DIAS
Danish Institute
for Advanced Study

University of Southern Denmark

Light Technicolor Higgs

Francesco Sannino

CP³ - Origins
Particle Physics & Cosmology

Higgs centre april 2013

Fermi Scale

$$v = 1/\sqrt{\sqrt{2}G_F} \approx 246 \text{ GeV}$$

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Top has the right energy scale!

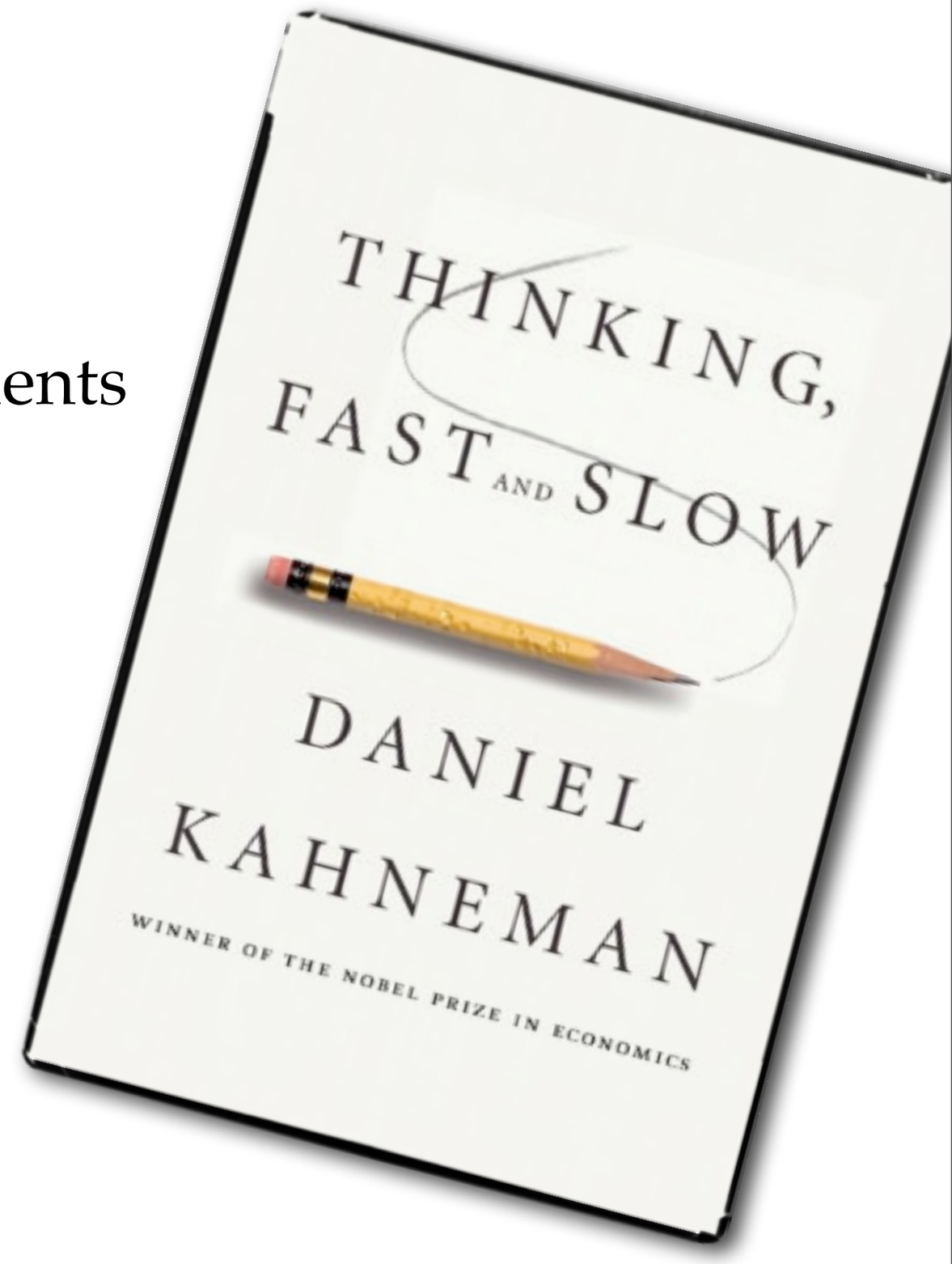
Light quarks and leptons are also natural!

Fundamental ?

- Would be the first time
- Spinors are space-time constituents
- Scalars are derived
- Susy? Can be emergent

  In <4d: Sung-Sik Lee 06

  4d: Antipin, Mojaza, Pica, Sannino 10



Compositeness

- Only Higgs sector is composite [Technicolor]
- Standard Model Fermions are composite [Preons]
- Partial compositeness: Bosonic/SUSY Technicolor ...
- X compositeness [Magnetic Standard Model] Sannino 11

What has LHC not seen ?

- Extra large, small or medium dimensions [kk states,..]
- Any sign of supersymmetry [gluino,...]
- Extra, mini, large Black-Holes [low scale gravity]

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In line with:

Composite dynamics

Technicolor

From SM to TC

$$DH^{\dagger}DH - V(H) + \overline{\Psi}_L H \psi_R$$

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Extended TC

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TC $\longleftrightarrow$ Extended TC

Technicolor vs Composite Higgs

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  If 4D underlying exists probably similar to Technicolor ?

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Example:

The $SU(2)_L$ x $SU(2)_R$ chiral Lagrangian can describe the Goldstone interactions coming from an underlying bosonic (i.e. unnatural) theory like the SM Higgs sector!

Need to go beyond QCD

- TC-fermion condensate enhancement/FCNC decoupling
- Minimal TC passing precision tests
- Need a TC Higgs
- Dark matter candidates

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QCD lightest scalar is $f_0(500)$ with mass ~ 400-550 MeV

Sannino & Schechter 95 PRD ['t Hooft 1/N, crossing, chiral, pole mass]
Harada, Sannino & Schechter 95 PRD [$f_0(980)$], 96PRL
Pelaez - Confinement X - lecture

Narrow state in Strong Dynamics?

Example $f_0(980)$

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S. Weinberg 2013

Higgs Effective Theory

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$$
\begin{aligned}
\mathcal{L} &= \mathcal{L}_{\overline{\rm SM}} + \left(1 + \frac{2r_\pi}{v} H + \frac{s_\pi}{v^2} H^2\right) \frac{v^2}{4} \mathrm{Tr}\; D_\mu U^\dagger D^\mu U + \frac{1}{2}\; \partial_\mu H\; \partial^\mu H \\
&- m_t \left(1 + \frac{r_t}{v} H\right) \left[\overline{q}_L\; U\; \left(\frac{1}{2} + T^3\right)\; q_R + \mathrm{h.c.}\right] \\
&- m_b \left(1 + \frac{r_b}{v} H\right) \left[\overline{q}_L\; U\; \left(\frac{1}{2} - T^3\right)\; q_R + \mathrm{h.c.}\right] + \cdots \\
&- \Delta S\; W^a_{\mu\nu} B^{\mu\nu}\; \mathrm{Tr}\; T^a U T^3 U^\dagger + \mathcal{O}\left(\frac{1}{M_\rho}\right) \qquad\qquad q \equiv (t, b)
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$$

$$
U = \exp\left(i\pi^a T^a / v\right) \qquad\qquad v \simeq 246\ \mathrm{GeV}
$$

$$
D_\mu U \equiv \partial_\mu U - i g W^a_\mu T^a U + i g' U B_\mu T^3
$$

EW - corrections

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$$\mathcal{L}_H \supset \frac{2\, m_W^2\, r_\pi}{v}\, H\, W_\mu^+\, W^{-\mu} + \frac{m_Z^2\, r_\pi}{v}\, H\, Z_\mu\, Z^\mu - \frac{m_t\, r_t}{v}\, H\, \bar{t}\, t$$

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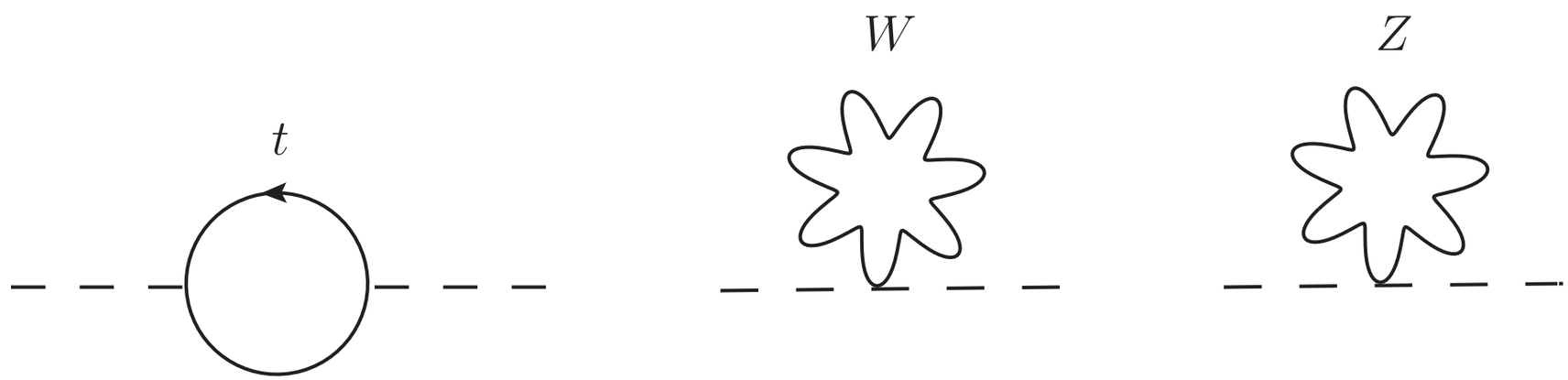

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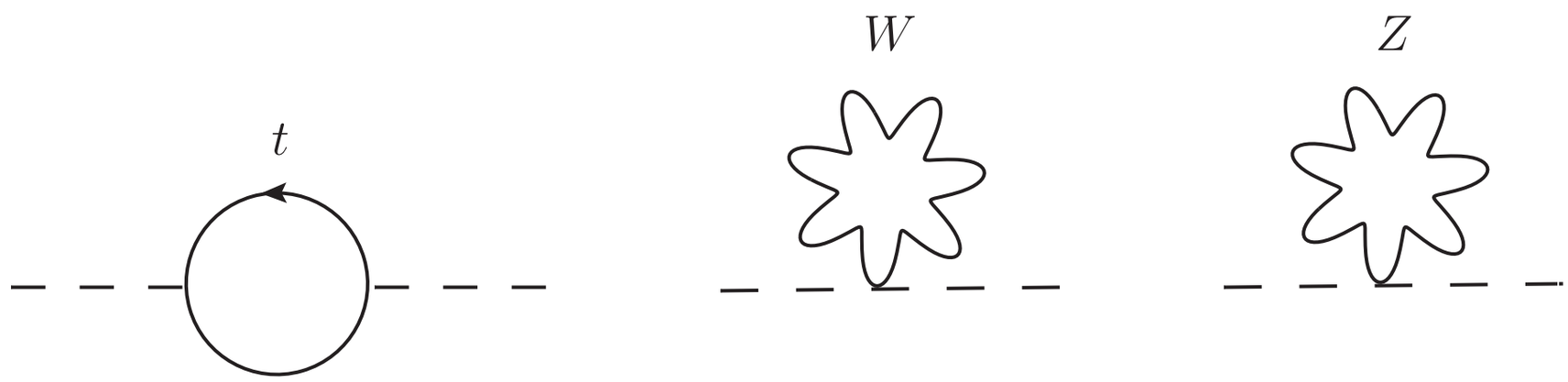

$$M_H^2 = (M_H^{\mathrm{TC}})^2 + \frac{3(4\pi\kappa F_\Pi)^2}{16\pi^2 v^2}\left[-4r_t^2 m_t^2 + 2s_\pi\left(m_W^2 + \frac{m_Z^2}{2}\right)\right] + \Delta_{M_H^2}(4\pi\kappa F_\Pi)$$

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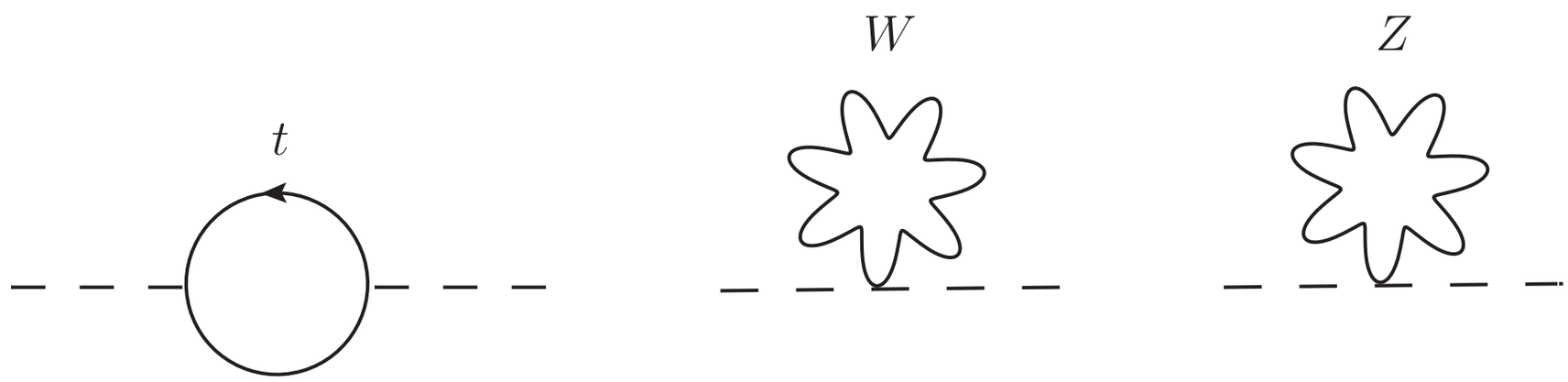

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Foadi, Frandsen, Sannino, 1211.1083

How light is the TC-Higgs ?

$$(M_H^{\rm TC})^2 \simeq M_H^2 + 12\ \kappa^2 r_t^2 m_t^2$$

$\kappa\ r_t \sim$ TC x ETC

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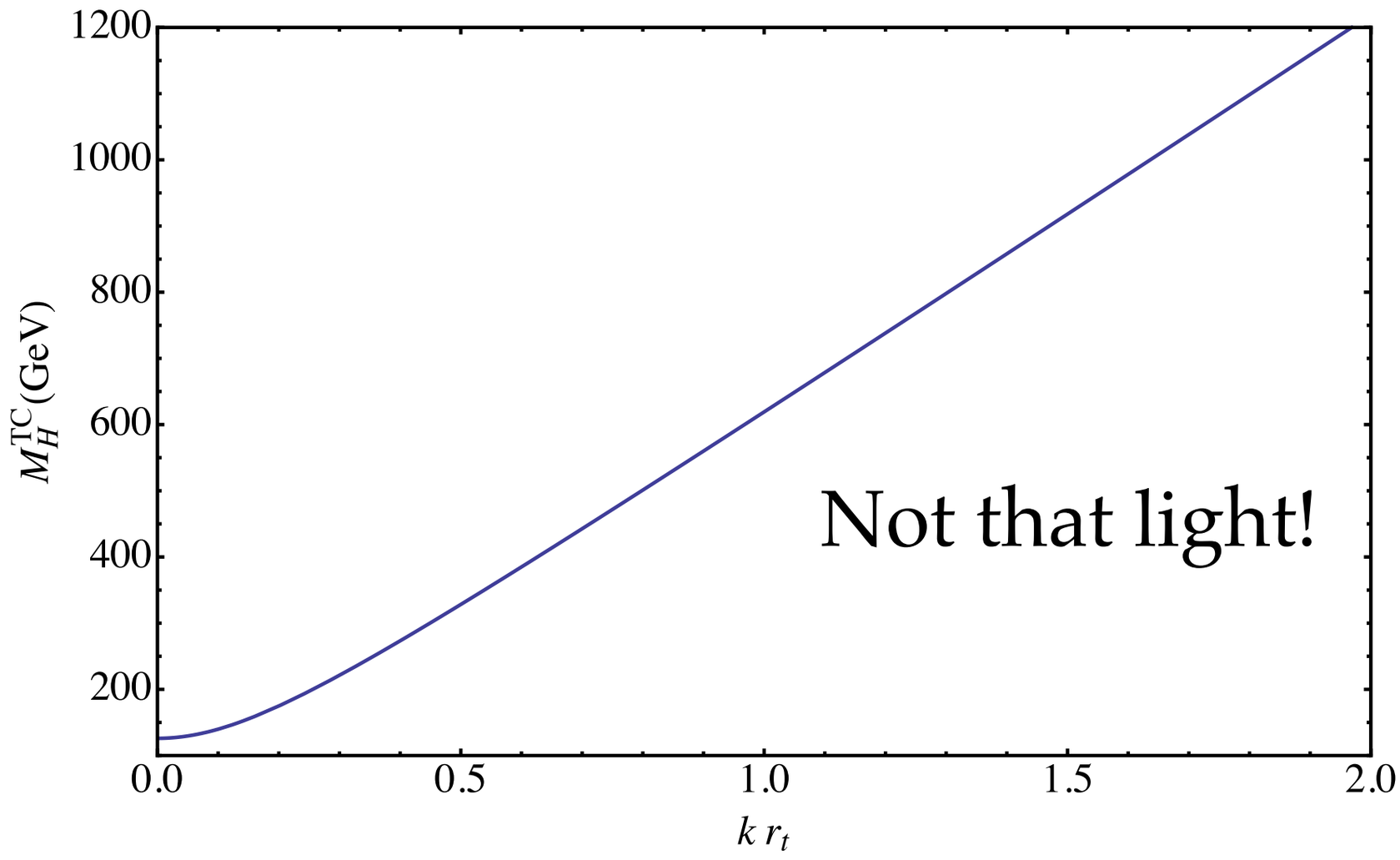

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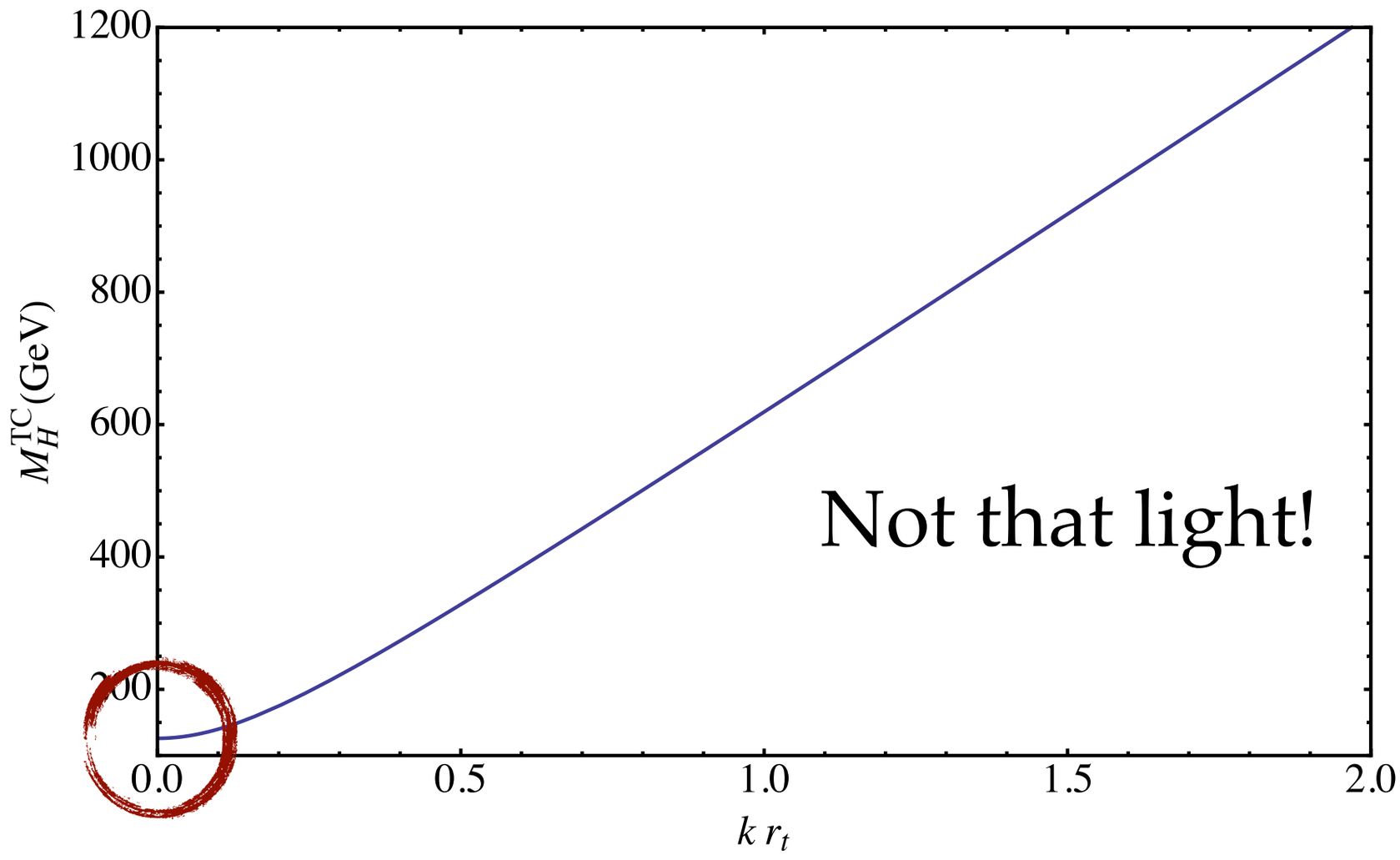

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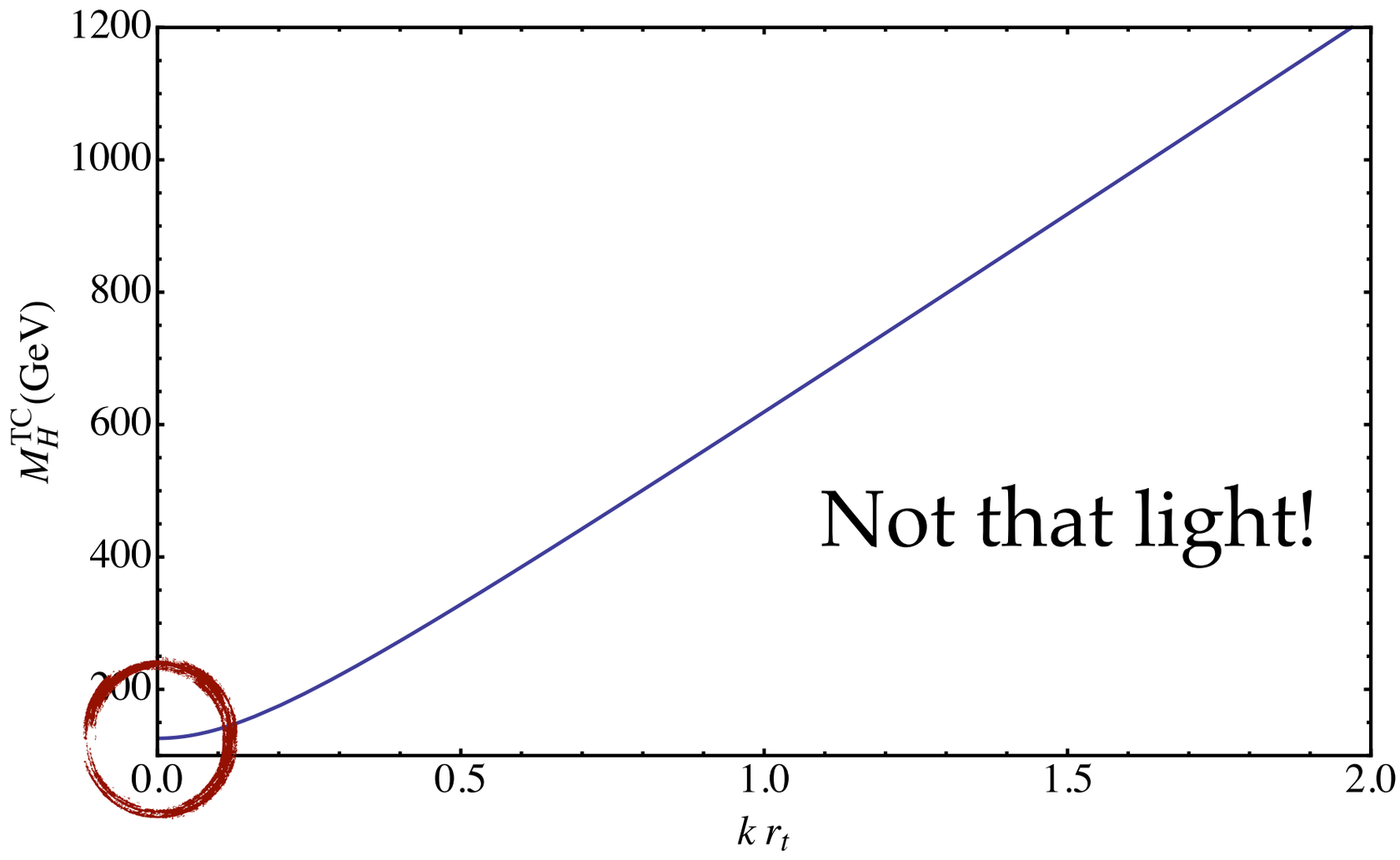

Narrow due to kinematics [Similar to $f_0(980)$ in QCD]

How to make a TC Higgs ?

Sannino 08

Sannino & Schechter 07

Foadi, Frandsen, Sannino 12

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Change # of TC-colors, matter repr., EW doublets

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$$M_H^{TC} \simeq 1.8 \frac{1}{\sqrt{N_D d(R_{TC})}} \quad \text{TeV}$$

$$d(2 - \text{index}_{TC}) = N_{TC} \frac{N_{TC} \pm 1}{2}$$

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Physical Higgs mass via gauge geometry

Sannino 08

Sannino & Schechter 07

Foadi, Frandsen, Sannino 12

Minimal Walking Theories

- SU(2) + 2 Dirac Adjoint — $SU(2)_A$ - MWT
- SU(3) + 2 Dirac Symmetric — $SU(3)_S$ - MWT
- SU(2) +2 Dirac Fund. + .. (U - MWT) — $SU(2)_F$ - MWT
- SO(4) + 2 Dirac Vector — $SO(2)_V$ - MWT
- SU(3) + 2 Dirac Fund. + Ungauged — $SU(3)_F$ - pMWT

Original name: Evans and Sannino, 2005 (Also for a sketch of ETC model)

Only one N_D gauged: Small S

next-MWT = $SU(3)_s$ MWT

SU(3)$_S$ **MWT: A Realistic theory**

Sannino & Tuominen hep-ph/0405209

$$N_D = 1 \quad d(\text{Symmetric}) = 6$$

$$M_H^{TC} \simeq 735 \text{ GeV}$$

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Lattice: Fodor, Holland, Kuti, Nogradi, Schroeder, Wong, 1209.0391:

$M_\rho \simeq 1754 \pm 104 \text{ GeV}$ $\qquad$ $M_{A_1} \simeq 2327 \pm 121 \text{ GeV}$

Lattice Mass of the TC Higgs?

Beware: Uncertain GMOR relation!

Minimal WTC Models

[Original 2004 Name: Light Composite Higgs]

SU(2) & SU(3) MWTC

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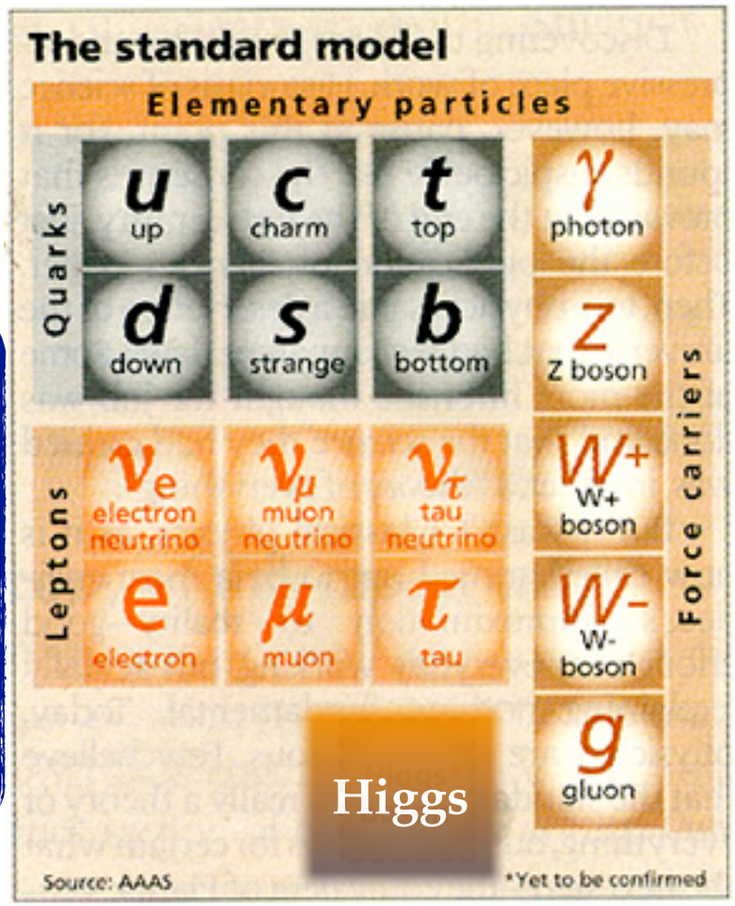

U(1)

SU(2)

SU(3)

SU(2)

SU(2) or SU(3)

SU(2) & SU(3) MWTC

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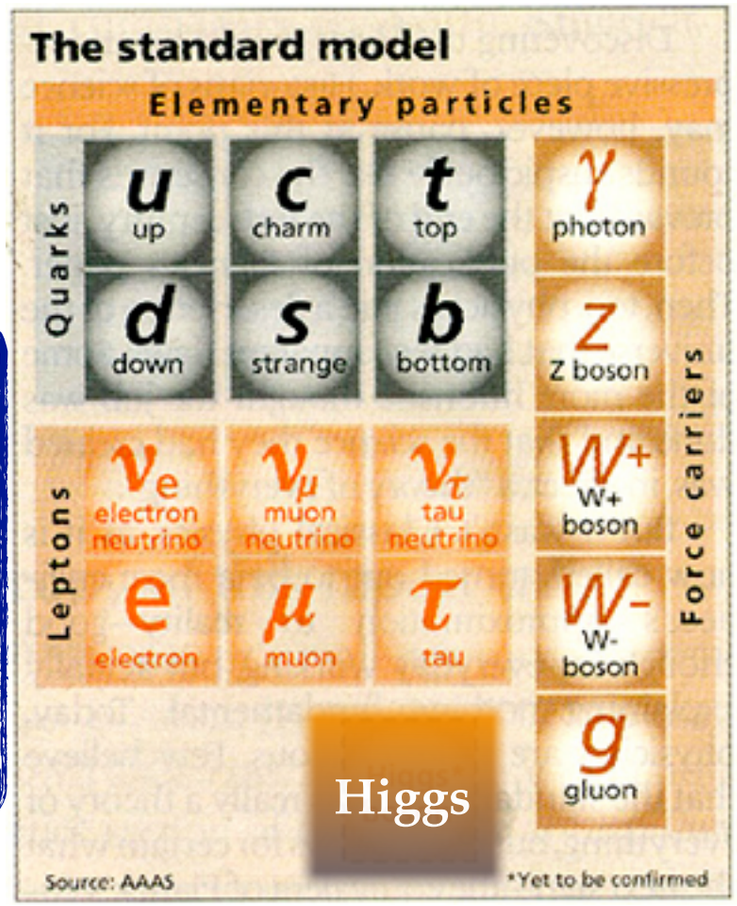


N
Extra Neutrino

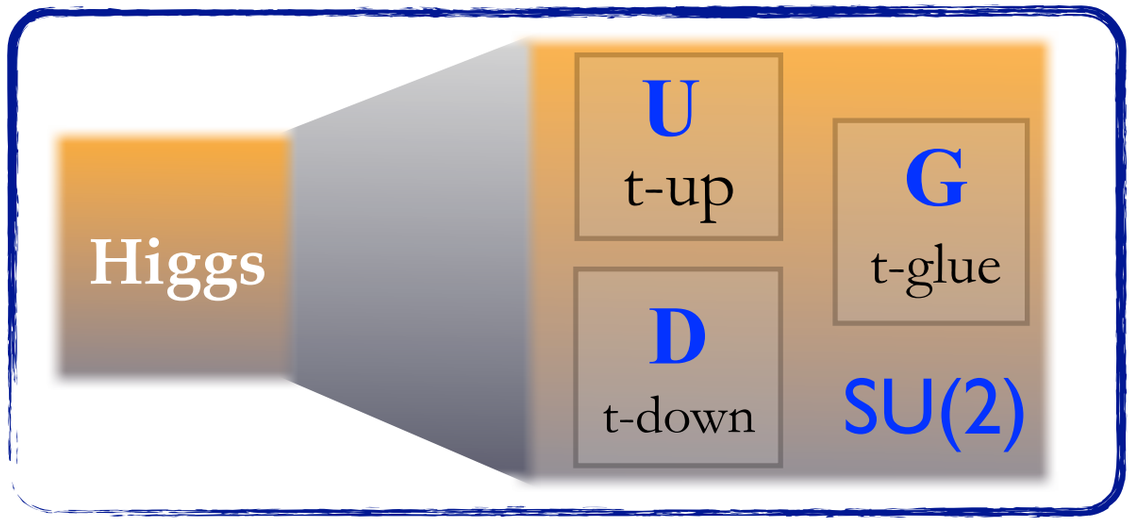
ζ
Extra Electron

SU(2)

U(1)

SU(2)

SU(3)



SU(2) or SU(3)

Sannino, Tuominen 04

Hong, Hsu, Sannino 04

Dietrich, Sannino, Tuominen 05

SU(2) & SU(3) MWTC

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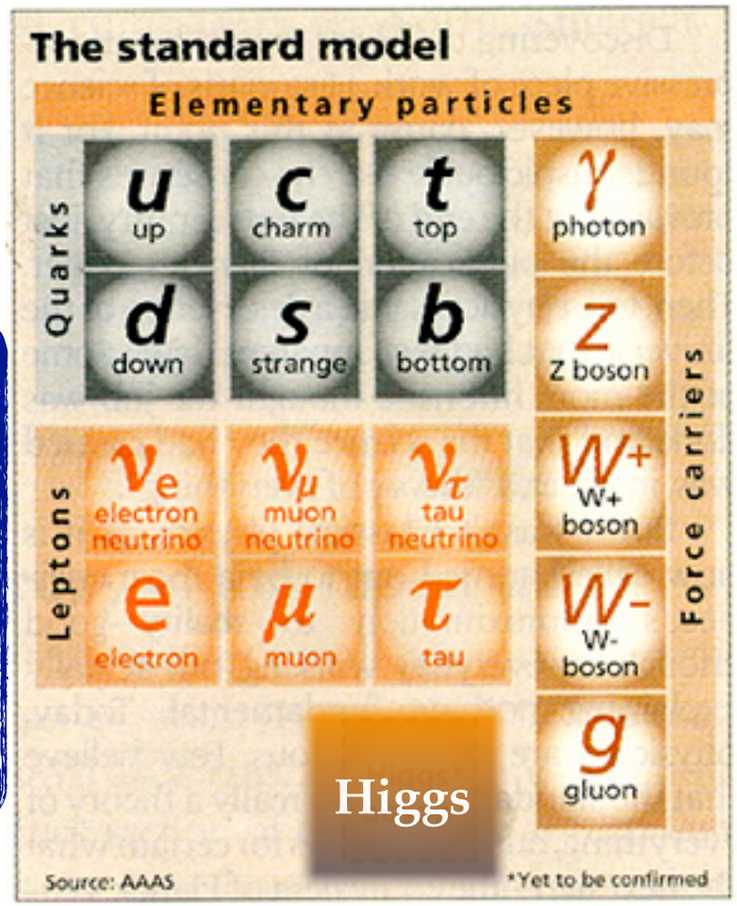

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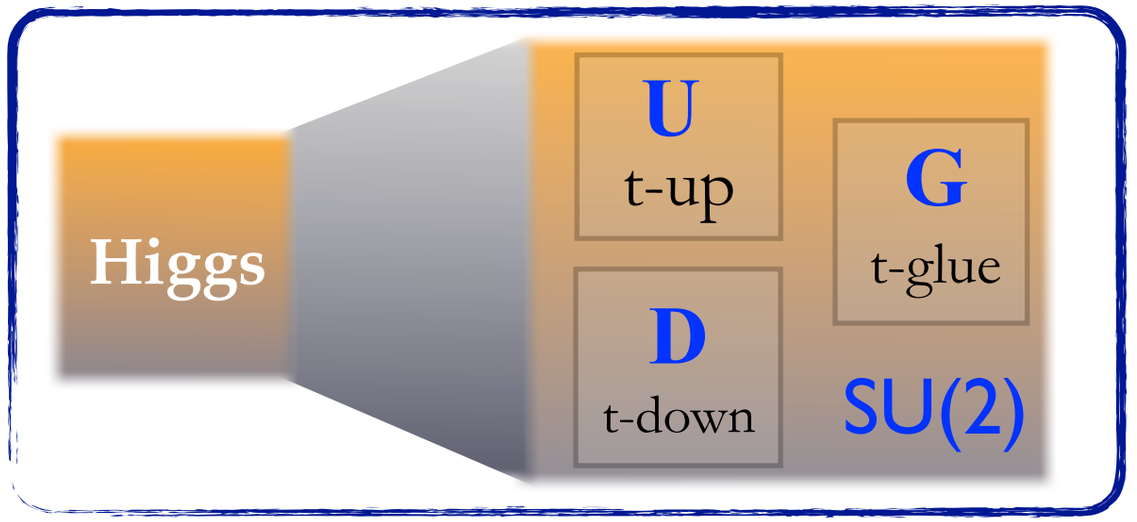

SU(2) or SU(3)

◉ Can feature Light TC/Dilaton Higgs

Sannino, Tuominen 04

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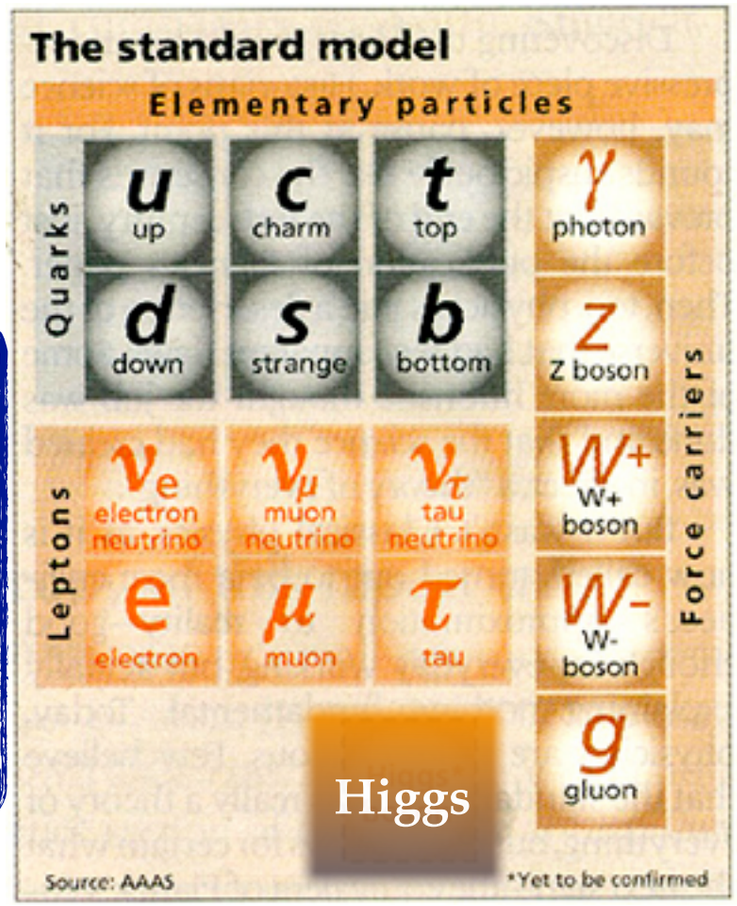

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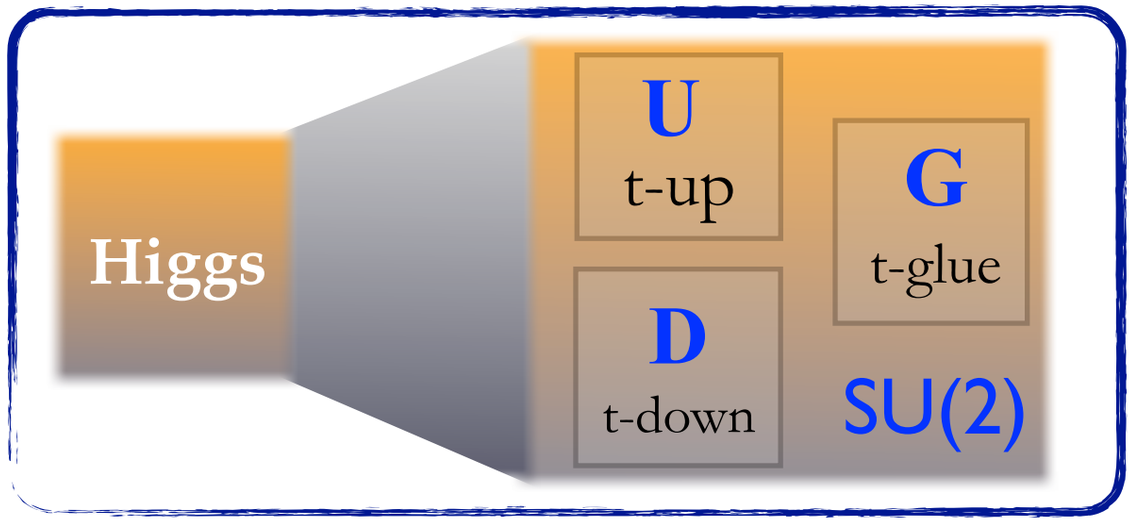

SU(2) or SU(3)

- Can feature Light TC/Dilaton Higgs
- Smallest S-parameter & FCNC

Sannino, Tuominen 04

Hong, Hsu, Sannino 04

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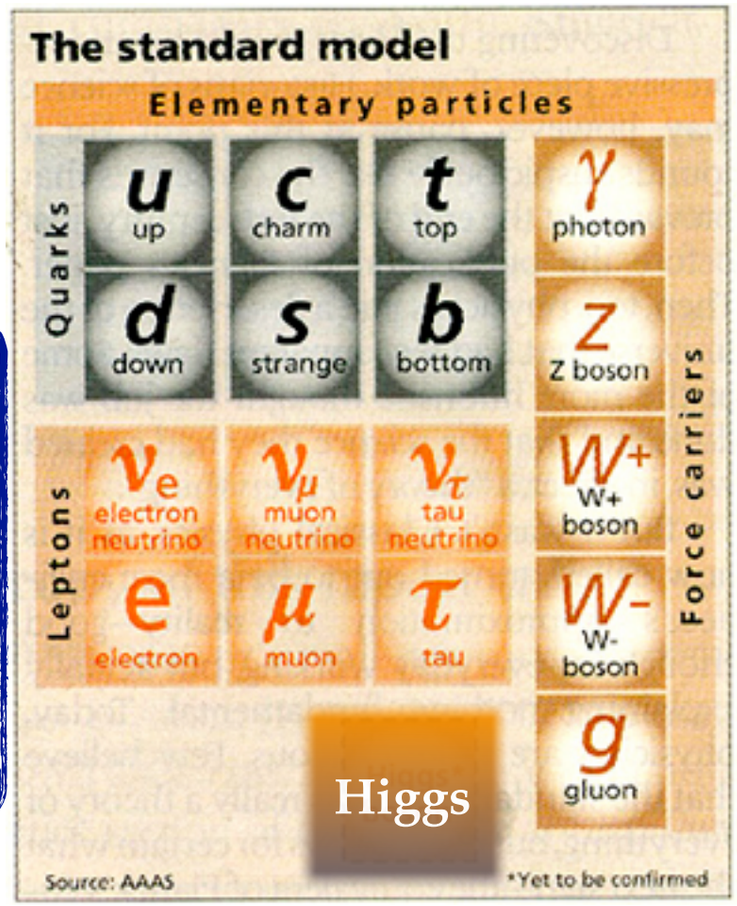

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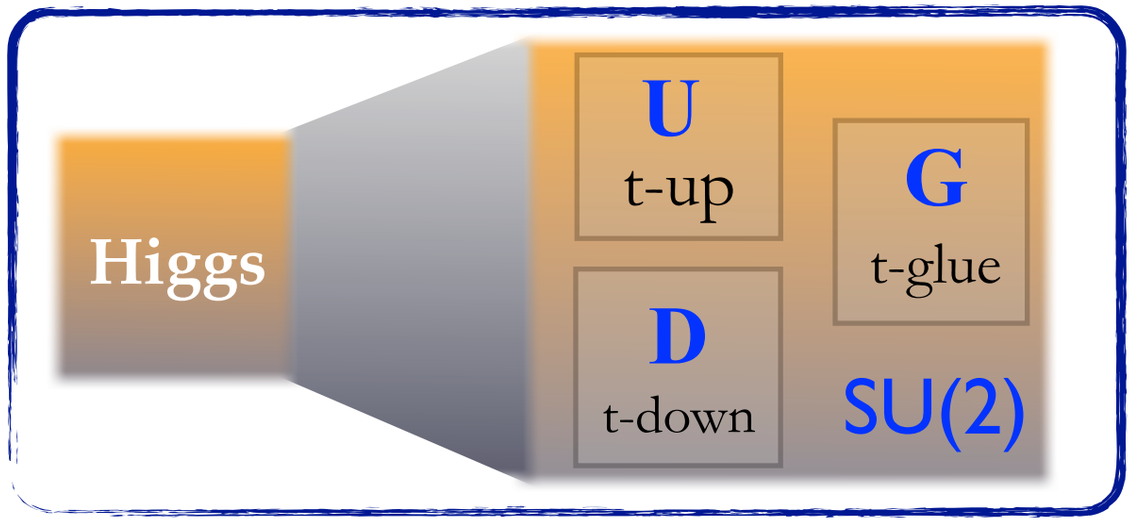

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- Smallest S-parameter & FCNC
- Dark matter candidates

Sannino, Tuominen 04

Hong, Hsu, Sannino 04

Dietrich, Sannino, Tuominen 05

Lattice

Catterall, Sannino 0705.1664

Hietanen, Rantaharju, Rummukainen, Tuominen 0812.1467

Del Debbio, Lucini, Patella, Pica, Rago 1004.3206

Fodor, Holland, Kuti, Nogradi, Schroeder, Wong, 1209.0391

Minimal TC states to discover

Higgs - like

TC Axial - Vector States

H

$R_{1,2}$

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Higgs - like

TC Axial - Vector States

H

$R_{1,2}$

Beyond minimal: (E)TC model dependent

TC pions

TC composite fermions

Elementary Leptons

Unexpected .....

Π

Ψ

L

U

LHC Search **Strategy**

- Indirect hints of heavy states
  - Modified Higgs couplings wrt SM
  - Study Higgs in association with W/Z
- Direct discovery of heavy states
  - Drell-Yan production of TC-rho/axial (R1,R2)
  - (exotic) pions
  - composite fermions
  - 4th heavy lepton family

Conclusions

- Discovered the TC Higgs?
- 125 Higgs via a not too light TC Higgs!
- Minimal TC & LHC signatures

Lots of fun ahead !

Ask if interested!

- a-theorem Conformal Window
- Jumping dynamics
- Dark matter on the lattice
- Composite inflation
- X compositeness

White Paper

- Strong Dynamics for BSM
- Technicolor Higgs
- Minimal Walking Theories
- Composite Dark Matter
- Composite ...