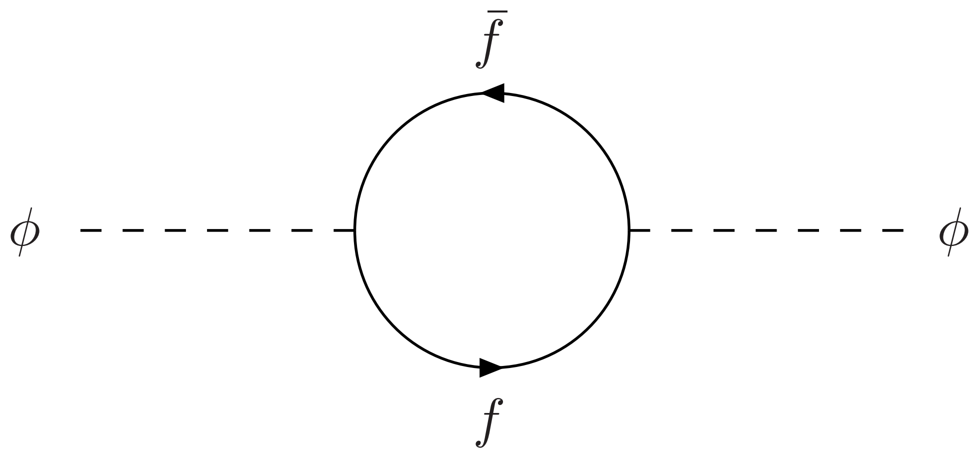




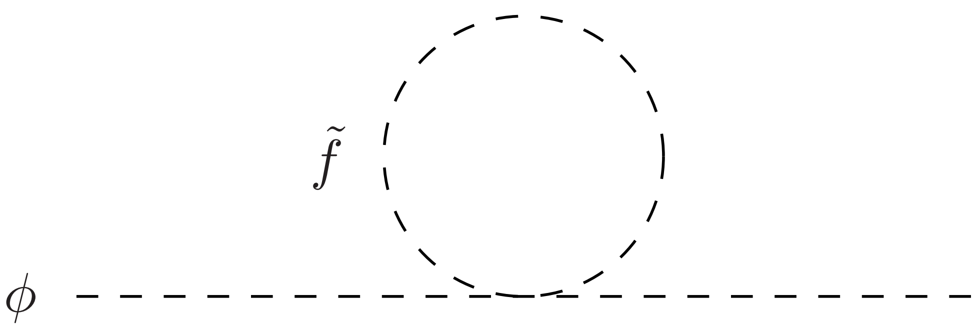
Standard Model:

- Minimal viable model
- Fine tuning

Supersymmetry



$$= -2N(f)\lambda_f^2 \int \frac{d^4k}{(2\pi)^4} \frac{k^2 + m_f^2}{\left(k^2 - m_f^2\right)^2} + \dots$$



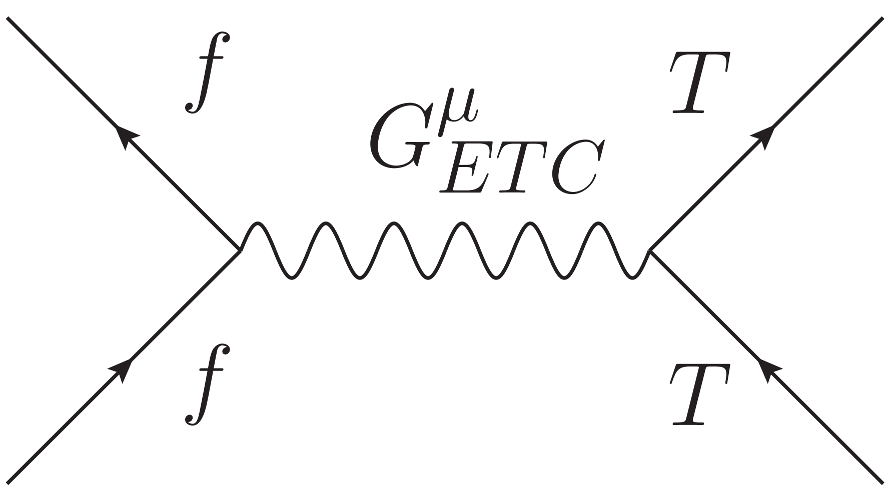
$$= -\tilde{\lambda}_f N(\tilde{f}) \int \frac{d^4k}{(2\pi)^4} \frac{2}{k^2 - m_{\tilde{f}}^2} + \dots$$

$N(\tilde{f}) = N(f),\ \lambda_f^2 = -\tilde{\lambda}_f \quad \Rightarrow$ No quadratic term in Λ_{UV}

Technicolor

$SU(N)_{TC}$ strong interaction responsible for techni-fermion EWSB condensate $< \bar{T}_L T_R >= \Lambda^3_{TC}$.

SM fermion masses generated by $SU(N_{ETC})$ interaction which breaks down to $SU(N)_{TC}$:



$$\longrightarrow \quad \Lambda^3_{ETC} \frac{g^2_{ETC}}{M^2} \bar{f} f$$

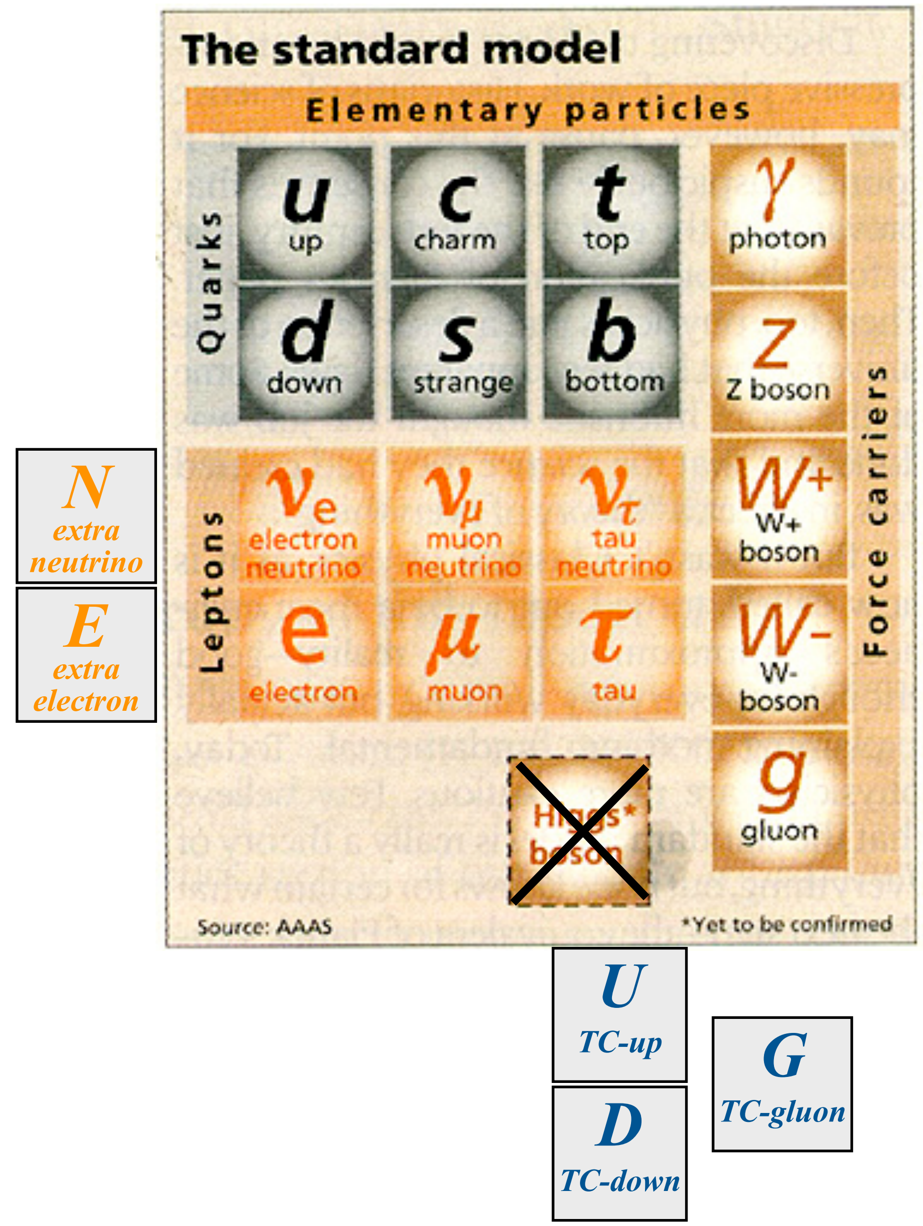
Minimal Walking Technicolor

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

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

Heavy leptons to cancel Witten anomaly

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



$U(1)_Y$

$SU(2)_L$

$SU(3)_C$

$SU(2)_{TC}$

Sannino, Tuominen ‘04; Dietrich, Sannino, Tuominen ‘05

Anomalies Cancellation

Gauge anomalies cancel for hypercharge assignment

$$Y(Q_L) = \frac{y}{2}, \qquad Y(U_R, D_R) = \left(\frac{y+1}{2}, \frac{y-1}{2}\right) ,$$

$$Y(L_L) = -3\frac{y}{2}, \qquad Y(N_R, E_R) = \left(\frac{-3y+1}{2}, \frac{-3y-1}{2}\right)$$

Fermion masses through strong ETC interaction, or, for $y = 1$, ...

Belyaev, Foadi, Frandsen, Jarvinen, Sannino, Pukhov '08

From MWT to N=4 SUSY

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

MSCT - States

	Superfield	$\mathrm{SU}(2)_{\mathrm{TC}}$	$\mathrm{SU}(3)_{\mathrm{c}}$	$\mathrm{SU}(2)_{\mathrm{L}}$	$\mathrm{U}(1)_{\mathrm{Y}}$
$\mathcal{N}=4$	Φ_L	Adj	1	$\square$	1/2
	Φ_3	Adj	1	1	-1
	V	Adj	1	1	0
4^{th} Lepton Family	Λ_L	1	1	$\square$	-3/2
	N	1	1	1	1
	E	1	1	1	2
	H	1	1	$\square$	1/2
	H'	1	1	$\square$	-1/2

Antola, SD, Sannino, Tuominen ‘10

MSCT - Superpotential

- Spectrum: techni- and extra lepton-superfields + MSSM superfields
- Conformality broken by gauge and Yukawa couplings

$$
\begin{aligned}
P_{TC} &= -\frac{g_{TC}}{3\sqrt{2}}\epsilon_{ijk}\epsilon^{abc}\Phi_i^a\Phi_j^b\Phi_k^c + y_U\epsilon_{ij3}\Phi_i^a H_j \Phi_3^a \\
&\quad + y_N\epsilon_{ij3}\Lambda_i H_j N + y_E\epsilon_{ij3}\Lambda_i H_j' E.
\end{aligned}
$$

We also add soft SUSY breaking terms.

Motivations

- $< \tilde{H} > \neq 0$ can be induced dynamically through Yukawa couplings
- Interpolates between Higgs and dynamical EWSB
- Natural, complete ETC theory
- Possibility to study landscape of theories

Simmons '89; Antola, Sannino, Tuominen '09

Perturbative MSCT

To generate masses for D_L^a and SM fermions:

$$< \tilde{D}_L^a >= v_{TC}^a, < \tilde{H} >= v_H s_\beta, < \tilde{H}' >= v_H c_\beta$$

$$SU(2)_{TC} \times SU(2)_L \times U(1)_Y \rightarrow U(1)_{EM} \times U(1)_{TC}$$

Gauge boson squared masses:

$$m_Z^2 = \frac{1}{4}\left(g_L^2 + g_Y^2\right)\left(v_{TC}^2 + v_H^2\right),$$

$$m_{W^\pm}^2 = \frac{1}{4} g_L^2 \left(v_{TC}^2 + v_H^2\right), m_{G_{TC}^{\pm 1}}^2 = g_{TC}^2 v_{TC}^2$$

Photon γ and TC-photon G_{TC}^0 stay massless.

Scalars

From the previous results it follows, at tree level:

$$\alpha S = \alpha T = 0$$

Scalar masses (tree level): CP-even: $m^2_{h^0_0} = 0$,

$$m^2_{h^0_{1,2}} = \frac{1}{2}\left(m^2_{A^0_1} + m^2_Z \mp \sqrt{\left(m^2_{A^0_1} - m^2_Z\right)^2 + 4m^2_{A^0_1} m^2_B s^2_{2\beta}}\right);$$

$$\mathrm{CP-odd}: m^2_{A^0_0} = 0,\ m^2_{A^0_1} = 2\frac{b}{s_{2\beta}};\ m^2_B = \frac{g^2_L + g^2_Y}{4} v^2_H;$$

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Two massless scalars!

1-Loop Masses

Effective 1-loop potential:

$$\Delta V_1 = \frac{1}{64\pi^2} \sum_j (-1)^{2j} (2j+1) \, \mathrm{Tr} \left[\mathcal{M}_j^4 \left(\log \frac{\mathcal{M}_j^2}{\mu_r^2} - \frac{3}{2} \right) \right]$$

- GB massless at 1-loop (as expected)
- h_0^0 and A_0^0 massive at 1-loop

Pheno Constraints

- $m_{\chi^\pm} > 94\ \mathrm{GeV}, m_{\chi^0} > 46\ \mathrm{GeV},$
  $\sqrt{v_{TC}^2 + v_H^2} = 246\ \mathrm{GeV}$
- minimum eigenvalue leading principal submatrix of $|\mathcal{M}_\chi|^2 \geq$ lightest m_χ^2

$\Rightarrow$

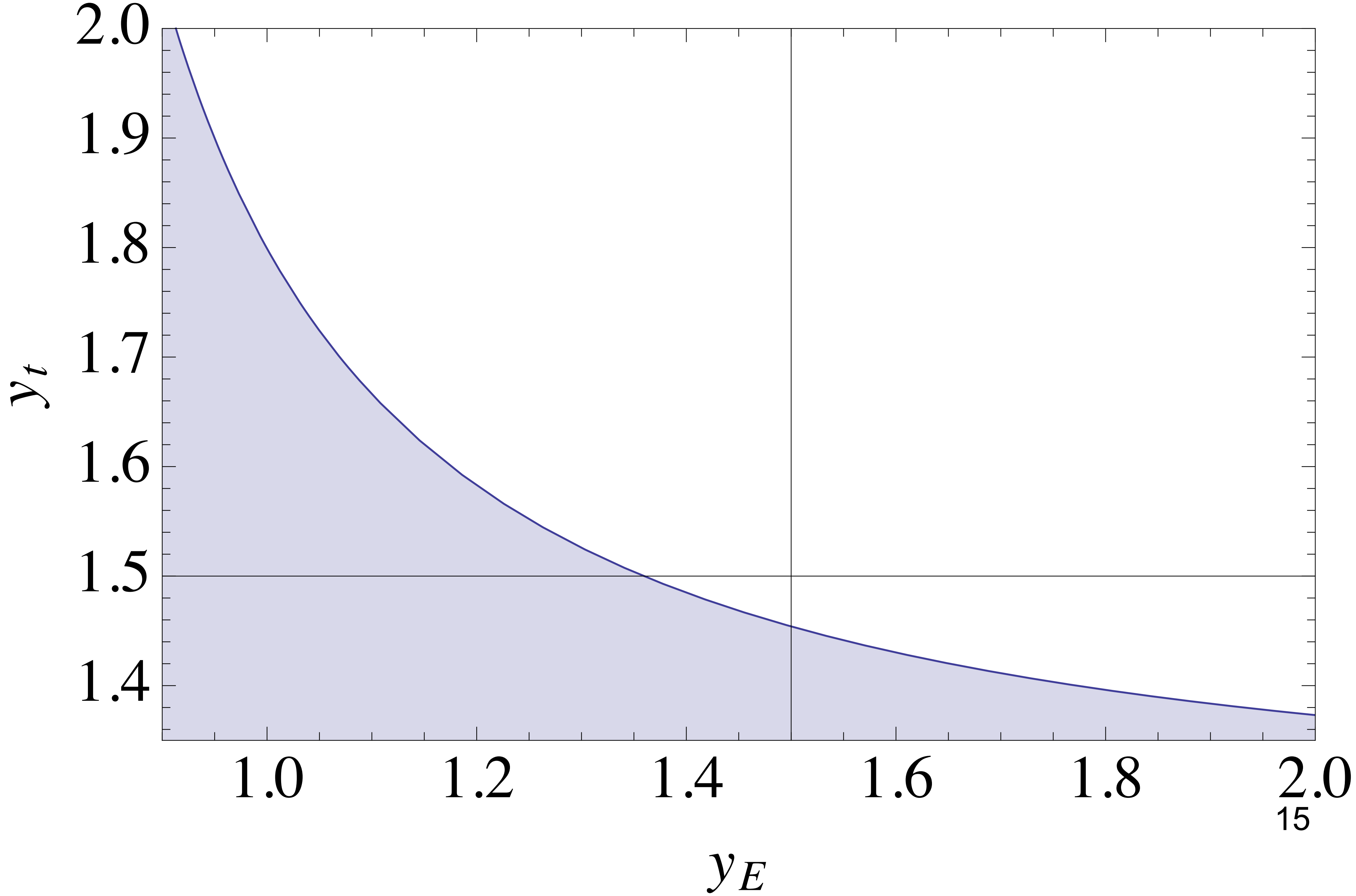
- $M_{\tilde{W}} > 63\ \mathrm{GeV}, 41\ \mathrm{GeV} > M_{\tilde{B}} > 13\ \mathrm{GeV}$
- $v_{TC} > 156\ \mathrm{GeV}, v_H < 190\ \mathrm{GeV}$

moreover $m_E = m_t / \tan\beta > 94$ GeV $(\mathcal{Q}(E) = 2e)$

Review of Particle Physics '09

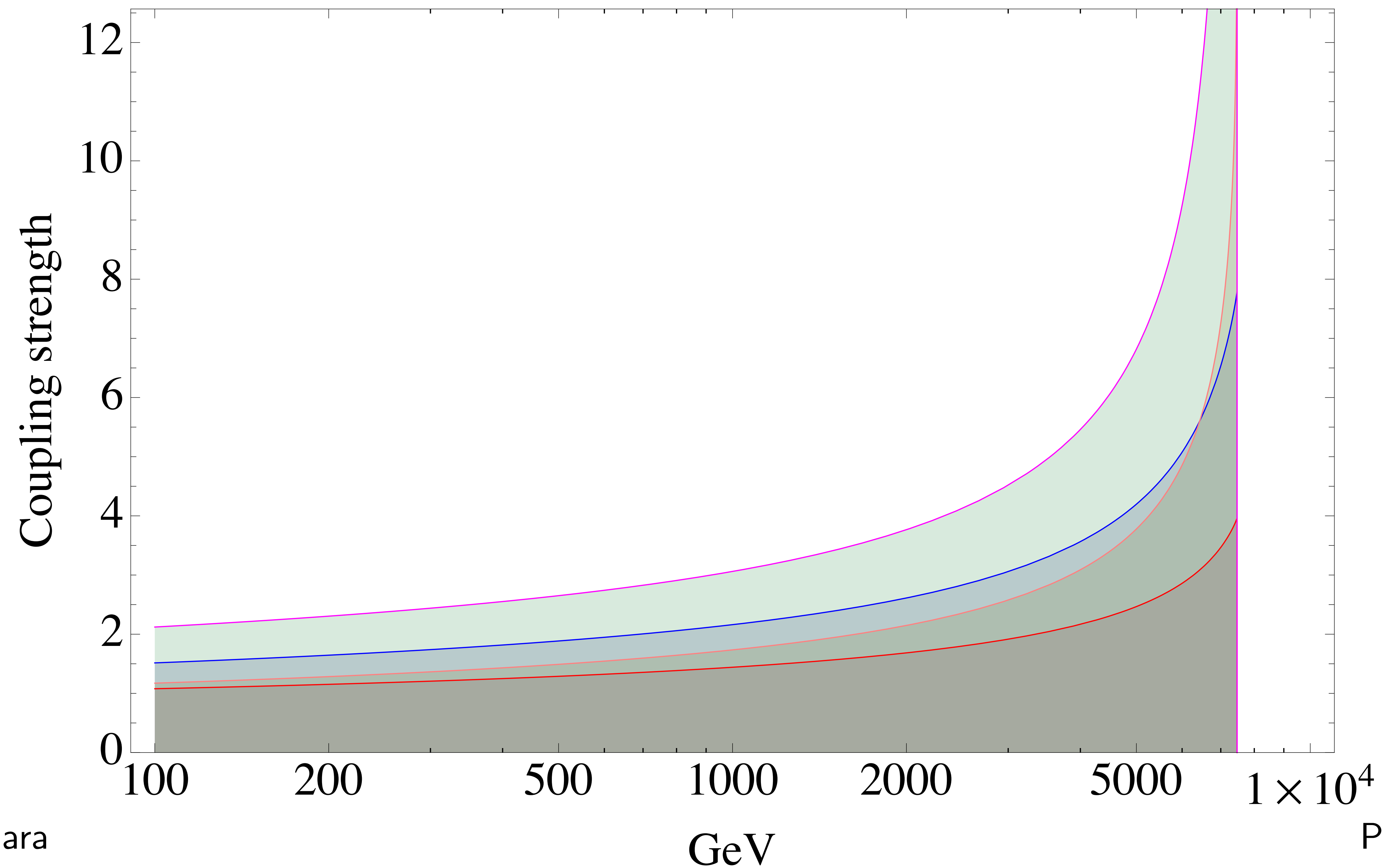
Yukawa Couplings

From previous results and $m_t = 173$ GeV (shaded area excluded):



Perturbativity @ LHC

For $y_t = 1.5, \ y_E = 2.1$ MSCT perturbative up to 7 TeV: (lower to higher at 100 GeV) $y_E, \ y_t, \ y_U, \ y_N$



Spectrum @ LHC

A random scan of the parameter space ($y_t = 1.5,\ y_E = 2.1$) maximizing the lightest m_χ produces

- fermions: $m_{\chi_0^0} = 33\ \mathrm{GeV},\ m_{\chi_0^\pm} = 98\ \mathrm{GeV}$
- scalars (1-loop): $m_{h_0^0} = 36\ \mathrm{GeV},\ m_{A_0^0} = 32\ \mathrm{GeV}$

In the not-excluded parameter space: $m_{\chi_0^0} \leq 41\ \mathrm{GeV}$

Viable spectrum for $y_t = 2.3,\ y_E = 2.4\ (\Lambda = 400\ \mathrm{Gev!})$

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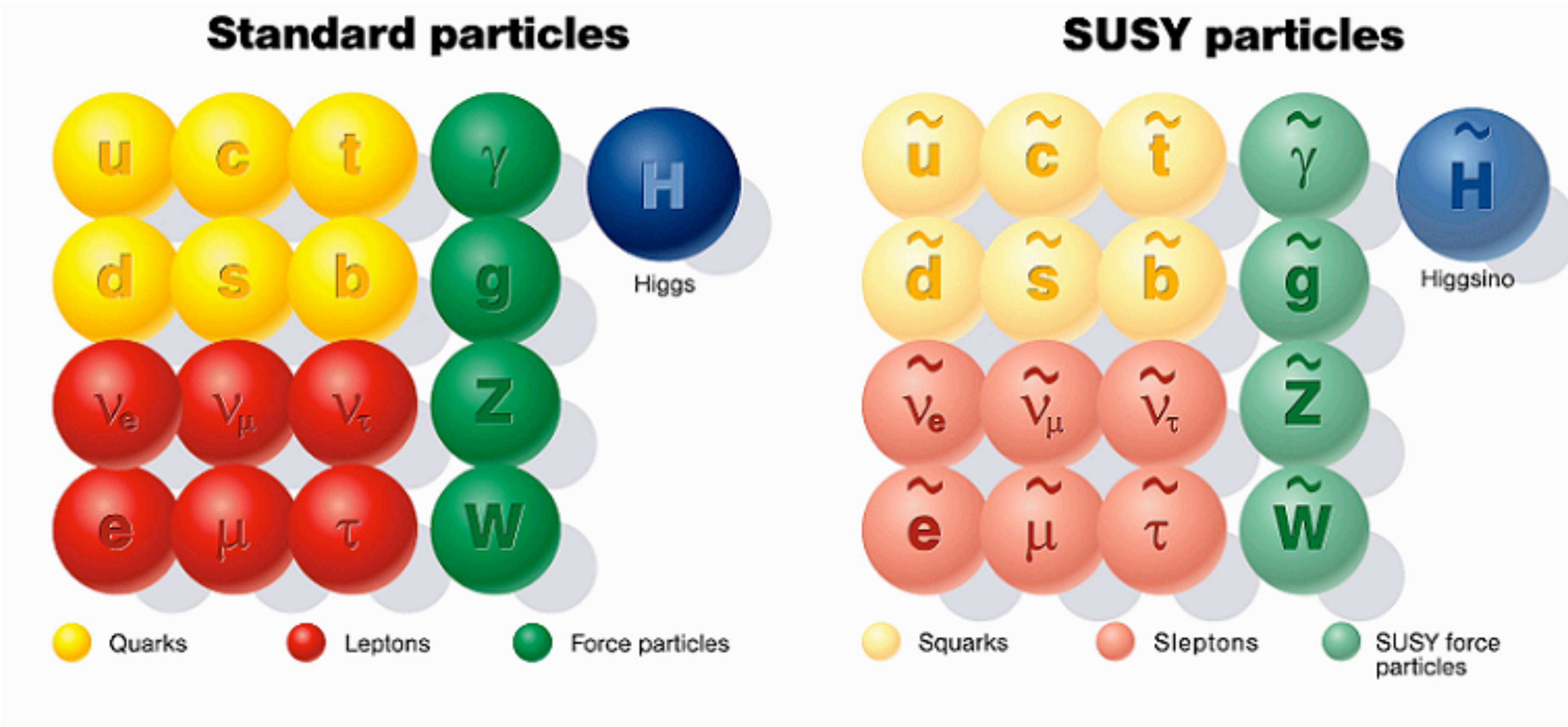
MSCT requires strong interaction to be possibly viable at LHC

Summary

- MWT extended by $\mathcal{N} = 4$ SUSY sector to give mass to fermions in a natural way
- Conformality broken by gauge and Yukawa couplings
- EWSB can be both Higgs and dynamical: experiment determines which is favored
- MSCT requires strong interaction to be possibly viable at LHC

Backup Slides

MSSM



No s-particles observed ⇒ SUSY softly broken Model:
$\mathcal{L}_{MSSM} = \mathcal{L}_{SUSY} + \mathcal{L}_{soft}$

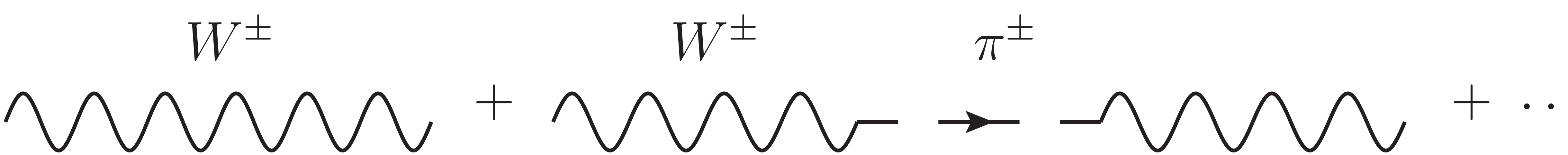
Dynamical EWSB

For a strong interaction binding a $\bar{q}q$ pair

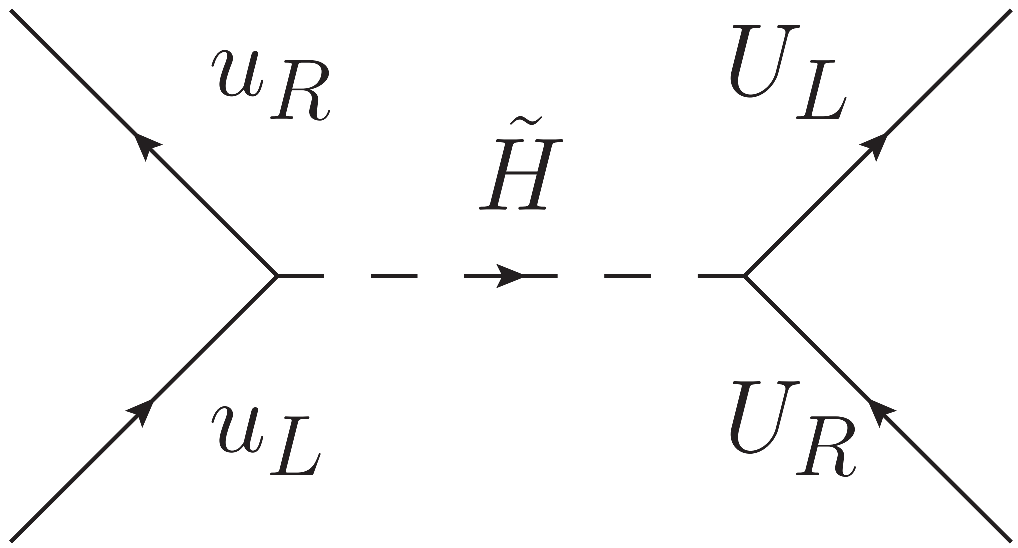
$$\bar{q}\gamma_\mu\gamma_5\frac{\sigma^a}{2}q \to f_\pi\partial_\mu\pi^a$$

Through the coupling to $\bar{q}q$ the $W^\pm$ and Z acquire masses

$$\frac{g^{\mu\nu}}{p^2} \to \frac{g^{\mu\nu}}{p^2 - (gf_\pi/2)^2} =$$



Fermion Masses & EWSB



$$\rightarrow \quad \frac{\Lambda^3}{|\mu|^2} y_U y_u \bar{u}_R u_L$$

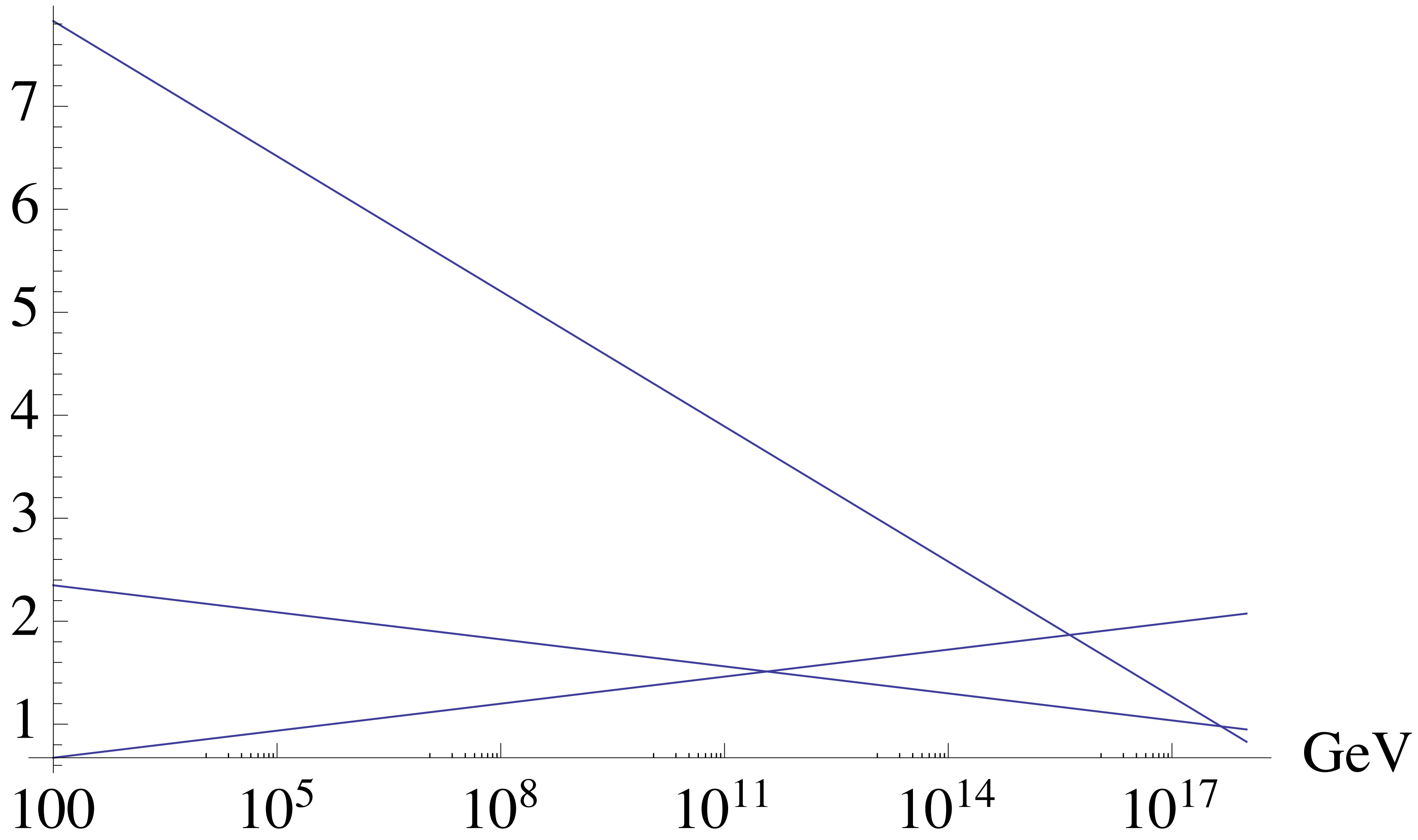
TC-Neutralinos

$$\bar{m}_{\chi^0_{TC}} = \{M_{\tilde{D}}, \frac{1}{2}\left(\sqrt{M^2_{\tilde{D}} + 4g^2_{TC}v^2_{TC}} \mp M_{\tilde{D}}\right)\}$$

TC-gaugino (right-handed neutrino) D^3_R can be very light (no Z coupling)

RG Equations

Gauge couplings $g_s, \; g_L, \; g_Y$ do not unify:



Viable Spectrum

Large Yukawa couplings to Higgs bosons needed to obtain viable spectrum: $y_t = 2.3,\ y_E = 2.4$.

Random scan of the parameter space maximizing the lightest m_χ produces

- fermions: $m_{\chi^0_0} = 47\ \mathrm{GeV},\ m_{\chi^\pm_0} = 96\ \mathrm{GeV}$
- scalars (1-loop): $m_{h^0_0} = 95\,\mathrm{GeV},\ m_{A^0_0} = 37\,\mathrm{GeV}$

Couplings diverge already at 400 GeV.