Technicolor and Beyond

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CP3 - Origins

Particle Physics & Origin of Mass

23 April 2010 @ Boost - Oxford

FS: 0911.0931


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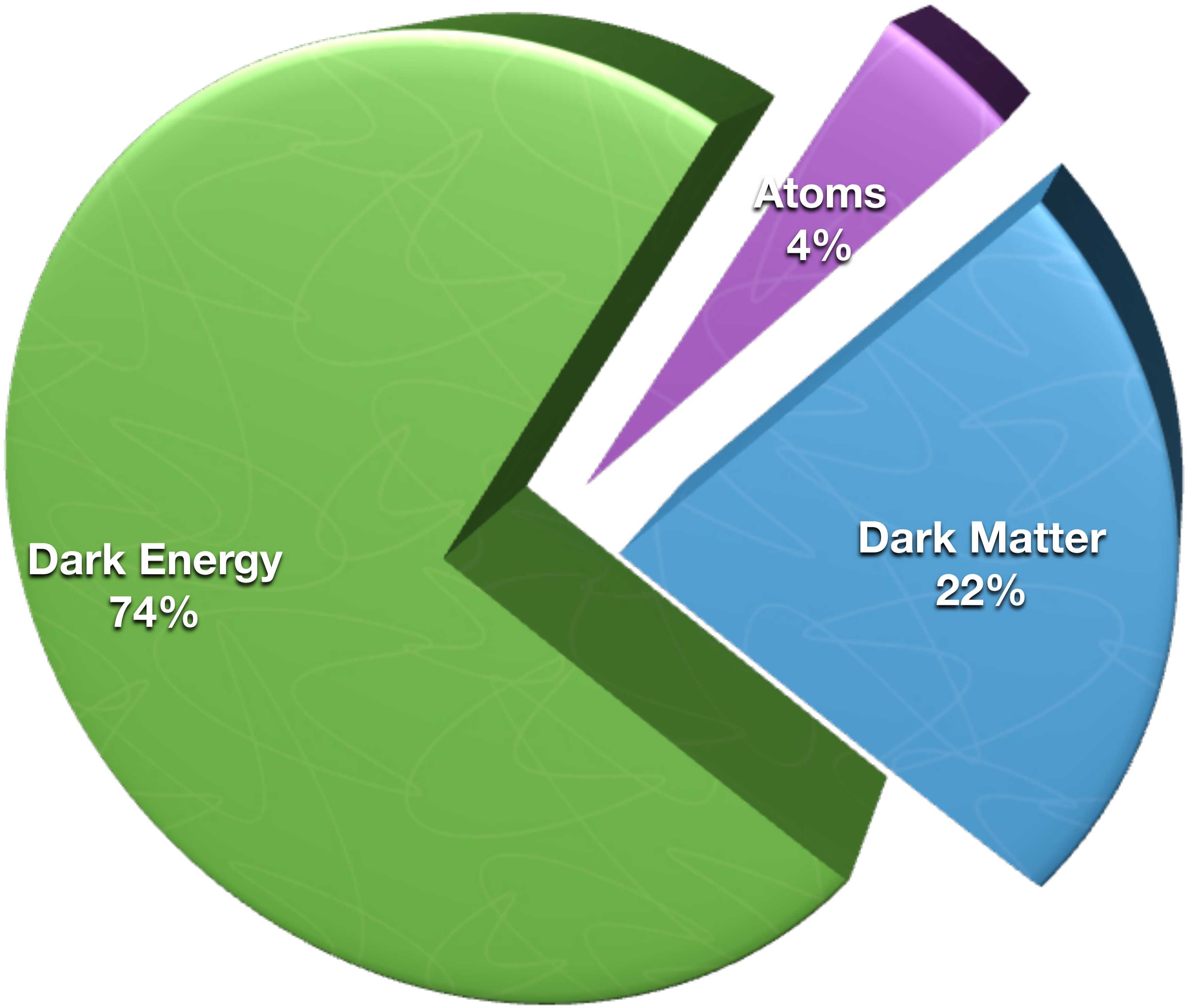
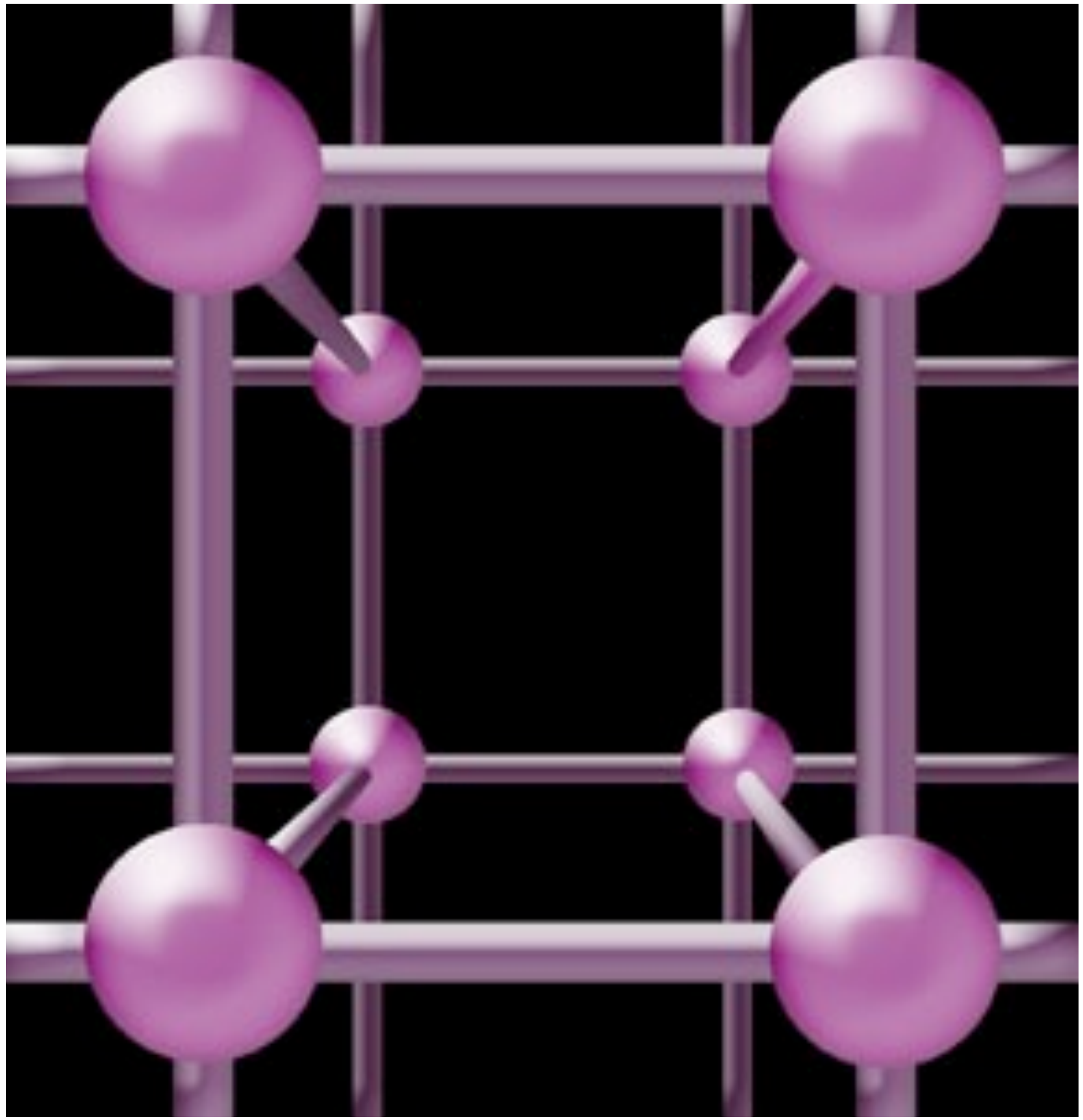

Atoms
4%
Dark Matter
22%
Dark Energy
74%

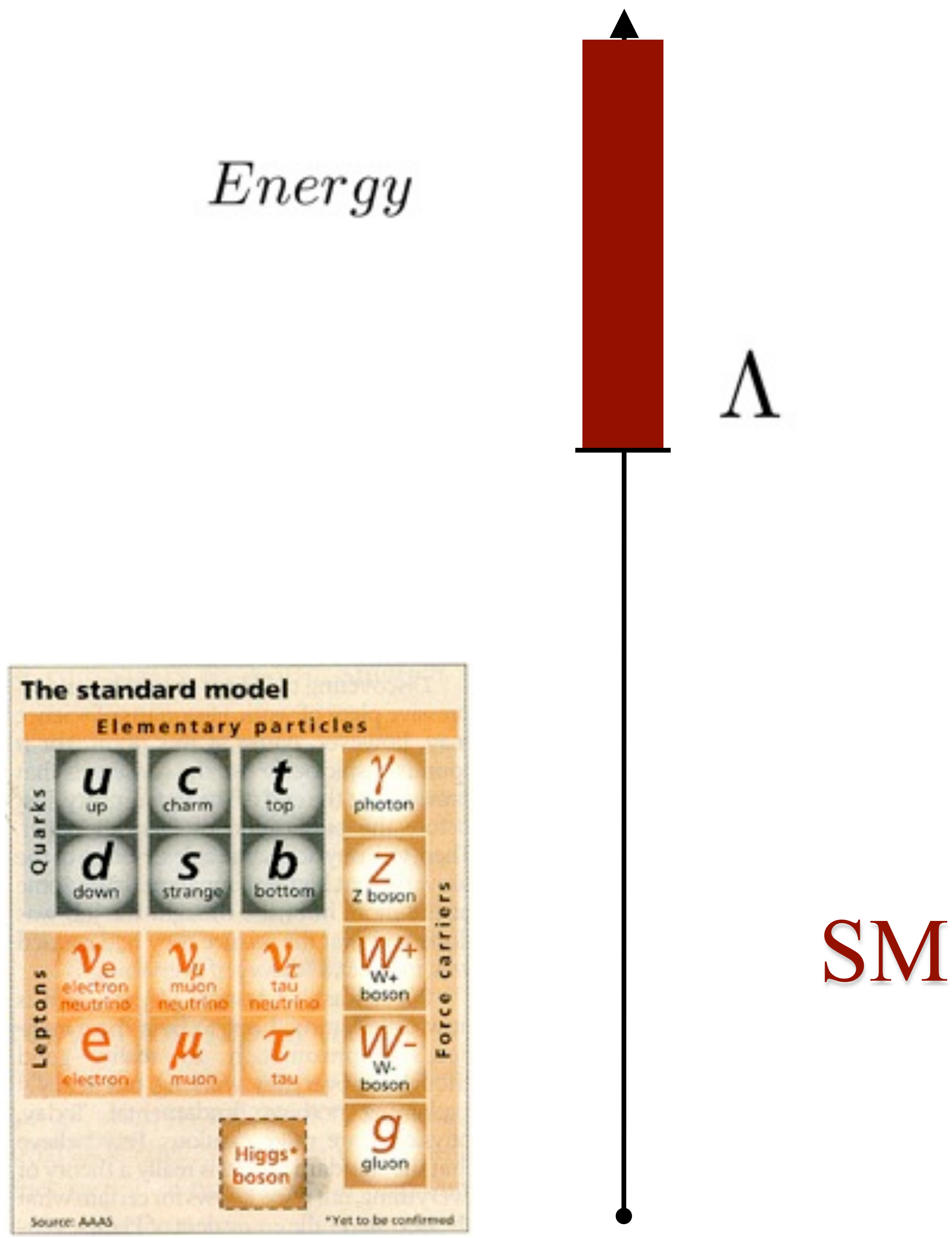
Natural Dark Matter

Electroweak Baryogenesis

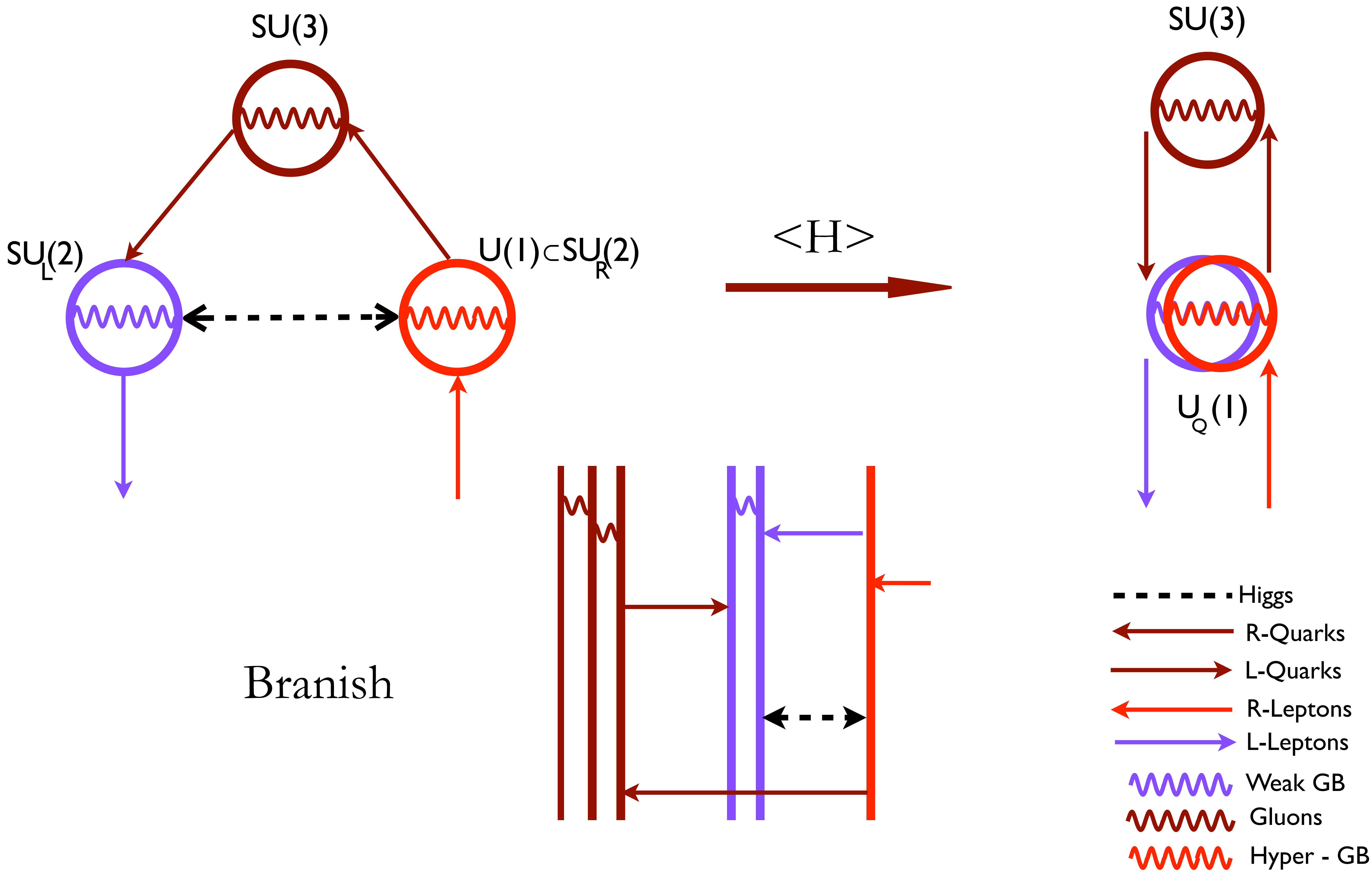


We can probe the dynamics of our extensions

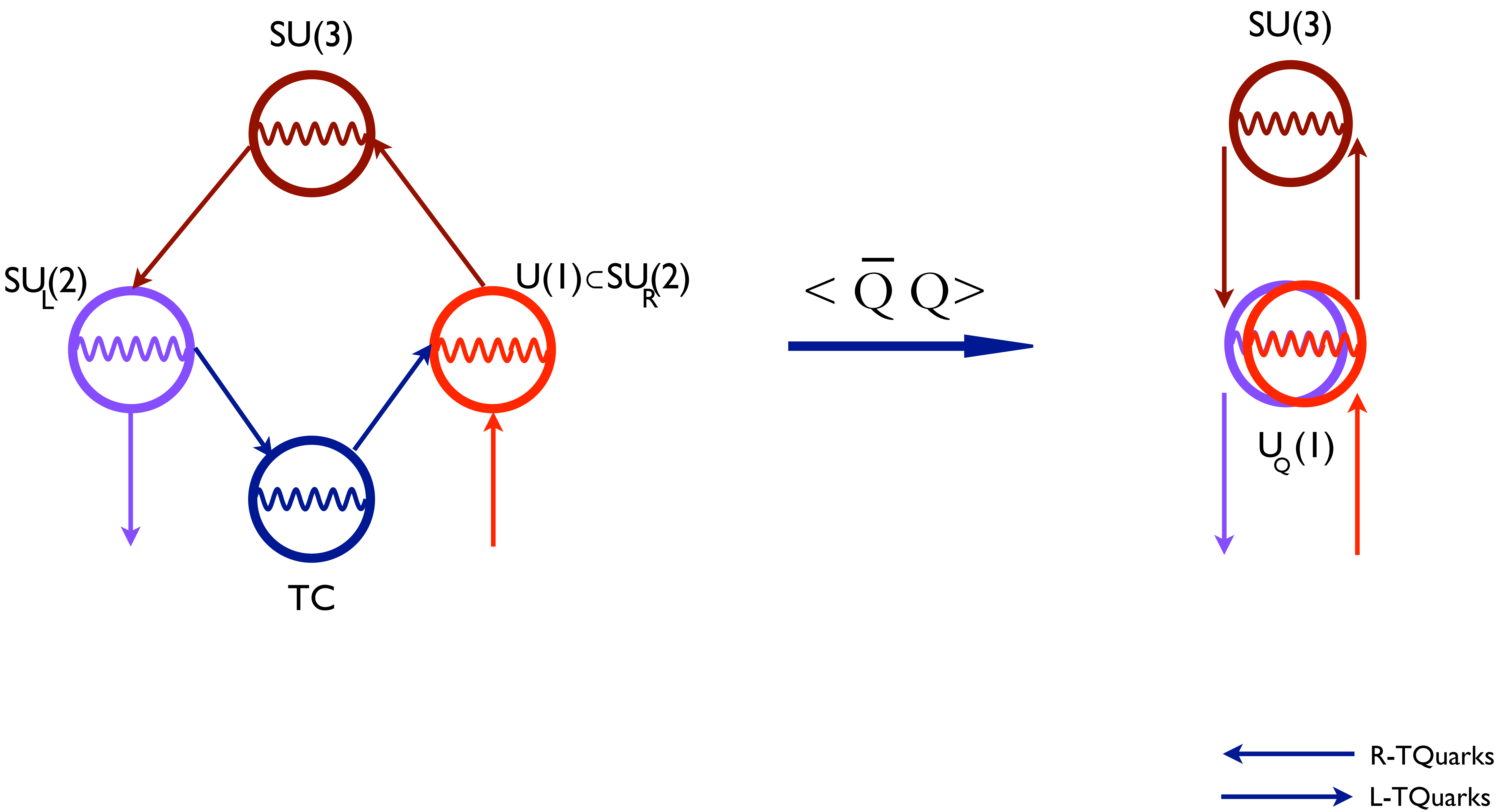
Low Energy Theory



SM - cartoon


SU(3)
$SU_L(2)$
$U(1) \subset SU_R(2)$
<H>
SU(3)
$U_Q(1)$
Branish
Higgs
R-Quarks
L-Quarks
R-Leptons
L-Leptons
Weak GB
Gluons
Hyper - GB

Technicolor - cartoon



QCD-like TC

New Strong Interactions at ~ 250 GeV
[Weinberg, Susskind]

Natural to use QCD-like dynamics.

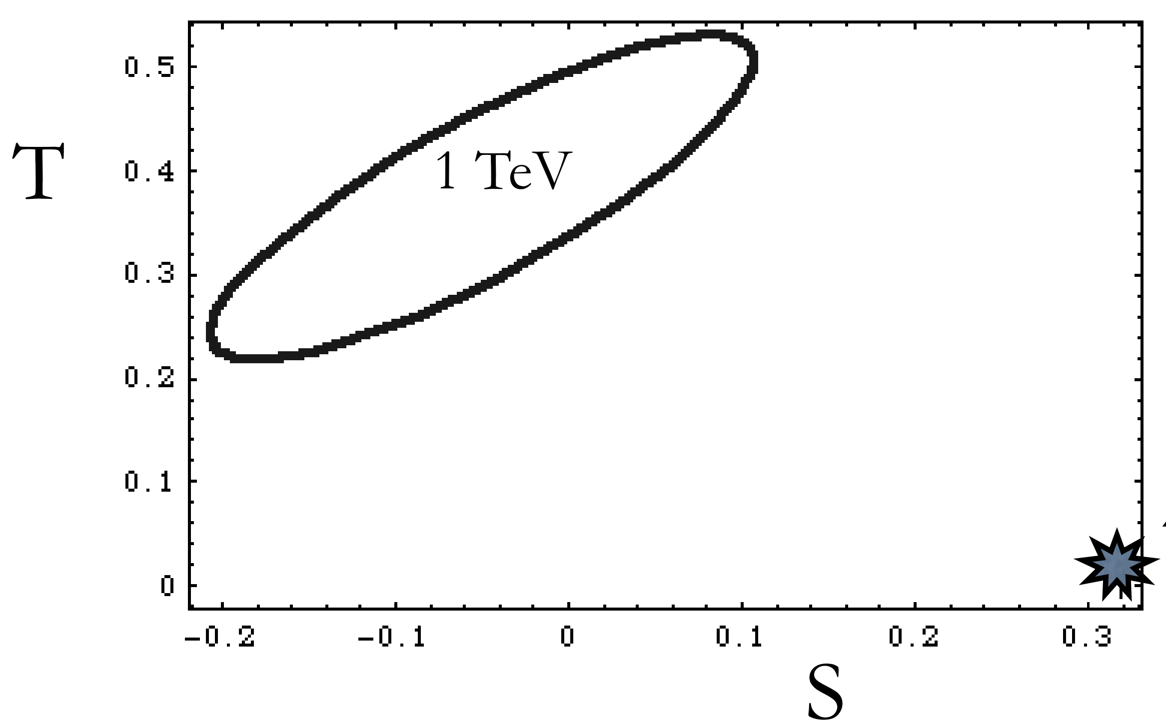
$$SU(N)_{TC} \times SU(3)_C \times SU_L(2) \times U_Y(1)$$

$$\langle Q^f \widetilde{Q}_{f'} \rangle = \Lambda^3_{TC} \qquad \qquad \Lambda_{TC} \simeq 1 \text{ TeV}$$

Precision EW Data

Large & Positive S from QCD-like Technicolor

Peskin and Takeuchi, 90



SU(3) + 1 Fund. Doublet

Weinberg, Susskind

Kennedy-Lynn, Peskin-Takeuchi, Altarelli-Barbieri, Bertolini- Sirlin, Marciano-Rosner

SM Fermion Masses

Extending Technicolor

$$\bar{L} \cdot H e_R \qquad \rightarrow \qquad \bar{L} \frac{\bar{Q}Q}{\Lambda_{ETC}^2} e_R$$

Different Approaches

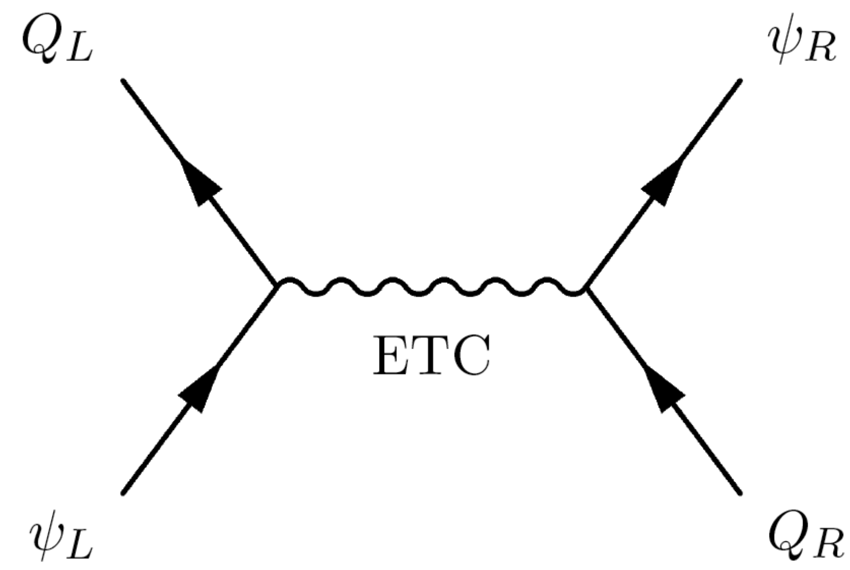
Scalar-less New Gauge Interactions (Extended TC)

Marry SUSY and Technicolor

Add New Scalars in the Flavor Sector

.....

Extended Technicolor

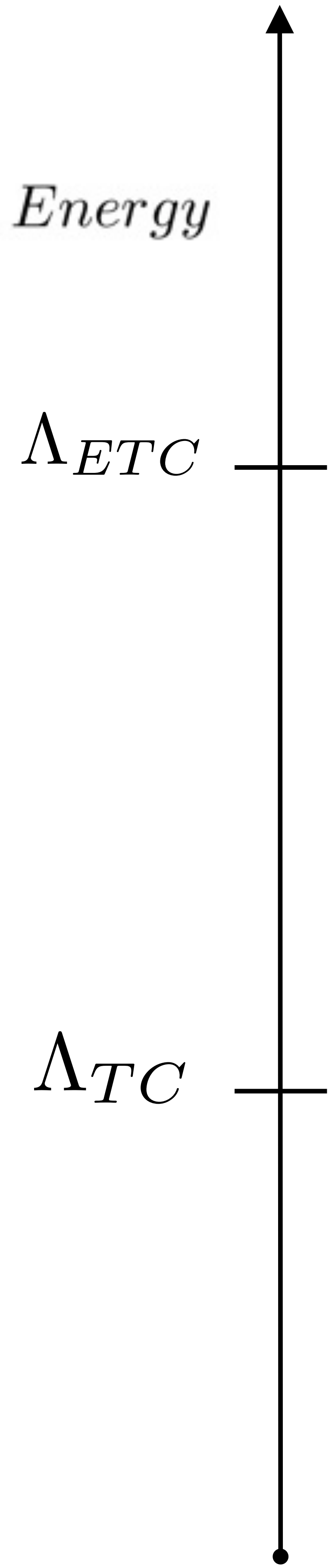


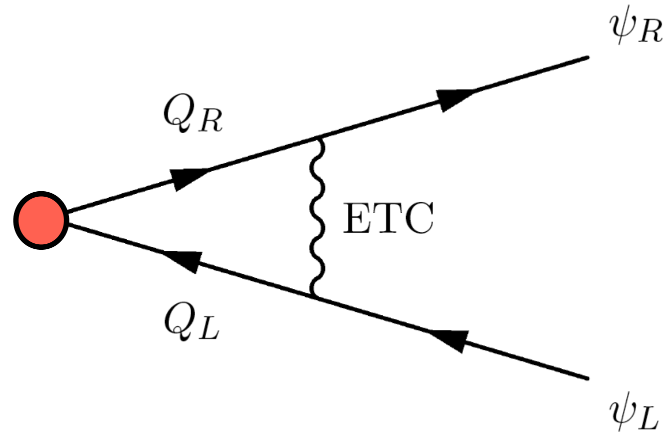
$$\alpha_{ab}\frac{\bar{Q}T^aQ\bar{Q}T^bQ}{\Lambda^2_{ETC}}+\beta_{ab}\frac{\bar{Q}_LT^aQ_R\bar{\psi}_RT^b\psi_L}{\Lambda^2_{ETC}}+\gamma_{ab}\frac{\bar{\psi}_LT^a\psi_R\bar{\psi}_RT^b\psi_L}{\Lambda^2_{ETC}}+\ldots$$

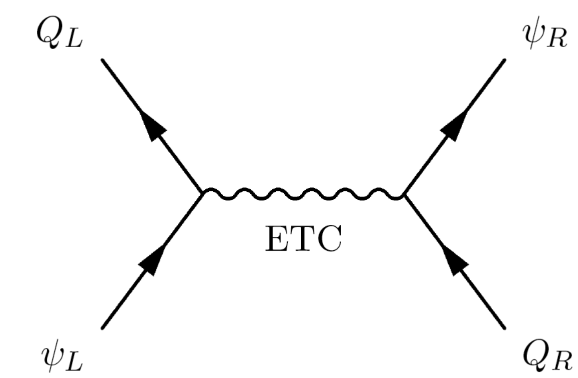
PNG Masses

SM-Fermion Masses

FCNC Operators







$$m_{\mathrm{f}} \approx \frac{g_{ETC}^2}{\Lambda_{ETC}^2} < \bar{Q}Q >_{ETC}$$

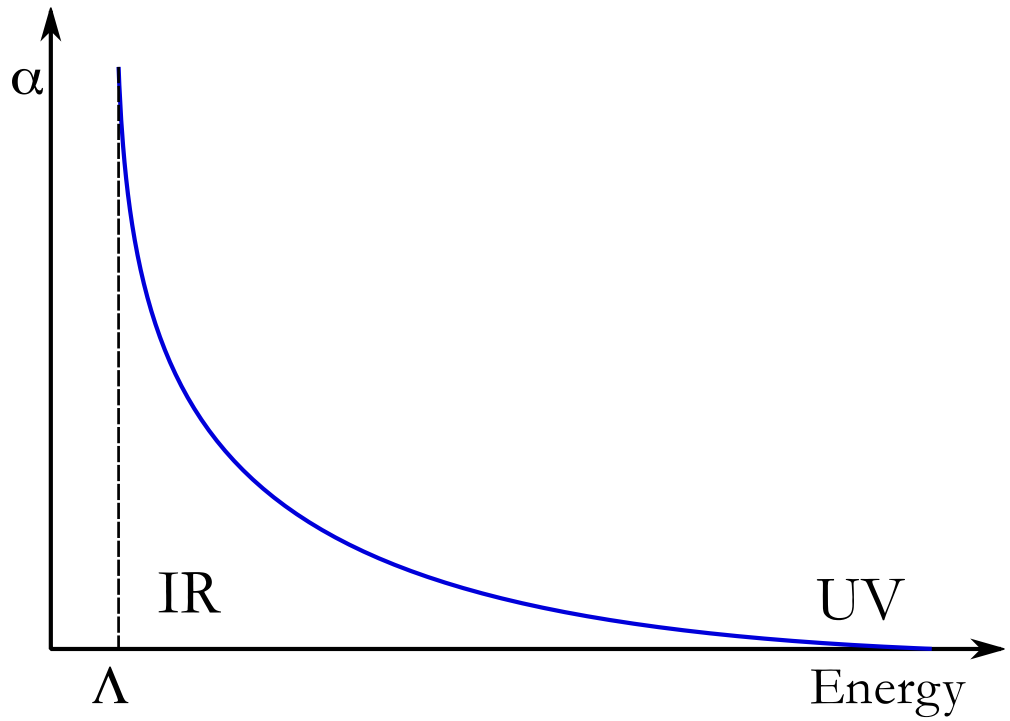
Electroweak breaks

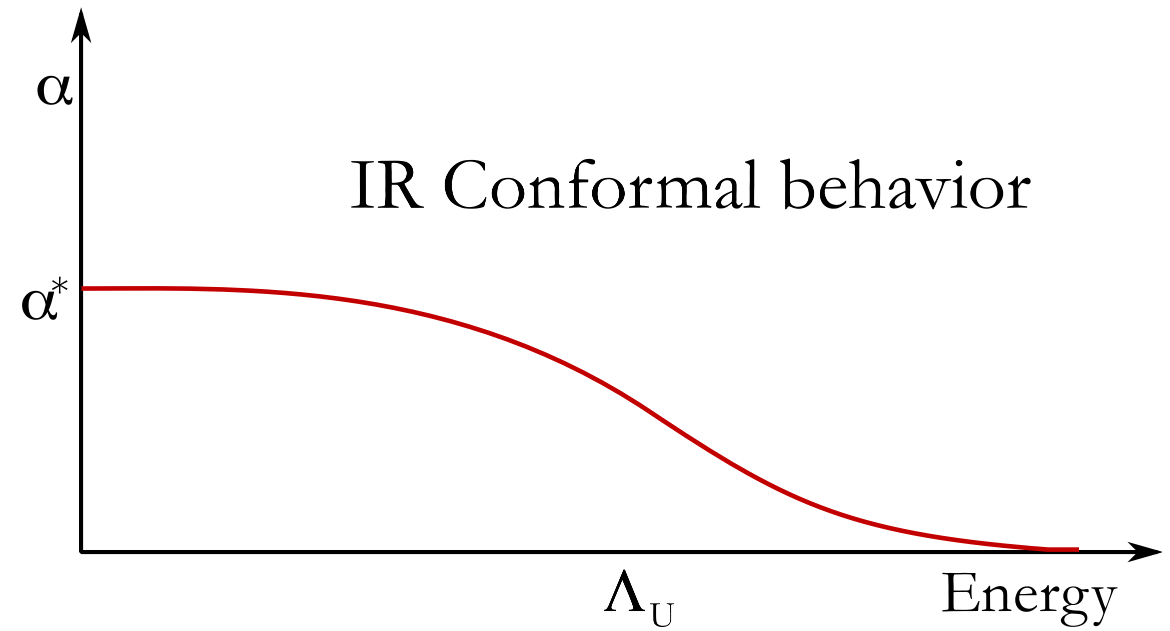
$$< \bar{Q}Q >_{ETC} \approx < \bar{Q}Q >_{TC} \sim \Lambda_{TC}^3$$

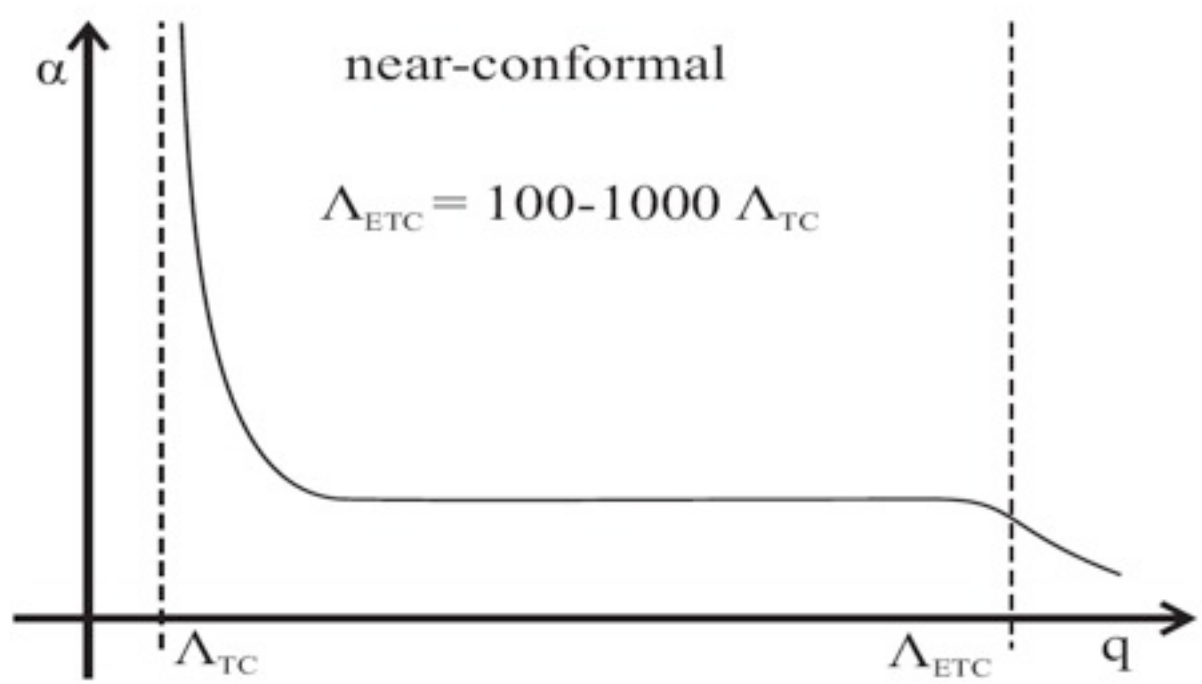
$$m_{\mathrm{f}} \approx \frac{g_{ETC}^2}{\Lambda_{ETC}^2} < \bar{Q}Q >_{ETC} \quad \ll \quad m_{\mathrm{Top}}$$

Novel type of dynamics

Near Conformal







Mass enhancement

$$\left\langle \bar{Q}Q_{ETC} \right\rangle = \exp\left(\int_{\Lambda_{TC}}^{\Lambda_{ETC}} d\ln(\mu)\, \gamma_m(\alpha(\mu)) \right) \left\langle \bar{Q}Q_{TC} \right\rangle$$

QCD-Like

$$\exp\left(\int_{\Lambda_{TC}}^{\Lambda_{ETC}} d\ln(\mu)\, \gamma_m(\alpha(\mu)) \right) \quad \sim \quad (\ln(\Lambda_{ETC}/\Lambda_{TC}))^{\gamma_m}$$

Near the conformal window

$$\exp\left(\int_{\Lambda_{TC}}^{\Lambda_{ETC}} d\ln(\mu)\, \gamma_m(\alpha(\mu)) \right) \quad \sim \quad (\Lambda_{ETC}/\Lambda_{TC})^{\gamma_m(\alpha^\star)}$$

Fermion Mass Enhancement

$$m_{\mathrm{f}} \approx \frac{g_{ETC}^2}{\Lambda_{ETC}^2} < \bar{Q}Q >_{ETC} = \frac{g_{ETC}^2}{\Lambda_{ETC}^2} \left(\frac{\Lambda_{ETC}}{\Lambda_{TC}} \right)^{\gamma_m(\alpha^*)} < \bar{Q}Q >_{TC}$$

Need large anomalous dimension, around $\gamma_m(\alpha^*) \sim 1.7$

S-parameter

$$S_{WTC} < S_{TC}$$

Appelquist, F.S. 98

Da Silva, Duan, F.S. 99

How low can S be ?

F.S. 10

$$S \geq \frac{1}{6\pi}\frac{N_f}{2}d(R)$$

Strong constraint

Conjecture obtained comparing exact results with QCD

In fact ...

$$S = S_{(W)TC} + S_{NS}$$

Offset the first term

Rule:

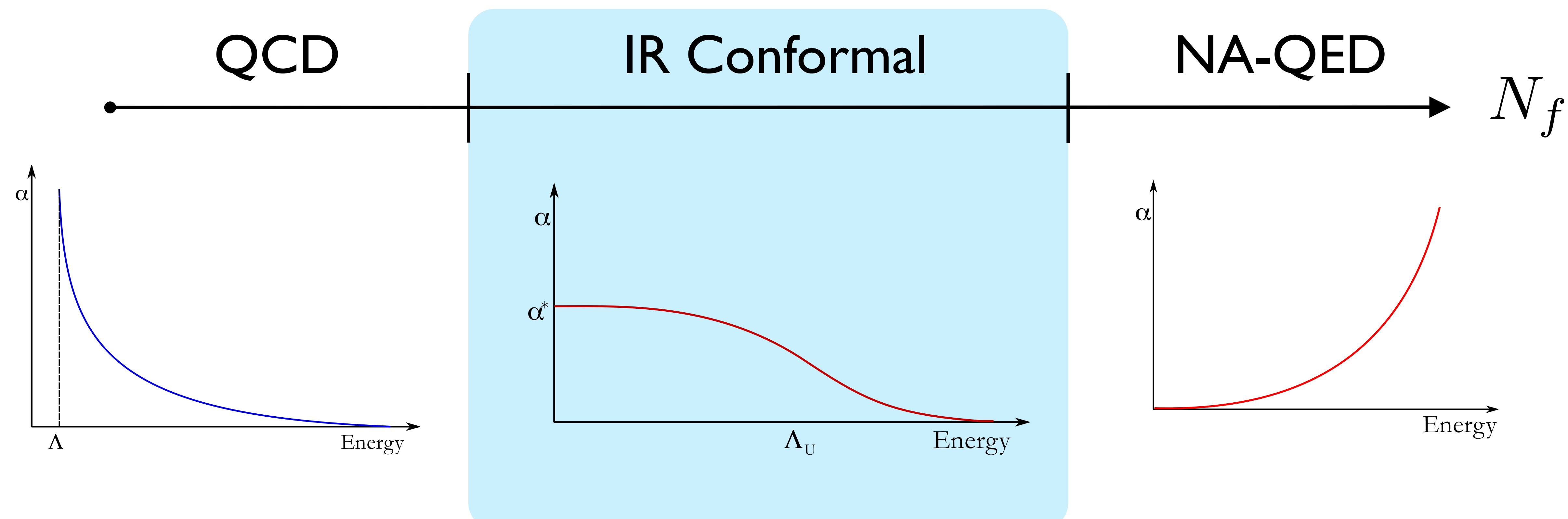
Find WT minimizing the lower bound for S

Gauge Theory Knobs

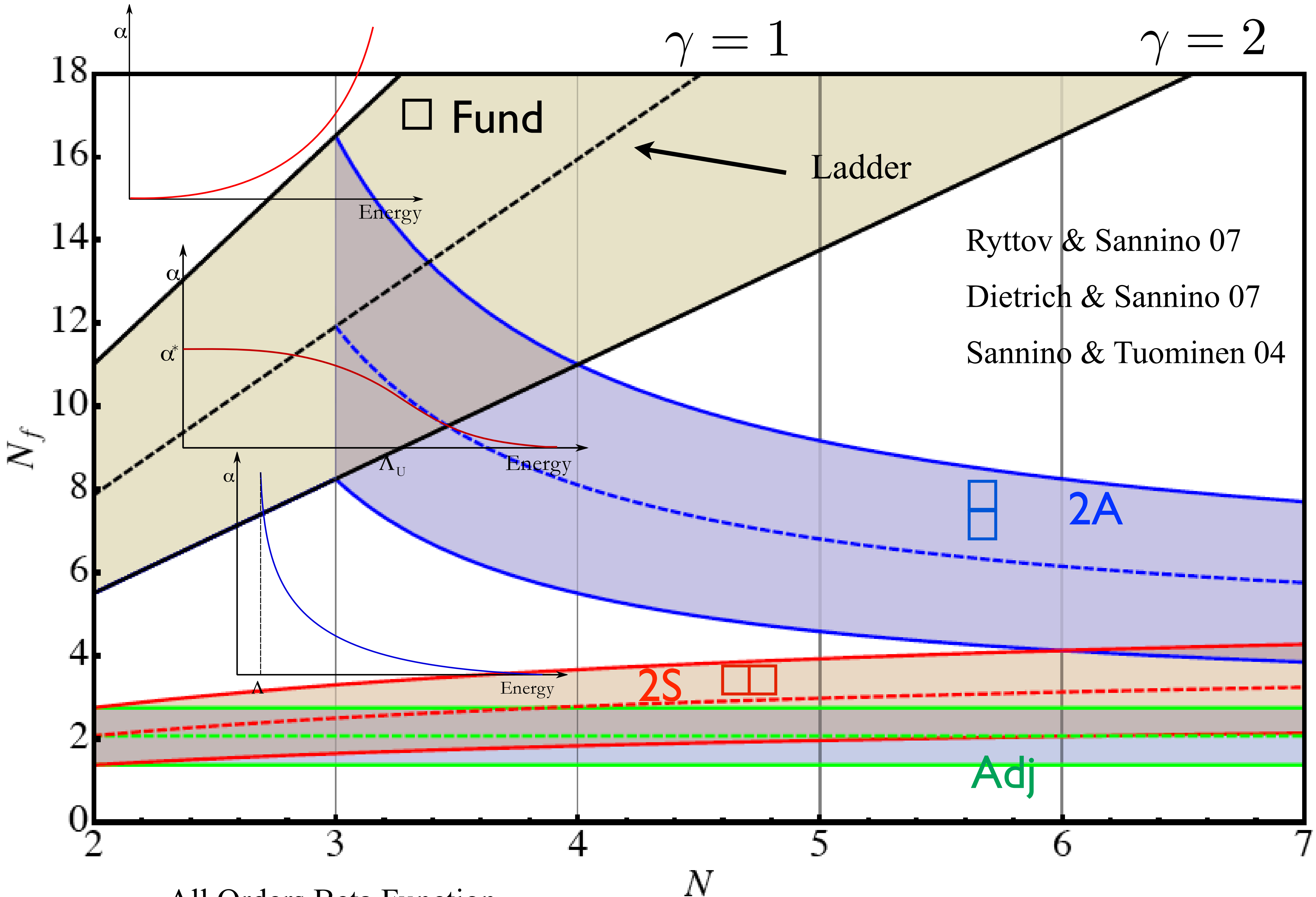
Gauge Group, i.e. SU, SO, SP

Matter Representation

# of Flavors per Representation



SU(N) Phase Diagram



All Orders Beta Function

Minimal models of Technicolor

- Minimal WT

$SU(2)_{TC}$ $\square\square$ **U D** **N E**

FS, Tuominen 04

Dietrich, FS, Tuominen 05

- Next to MWT

$SU(3)_{TC}$ $\square\square$ **U D**

FS, Tuominen 04

Dietrich, FS, Tuominen 05

- Orthogonal

$SO(4)_{TC}$ $\square$ **U D**

Frandsen, FS 09

- Ultra MT

$SU(2)_{TC}$ $\square$ **U D**

Ryttov, FS 08

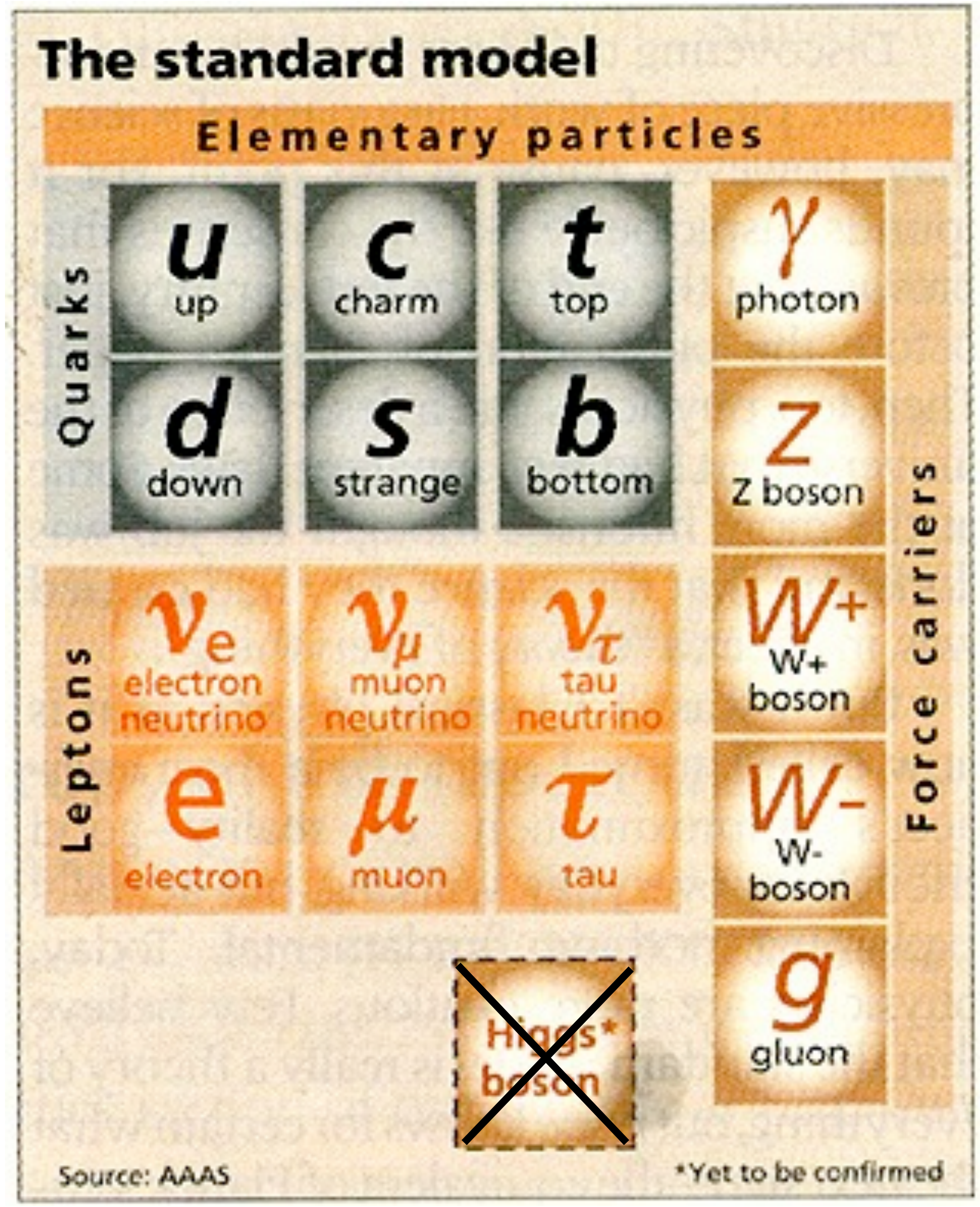
- Other models/ETC

Farhi and Susskind 79;
Eichten and Lane 89;
Appelquist and Terning 94;
Appelquist, Christensen, Pia and Shrock 04
Evans and FS 08
Ryttov and Shrock 09,10

- Effective Theories

Appelquist, Da Silva, FS 99;
Da Silva, Duan, F.S. 99
Foadi, Frandsen, Ryttov, F.S. 07
Lane and Martin 09

Minimal Walking Technicolor



U(1)

SU(2)

SU(3)

N Extra Neutrino

E Extra Electron

U t-up

G t-glue

D t-down

SU(2)

U and D: Adj of SU(2)

F.S. + Tuominen 04

Dietrich, F.S., Tuominen 05

MWT Features

- The most economical WT theory
- Compatible with precision measurements
- Possible DM candidates and Unification
- Can support 1st order Electroweak Phase Transition
- Can feature a light composite Higgs
  Dietrich, F.S., Tuominen 05.
  Da Silva, Doff, Natale 08, 09.
- Lattice studies have begun

MWT Effective Lagrangian

$$\mathcal{L}(\text{Composites}) + \mathcal{L}(\text{Mixing with SM}) + \mathcal{L}(\text{New Leptons}) + \mathcal{L}(\text{SM} - \text{Higgs})$$

Initial investigation we include:

Composite Higgs H

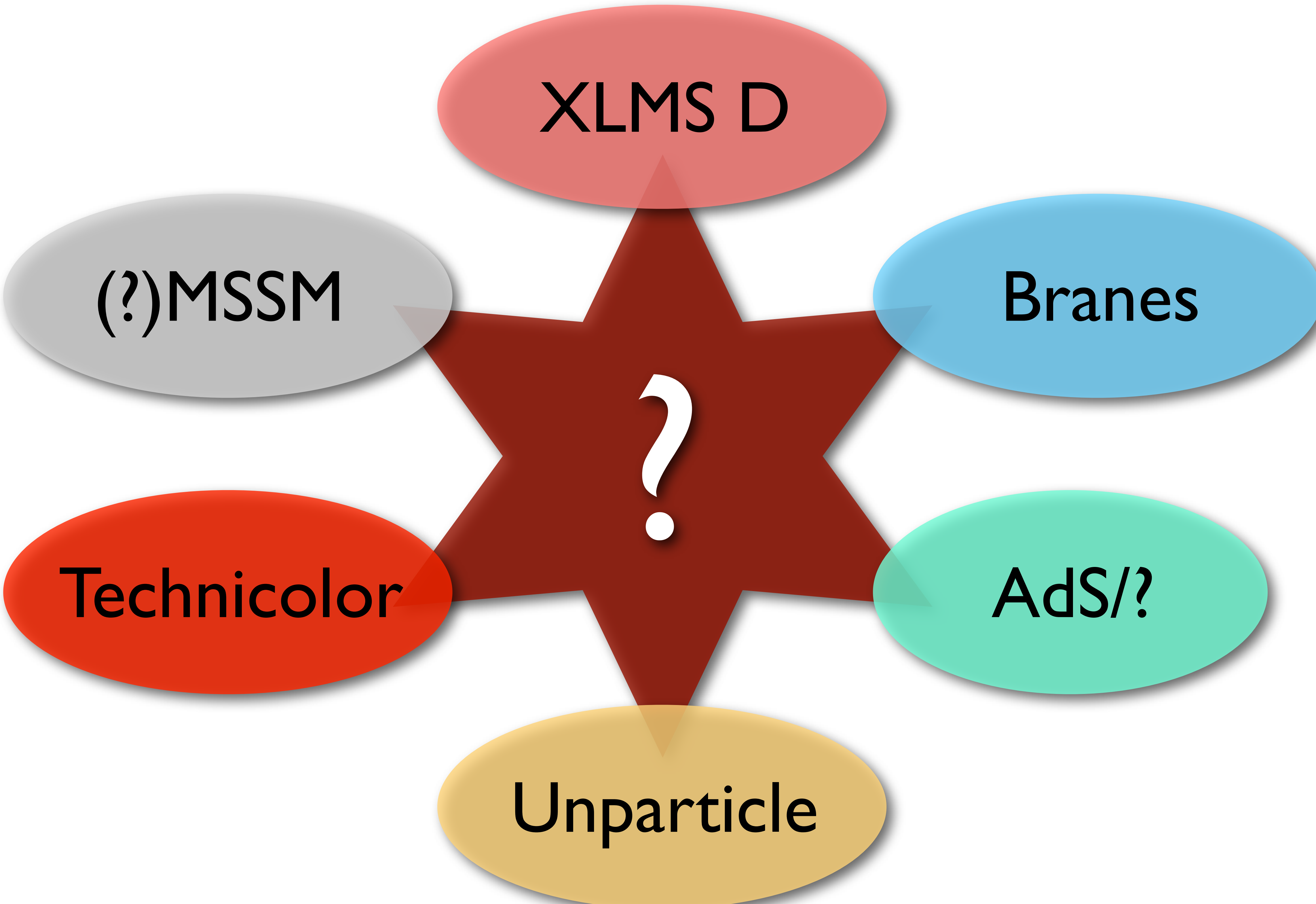
Composite Axial - Vector States $R_{1,2}$

See Frandsen talk for the (boosted) phenomenology

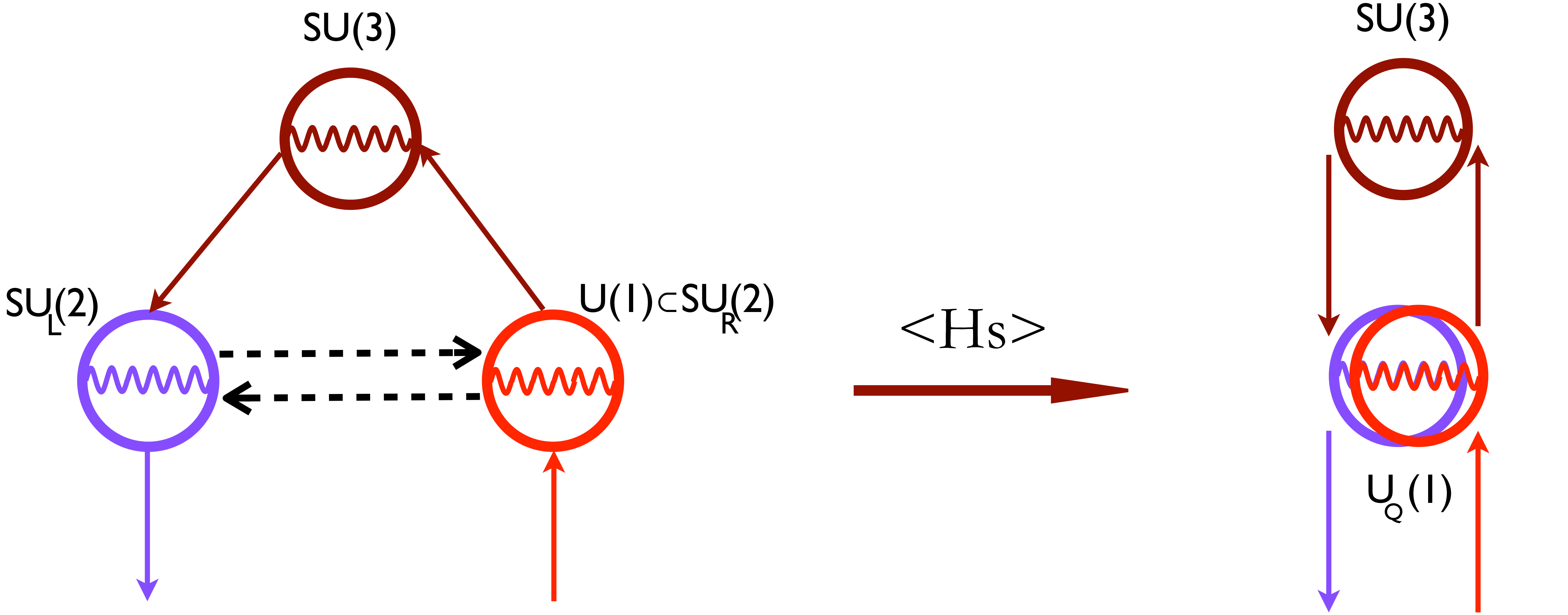
Many Models

- (?)MSSM
- XLMS D
- Technicolor
- Branes
- ......
- Unparticle
- AdS/?

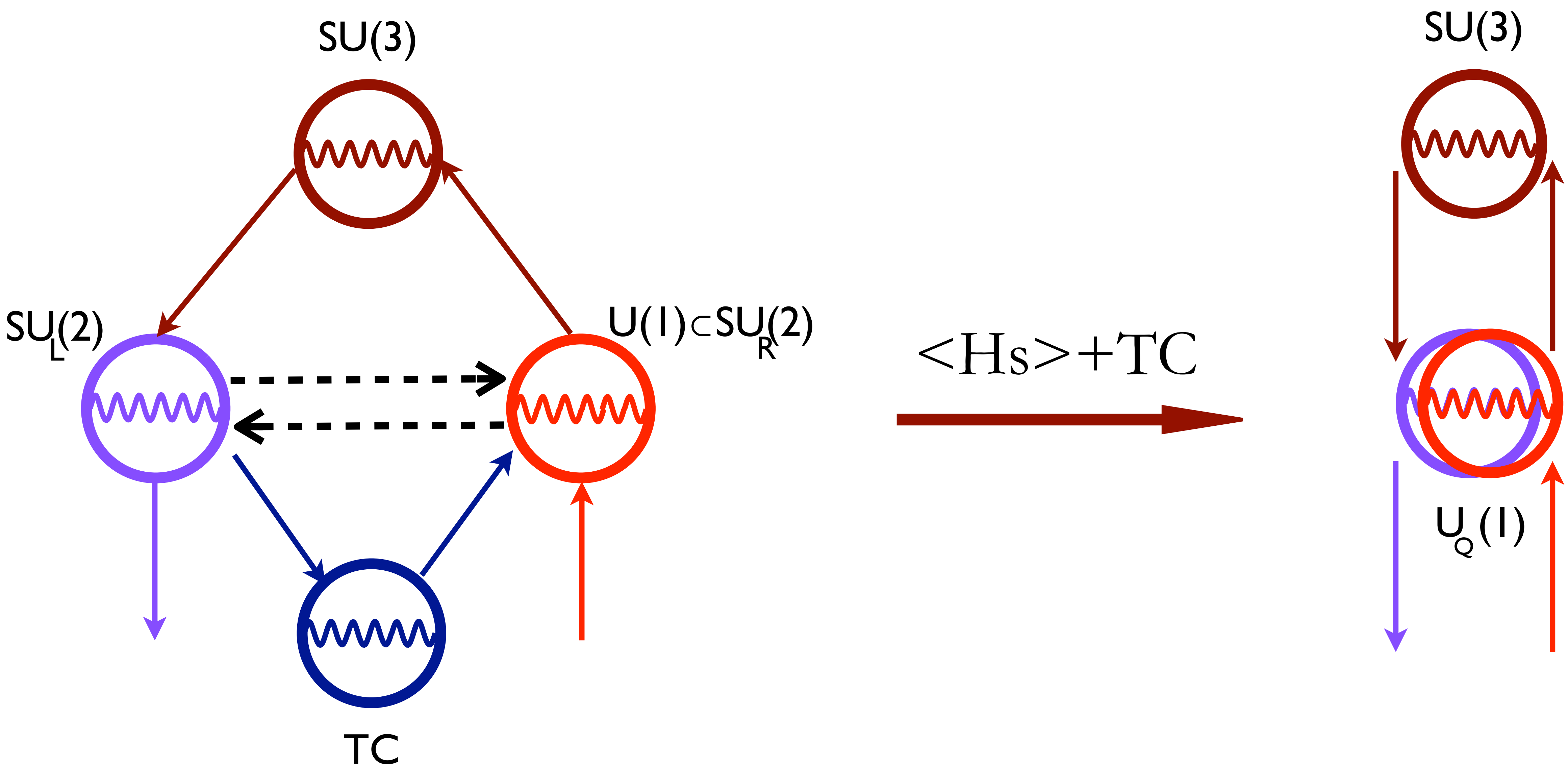
Unification in Model Space



MSSM - cartoon



Super Technicolor



From MWT to N=4

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

N=4 - SU(N) requires

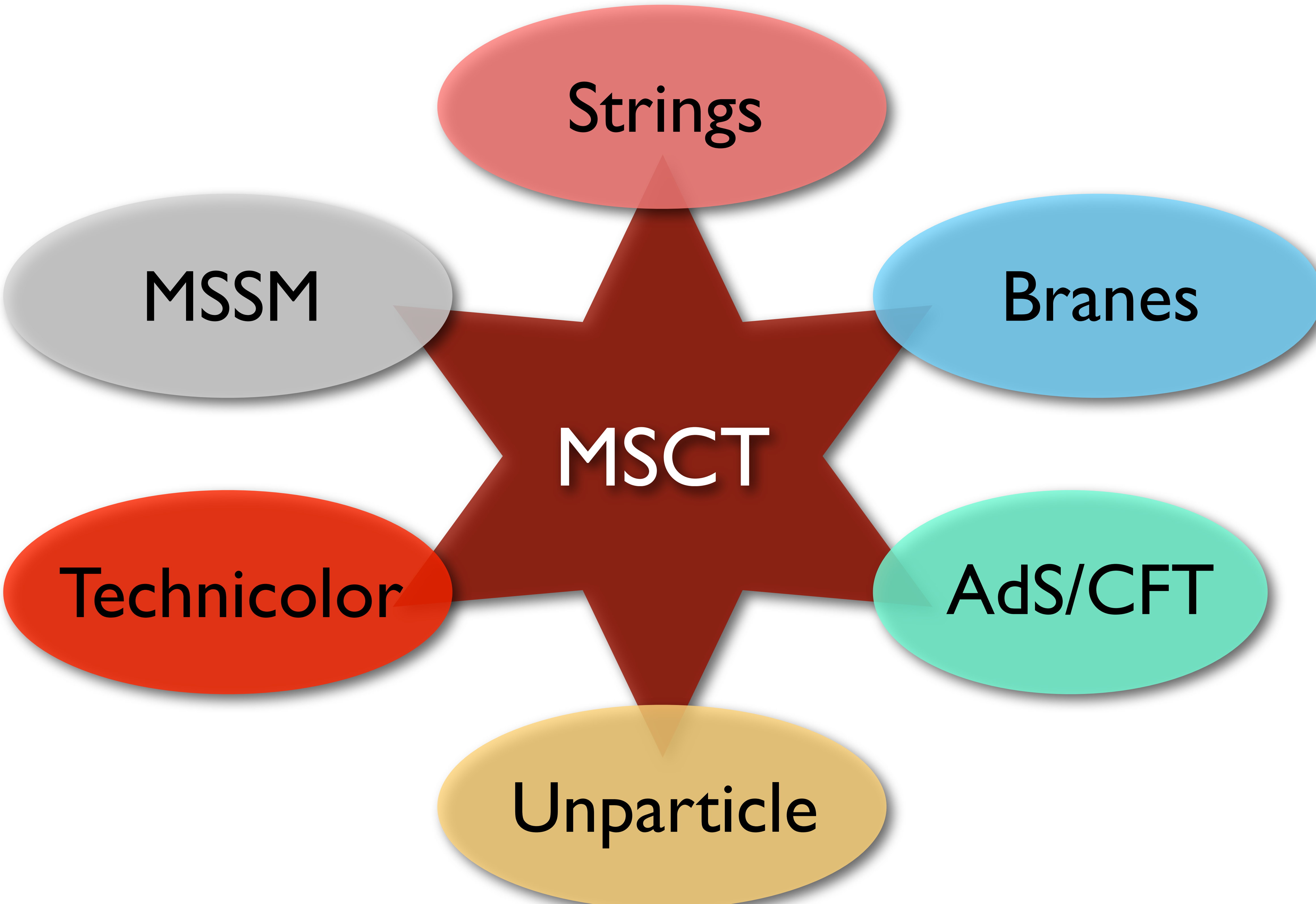
$$P = -\frac{g}{3\sqrt{2}}\epsilon_{ijk}f^{abc}\Phi_i^a\Phi_j^b\Phi_k^c,\; i = 1,2,3; a = 1,\cdots, N^2-1$$

Antola, Di Chiara, FS, Tuominen 10

... and now

- N=4 breaks to N=1 via electroweak interactions
- Add MSSM superpotential and SUSY breaking

Minimal Super Conformal Technicolor



Conclusions

- DEWSB can naturally occur at the LHC
- Phase Diagram of strongly interacting theories
- Minimal models of technicolor
- Unification in theory space/Technicolor meets string theory
- DEWSB cosmology is exciting... another time