Minimal Superconformal Technicolor and the Origin of Mass

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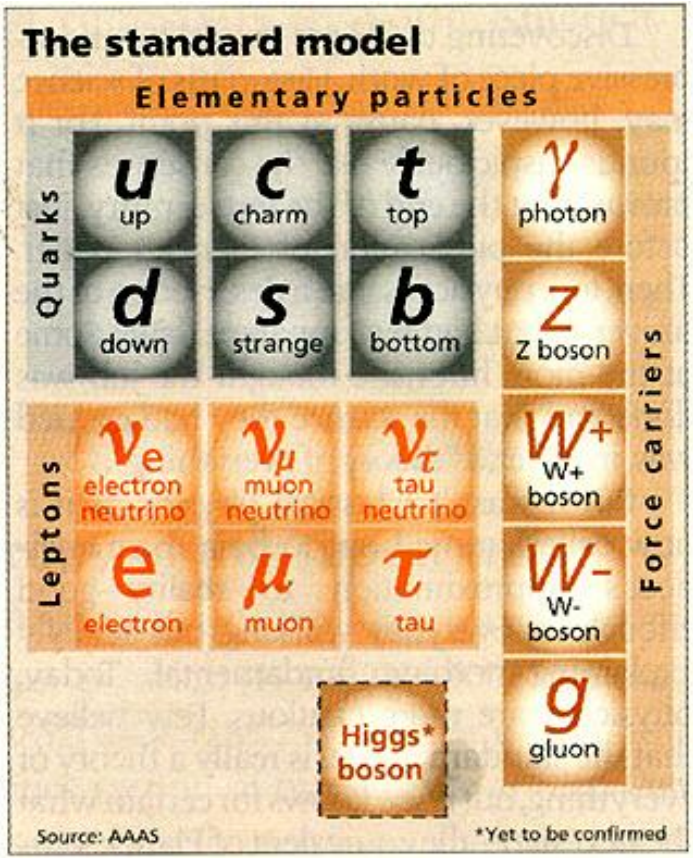
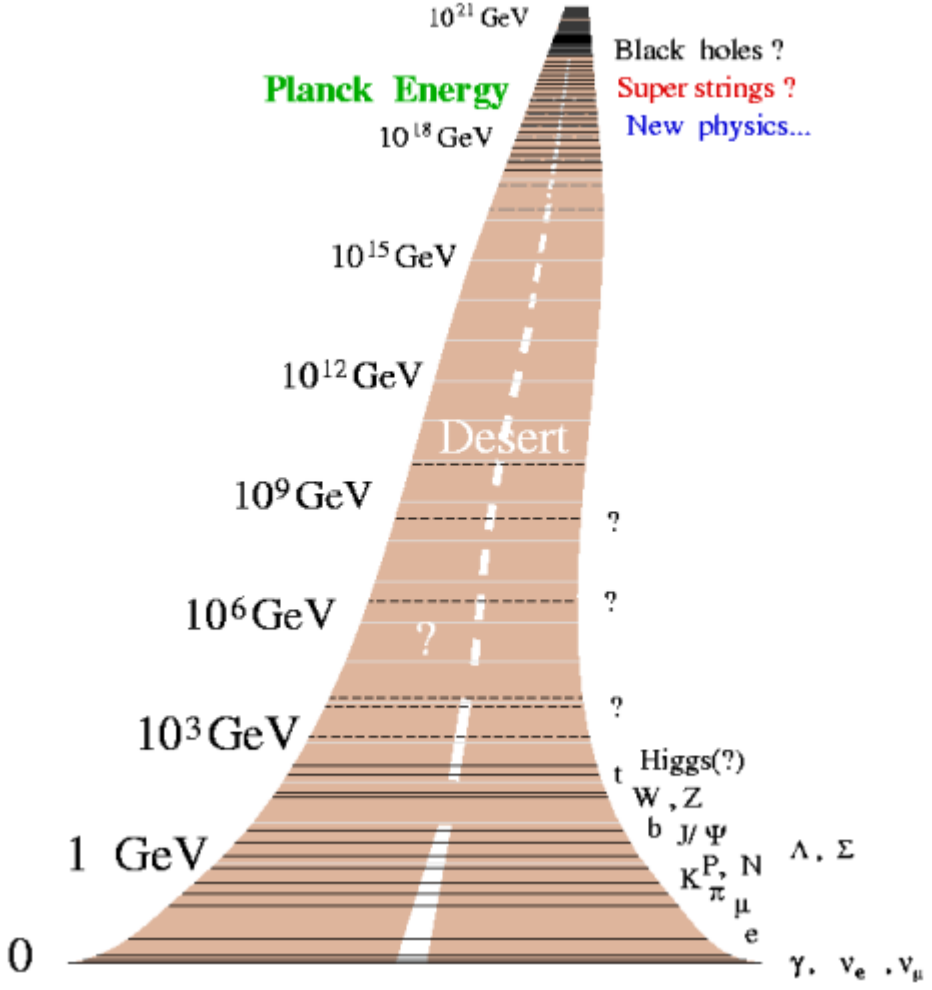
The Standard Model



- The Higgs gives mass to known elementary particles and is THE window to new physics (triviality/stability, unitarity)

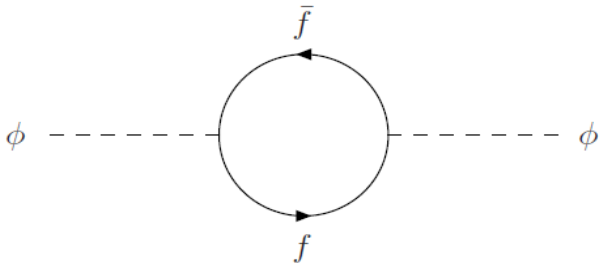
Hierarchies, Naturalness & Fine-tuning

- Are these hierarchies generated by some mechanism? e.g. Λ_{QCD}
- Natural parameters are insensitive to short range physics; fine-tuned parameters are not O(1). e.g. m_b and m_e vs. m_H
- "Gauge hierarchy problem"

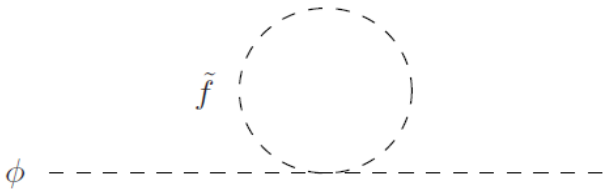


Supersymmetry

- In SUSY theories a small Higgs mass is natural



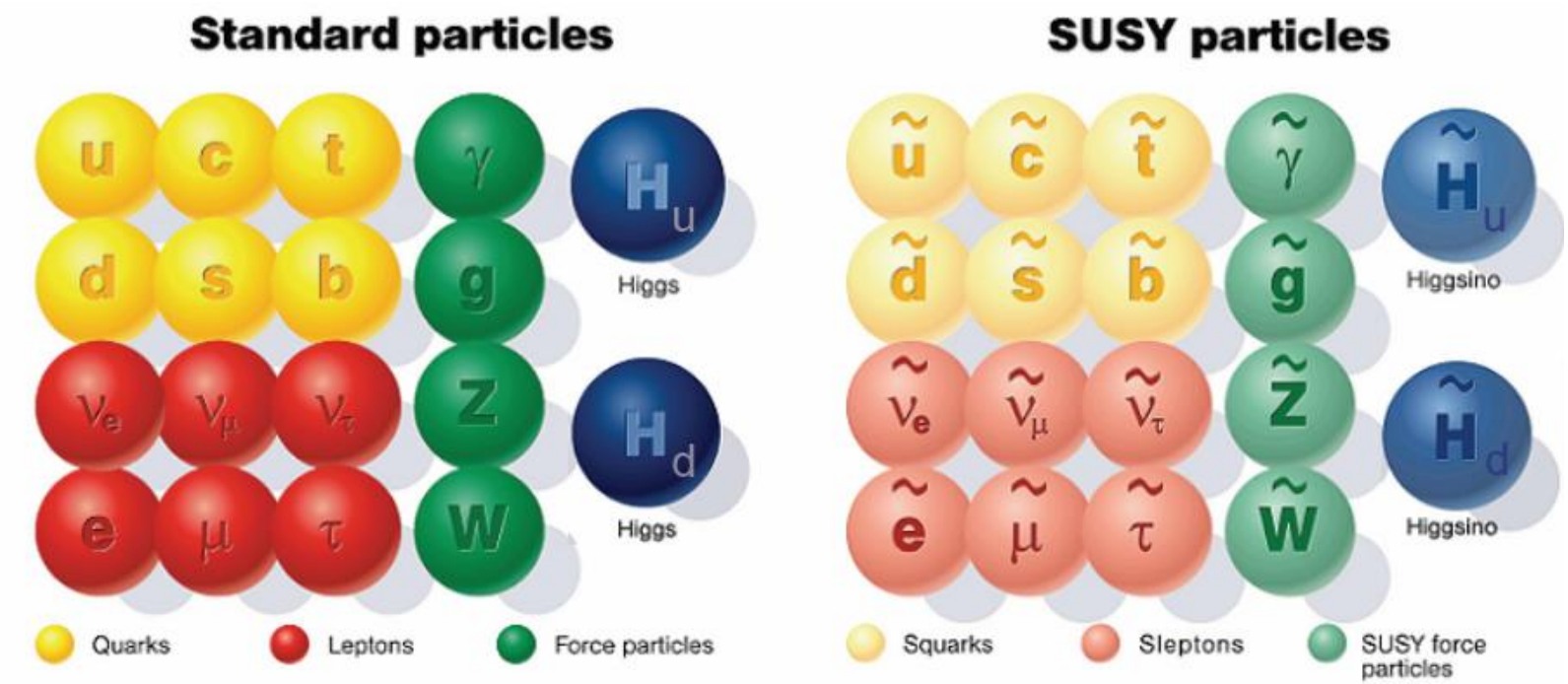
$$= -2N(f)\lambda_f^2 \int \frac{d^4k}{(2\pi)^4} \frac{k^2 + m_f^2}{\left(k^2 - m_f^2\right)^2} + \dots$$



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

$N(\tilde{f}) = N(f),\ \lambda_f^2 = -\tilde{\lambda}_f \quad \Rightarrow \quad$ No quadratic mass correction

Minimal Supersymmetric Standard Model



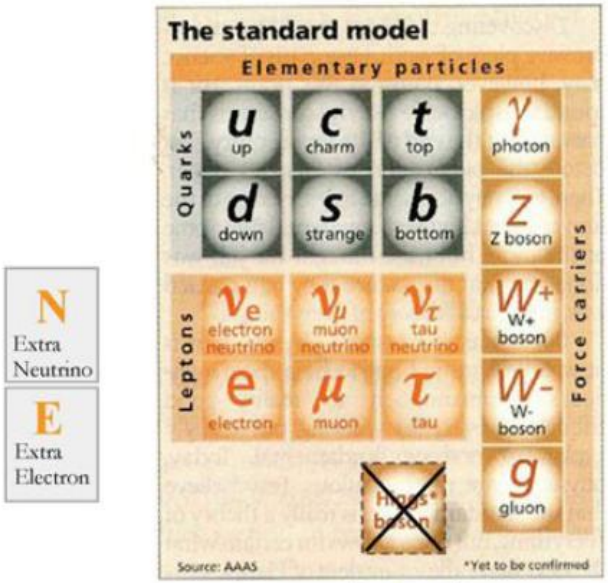
$$\mathcal{L}_{MSSM} = \mathcal{L}_{SUSY} + \mathcal{L}_{soft}$$

- Fine-tuned μ

Minimal Walking Technicolor

(F. Sannino, K. Tuominen: hep-ph/0405209)

- Could the Higgs be composite, like in the Ginzburg-Landau model of superconductivity or the sigma model of chiral symmetry breaking?

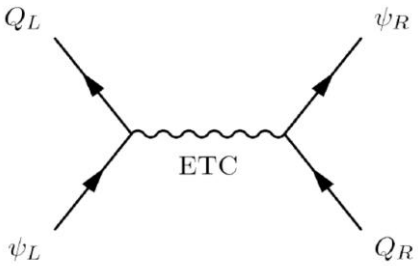


$$\mathcal{L}_H = -\frac{1}{4}\mathcal{F}^a_{\mu\nu}\mathcal{F}^{a\mu\nu} + i\bar{Q}_L \not{D} Q_L + i\bar{U}_R \not{D} U_R + i\bar{D}_R \not{D} D_R$$

where $Q^a_L = \begin{pmatrix} U^a \\ D^a \end{pmatrix}$, U^a_R, D^a_R, $a = 1, 2, 3 \in \mathrm{TC}$

- Solves the gauge hierarchy problem
- EWSB: $\langle \bar{U}_R U_L + \bar{D}_R D_L \rangle \neq 0$

Extended Technicolor



$$G_{ETC} \xrightarrow{\Lambda_{ETC}} SU(2)_{TC} \otimes SU(3)_c \otimes SU(2)_L \otimes U(1)_Y$$

- A full ETC model would explain all flavor physics…
- Need walking:

$$\text{fcnc} \propto \frac{1}{\Lambda_{ETC}^2} \qquad m_q \propto \frac{\langle \bar{Q}Q \rangle_{ETC}}{\Lambda_{ETC}^2} \qquad \langle \bar{Q}Q \rangle_{ETC} \overset{\text{QCD-like}}{\sim} \log \frac{\Lambda_{ETC}}{\Lambda_{TC}} \langle \bar{Q}Q \rangle_{TC}$$

$$\langle \bar{Q}Q \rangle_{TC} \sim v_w^3 \qquad S_{naive} = N_D \frac{d(R_{TC})}{6\pi} \qquad \overset{\text{walking}}{\sim} \left(\frac{\Lambda_{ETC}}{\Lambda_{TC}} \right)^{\gamma_\star} \langle \bar{Q}Q \rangle_{TC}$$

- Minimal Working Technicolor: small S=1/6π with walking behavior!

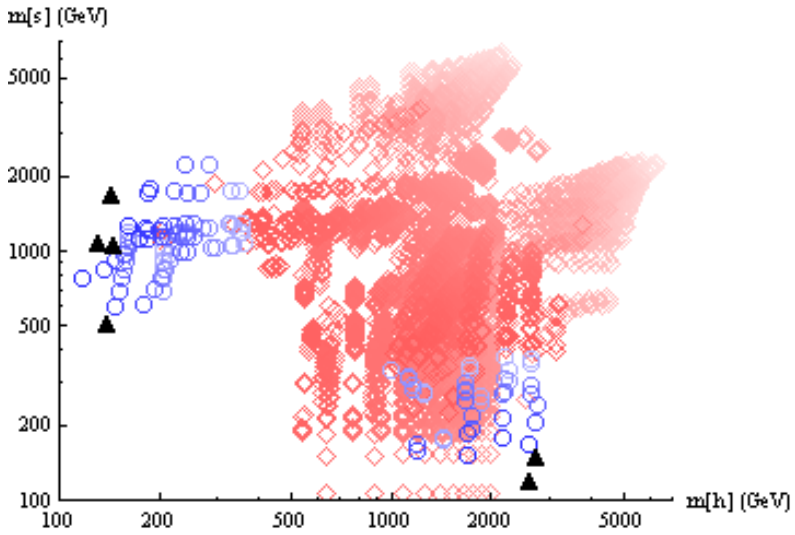
Bosonic Technicolor Models

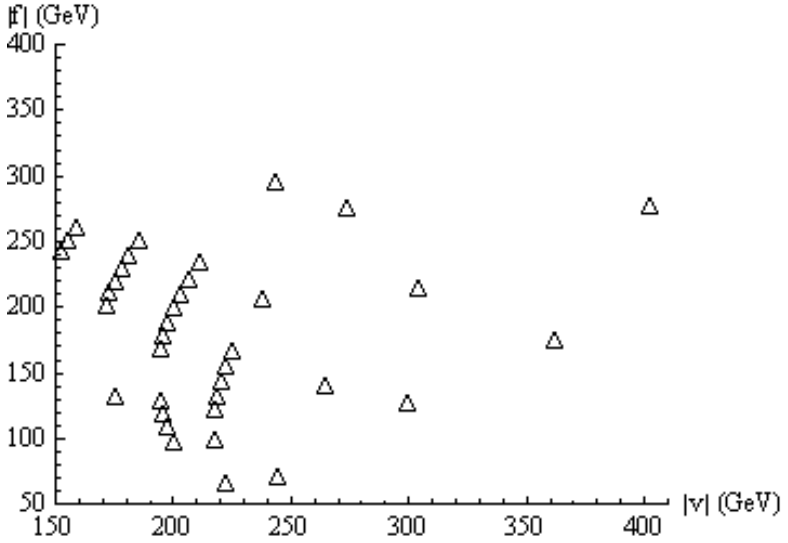
- Technicolorwith fundamental scalars (Pioneers E. H. Simmons, A. Kagan and S. Samuel, C. D. Carone and H. Georgi)
- Offers a calculable approach with fermion masses

$$\mathcal{L}_{UTC} = \mathcal{L}_{SM}\Big|_{Higgs=0} + \mathcal{L}_{TC} + \mathcal{L}_{Higgs} + \mathcal{L}_{Yukawa}$$

- Yukawa term tilts potential of scalar when technifermions condense
  - Schematically: $yh\bar{Q}Q \longrightarrow yh\Lambda^3$
  - Fermion masses even with large positive Higgs mass!

- We found this type of model is still viable (M. Antola, M. Heikinheimo, F. Sannino, K. Tuominen. arXiv:0910.3681v1)
- Contribution from two scalar fields to S and T minimized when one is SM-like, the other heavy
- Both scalars can have a large vev (~v_{weak}) because of kinetic mixing





Origin of Mass

- We want a natural theory to describe origin of all mass, hopefully also dark matter
- The origin of mass of fermions and gauge bosons is probably intertwined. Can we unify various approches and let nature choose?

Supersymmetric Technicolor!

(Dine, Fischler and Srednicki, 81; Dimopoulos and Raby, 81)

Minimal superpartners

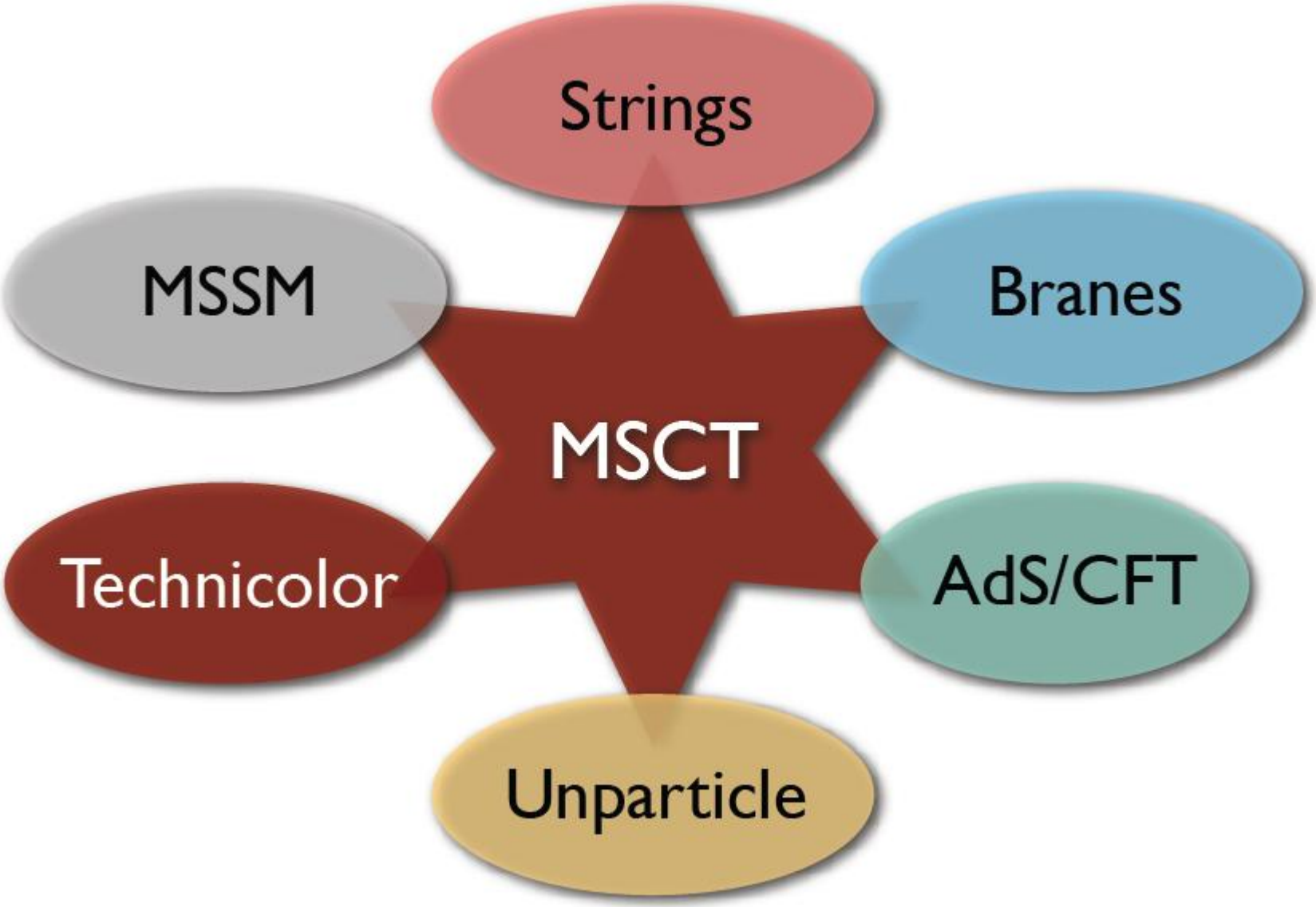
MWT	Minimal S-partners	N=1 Multiplets	N=4
G_μ	G_μ $\bar{D}_R$	V	V Φ_3 Φ_1 Φ_2
$\bar{D}_R$			
$\bar{U}_R$	$\bar{U}_R$ $\tilde{\bar{U}}_R$	Φ_3	
U_L	U_L $\tilde{U}_L$	Φ_1	
D_L	D_L $\tilde{D}_L$	Φ_2	

- The chiral symmetry of MWT is the R-symmetry $SU(4)_R$
- $SU(2)_L$ and $SU(2)_R$ are on unequal footing

	Superfield	$SU(2)_{TC}$	$SU(3)_c$	$SU(2)_L$	$U(1)_Y$
$\mathcal{N}=4$	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

$$P_{TC} = -\frac{y_{TC}}{\sqrt{2}}\epsilon^{abc}\Phi_L^a\cdot\Phi_L^b\Phi_3^c + y_U\Phi_L^a\cdot H\Phi_3^a + y_R\Phi_3^a\Phi_3^a E + y_N\Lambda_L\cdot HN + y_E\Lambda_L\cdot H'E$$

- The N=4 limit is infrared attractive $y_{TC} = g_{TC}$


Strings
MSSM
Branes
MSCT
Technicolor
AdS/CFT
Unparticle

The Playground

- Perturbative technicolor coupling at the EW scale → see next talk by Di Chiara
  - Technisquarks must gain a vev since the spectrum is unseen to date
- Strong technicolor coupling at the EW scale → unparticles
- Strong coupling and techniscalars decoupled → bosonic TC
  - Can interpolate between different explanations of the EWSB scale: chiral symmetry breaking in the technicolor sector or the mechanisms of usual MSSM (maybe radiative EWSB)

Summary

- Introduced MSCT: a N=1 SUSY theory with approximate N=4 supersymmetry
- MSCT extends MWT with a natural theory of flavor (ETC), but the price is soft SUSY breaking
- MSCT looks very different at the LHC depending on the gauge coupling and SUSY breaking scale

Thank you!