

Technicolor

Francesco Sannino

CP³ - Origins



Particle Physics & Cosmology

9th b-Physics Workshop 2013

Fermi Scale

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

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$$M_H^2 = 2\lambda v^2$$

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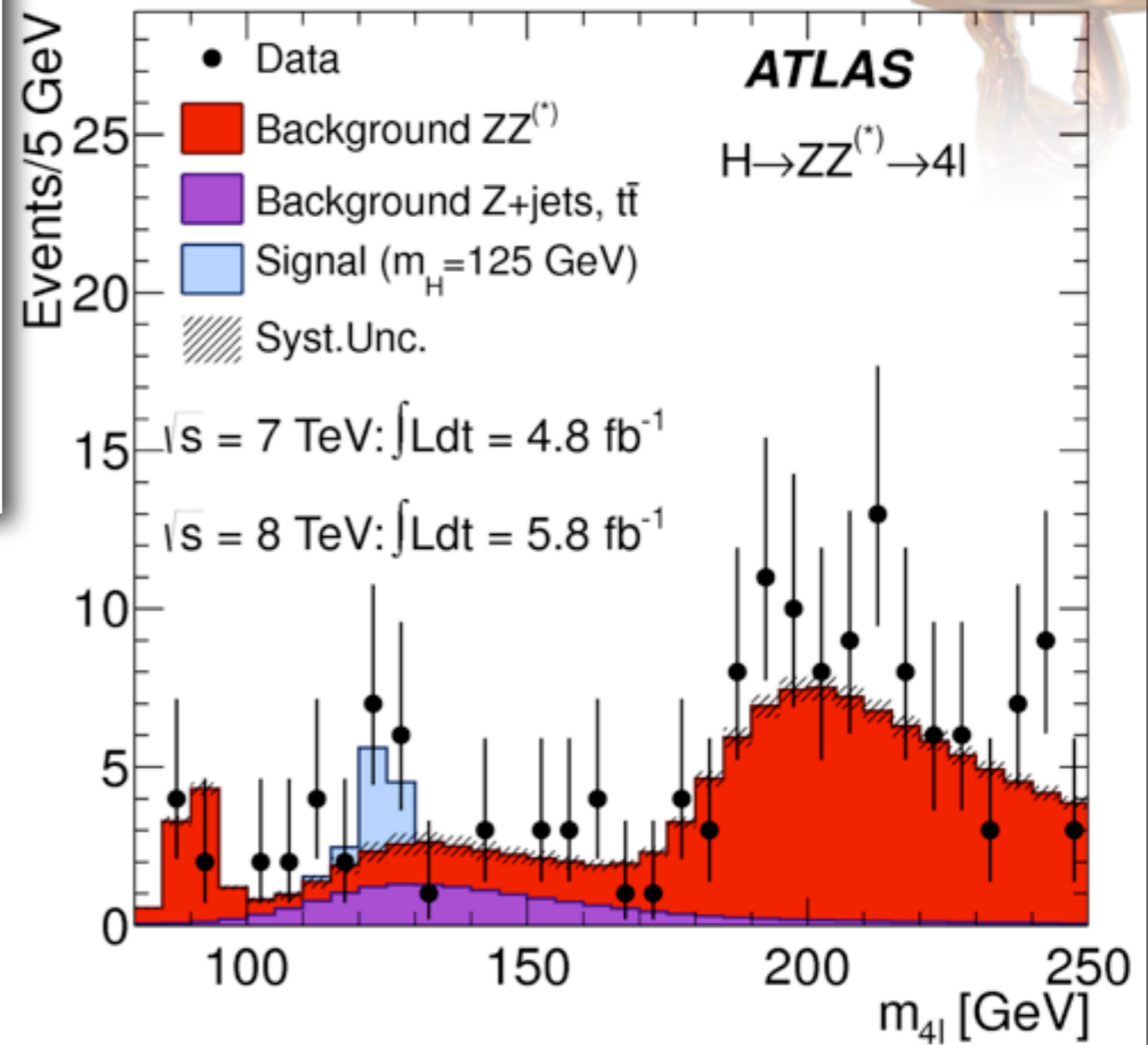
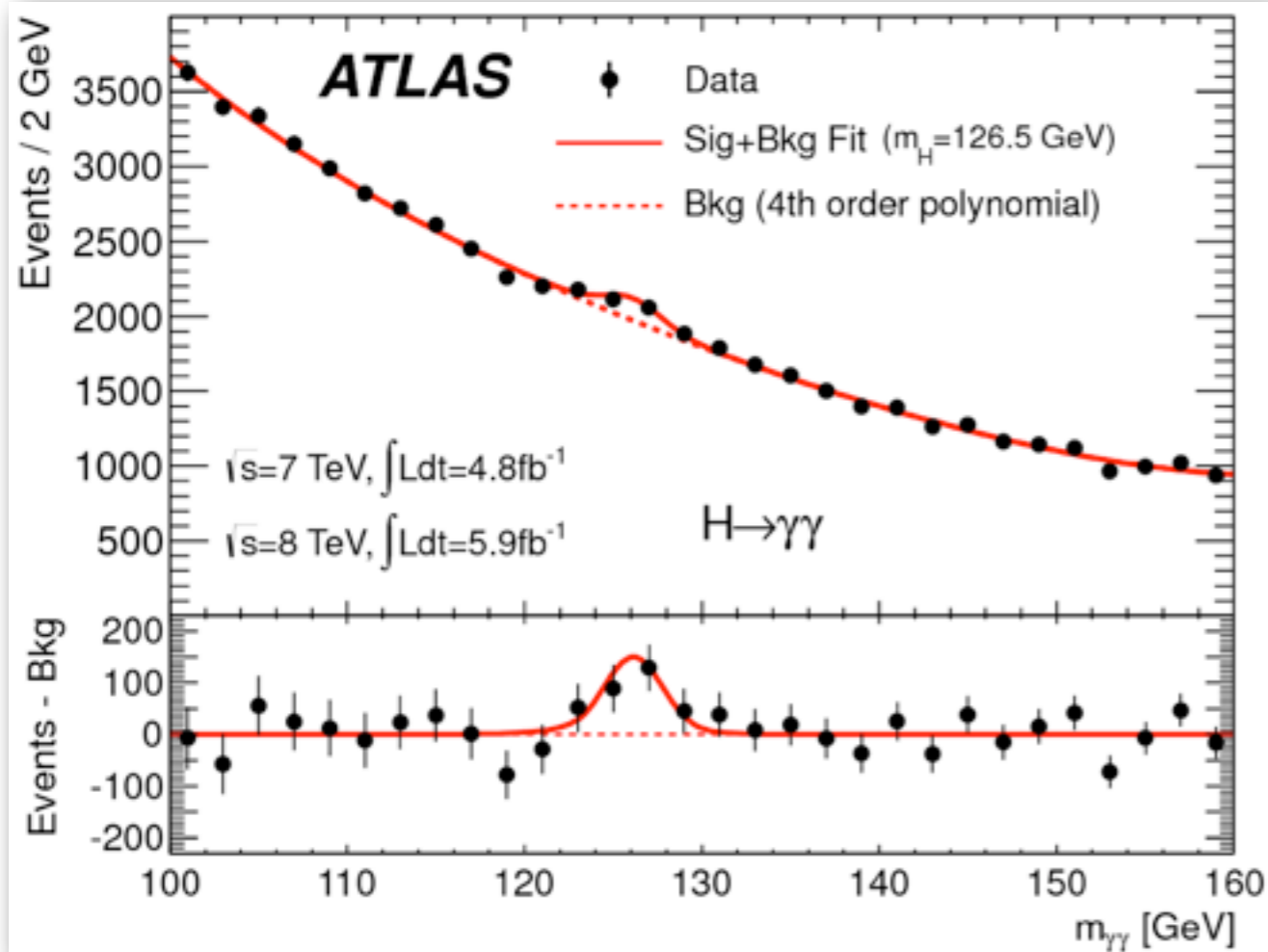
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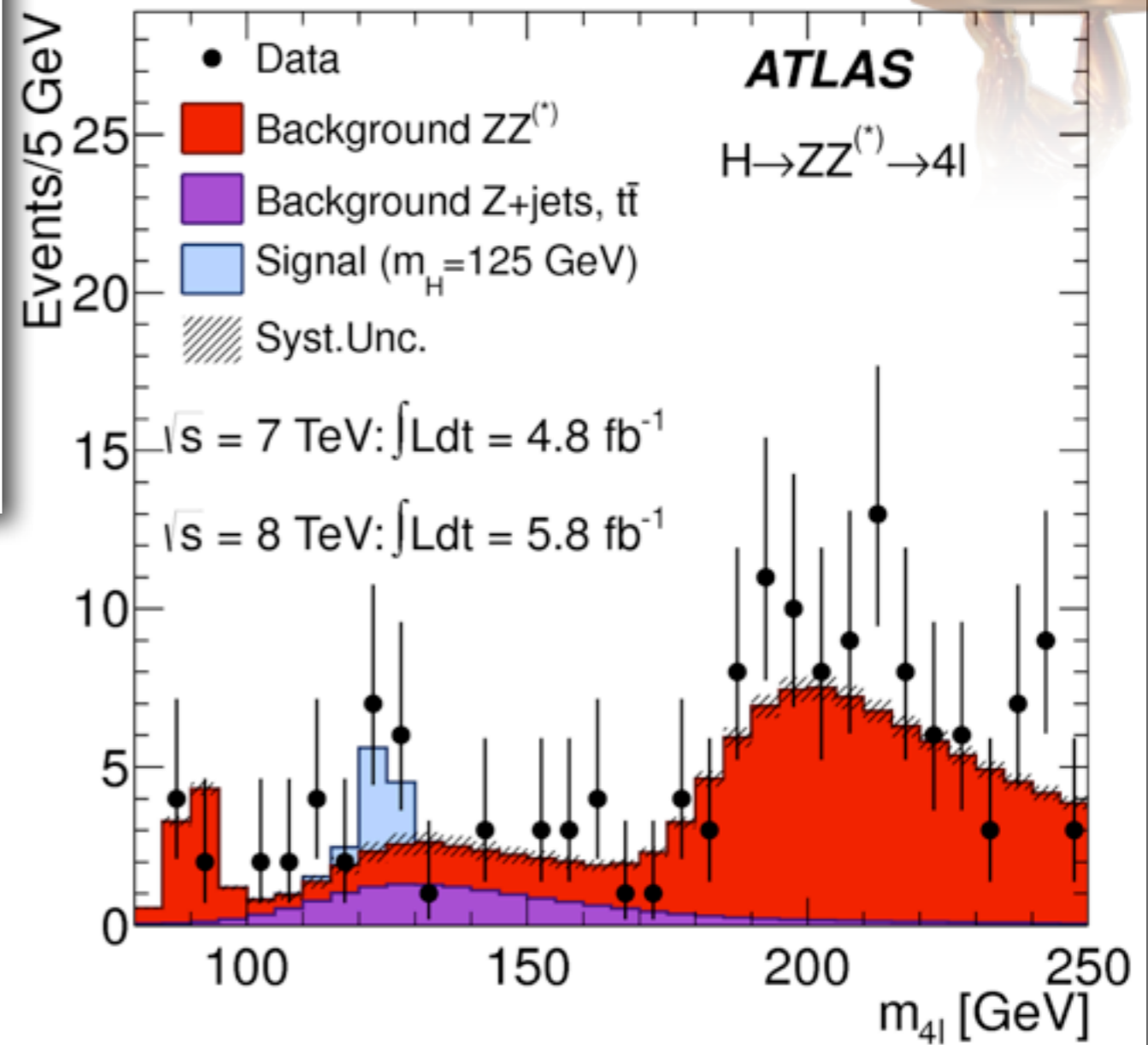
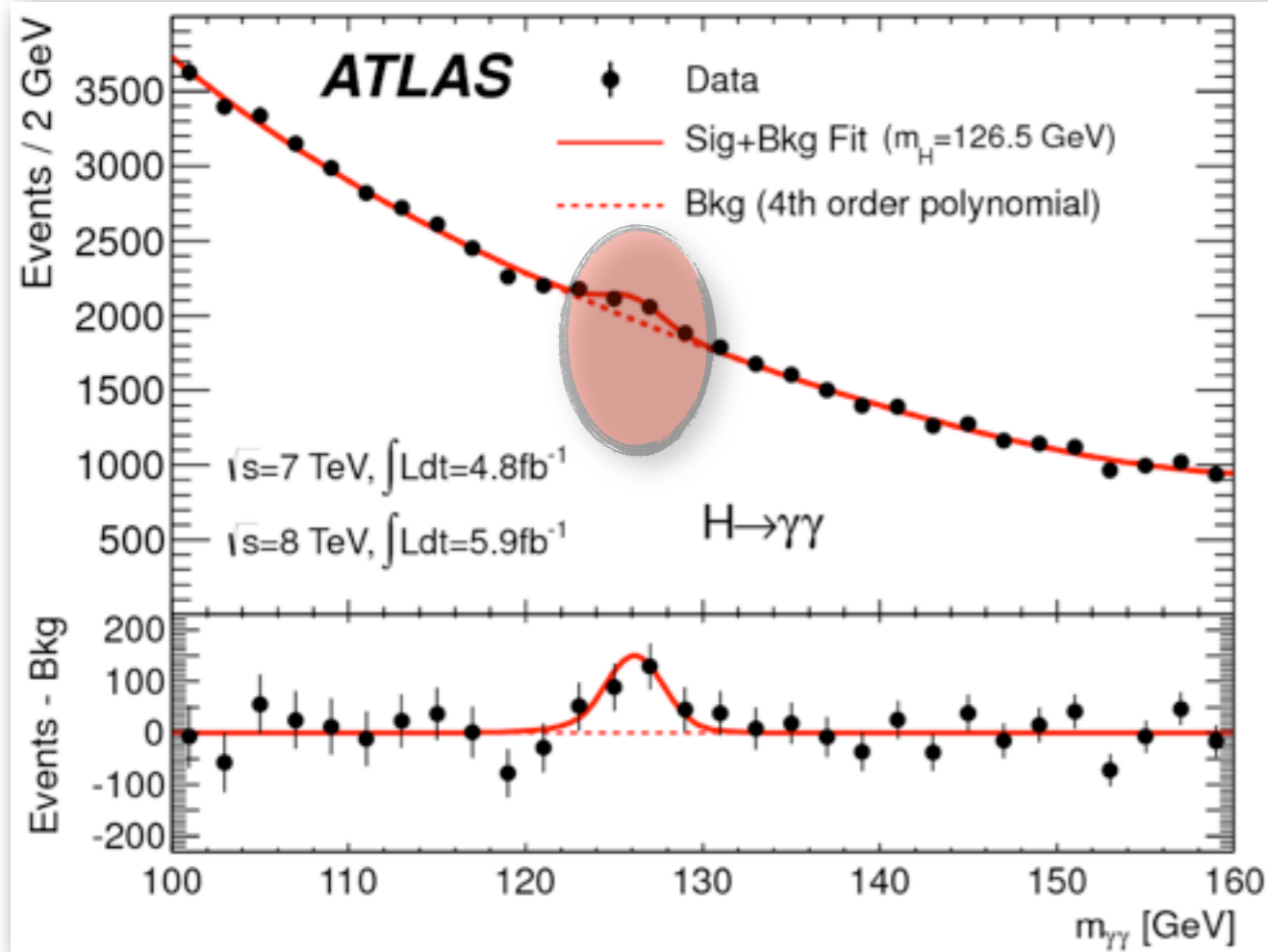
Light quarks and leptons are also natural!

The scent of the Higgs

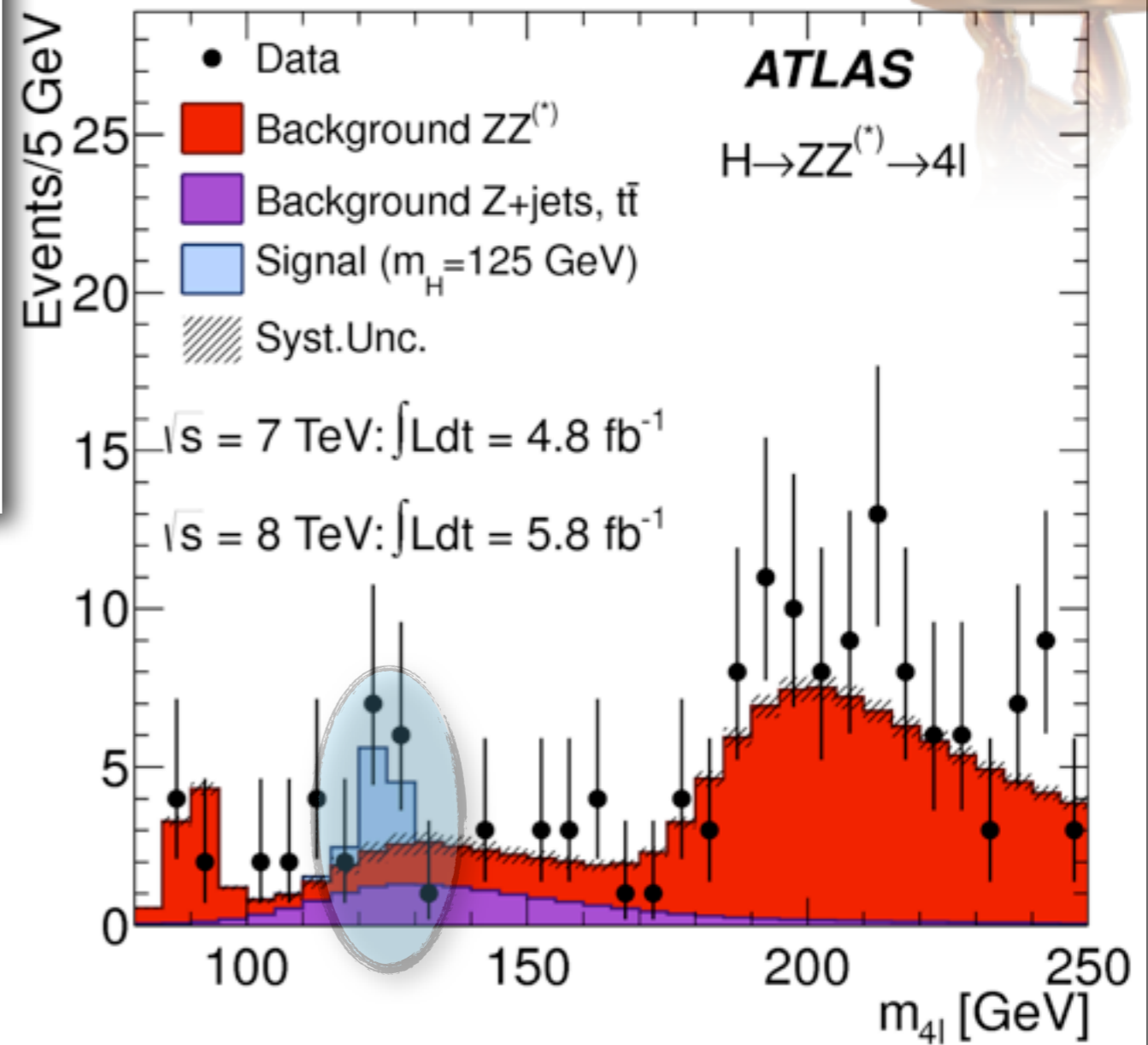
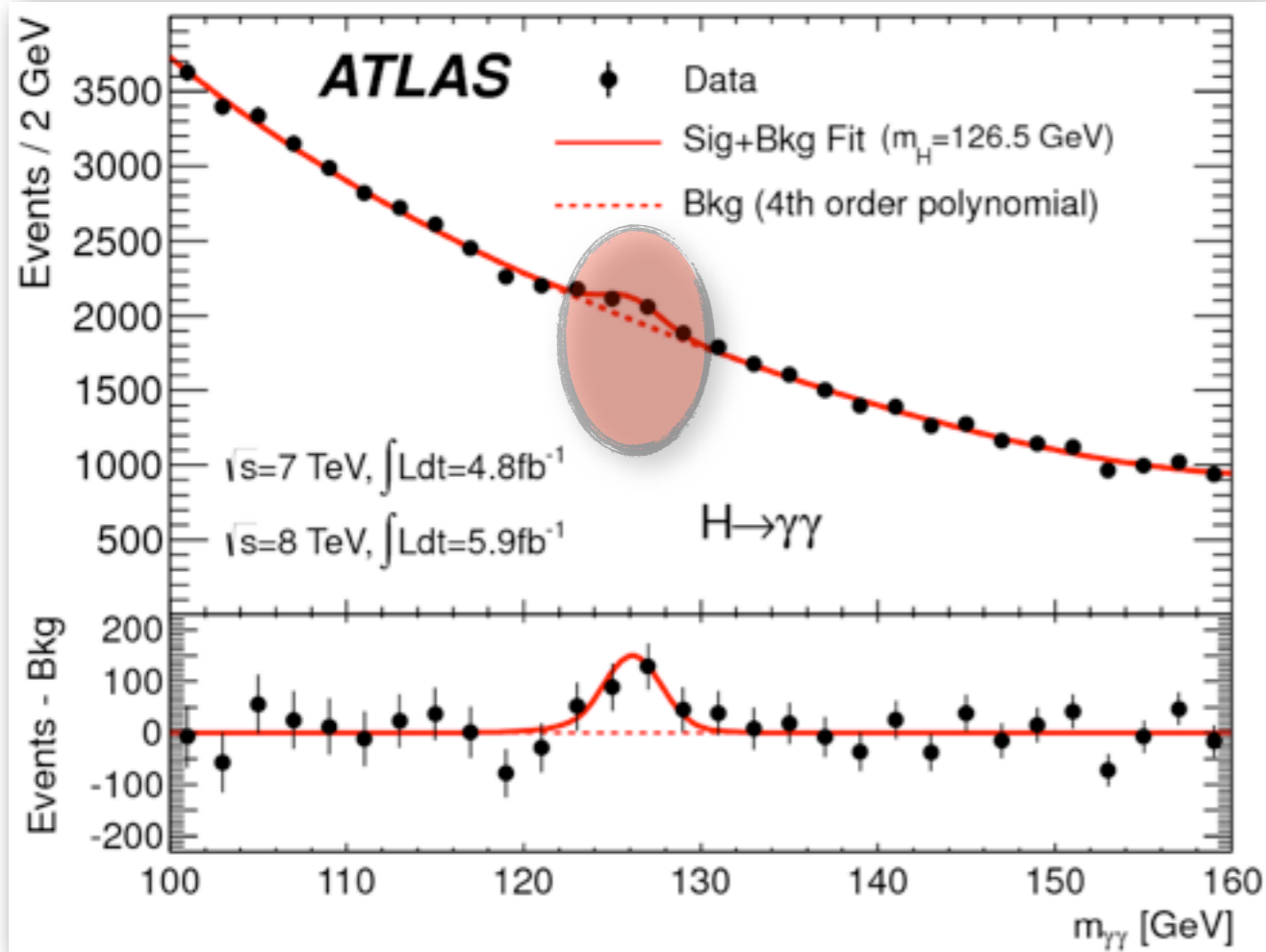
2 bumps



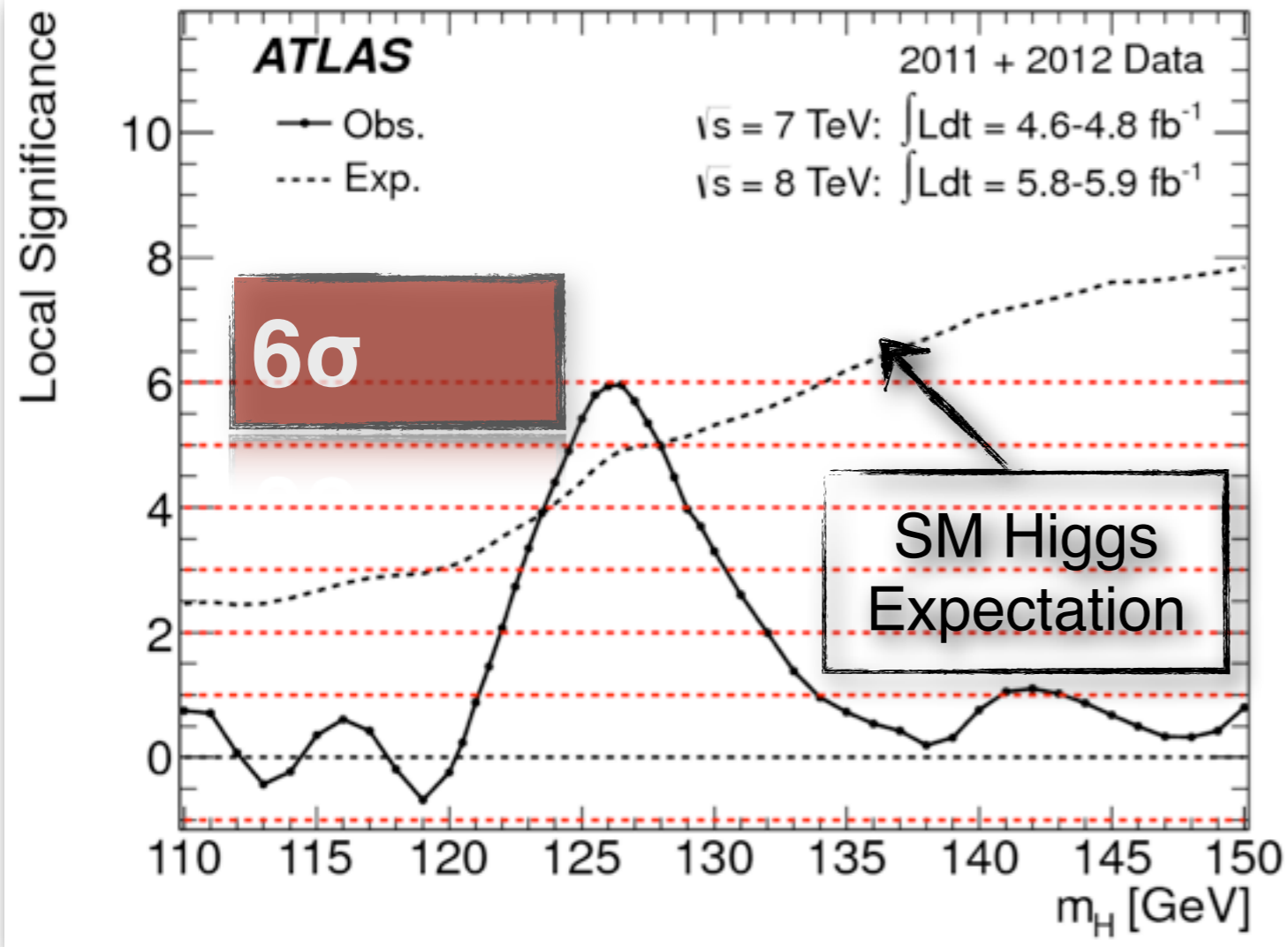
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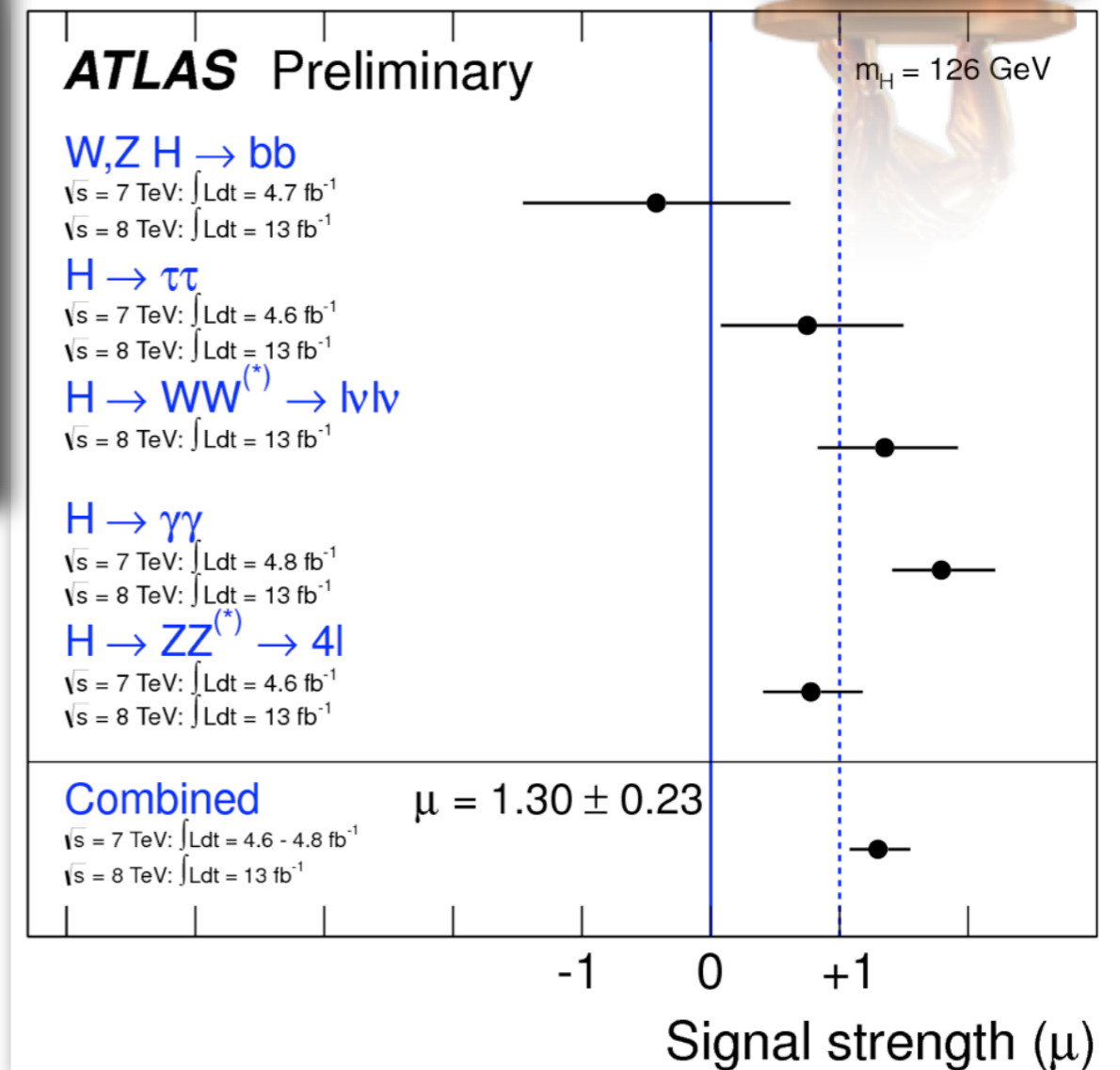
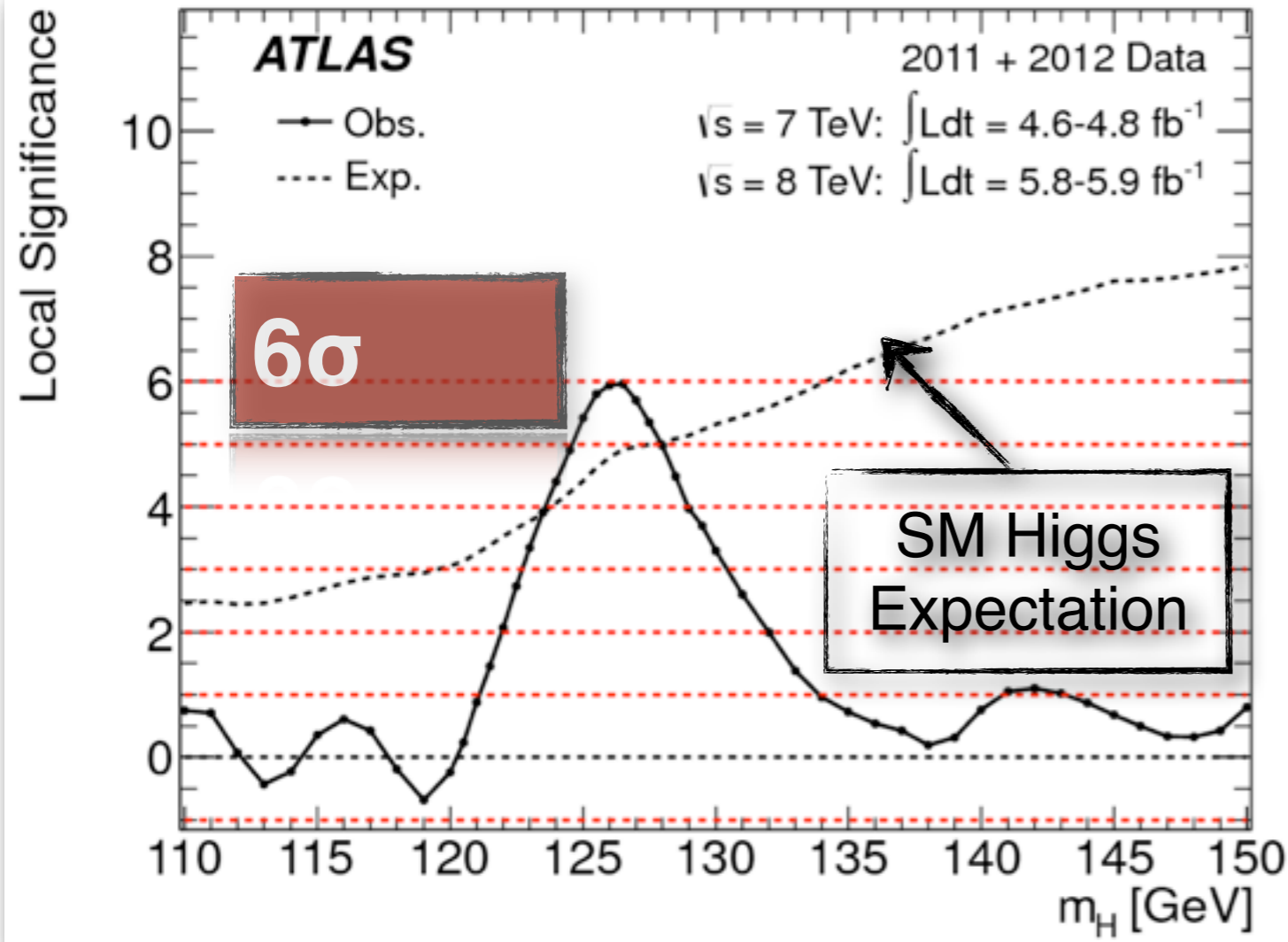
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Higgs discovery



Higgs discovery

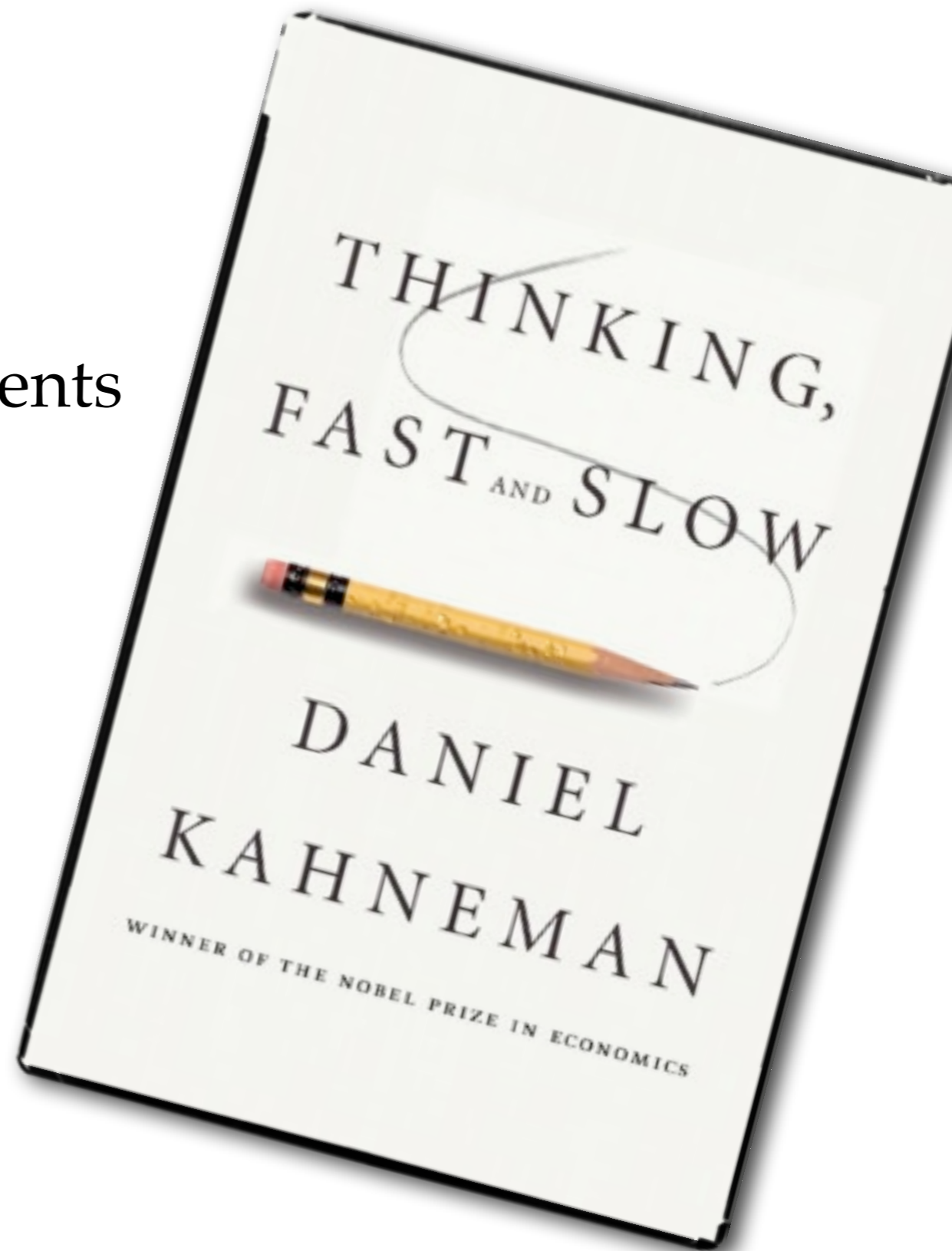


Fundamental ?

- 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

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

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Extended TC

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TC



Extended TC

Technicolor vs Composite Higgs

- Technicolor:

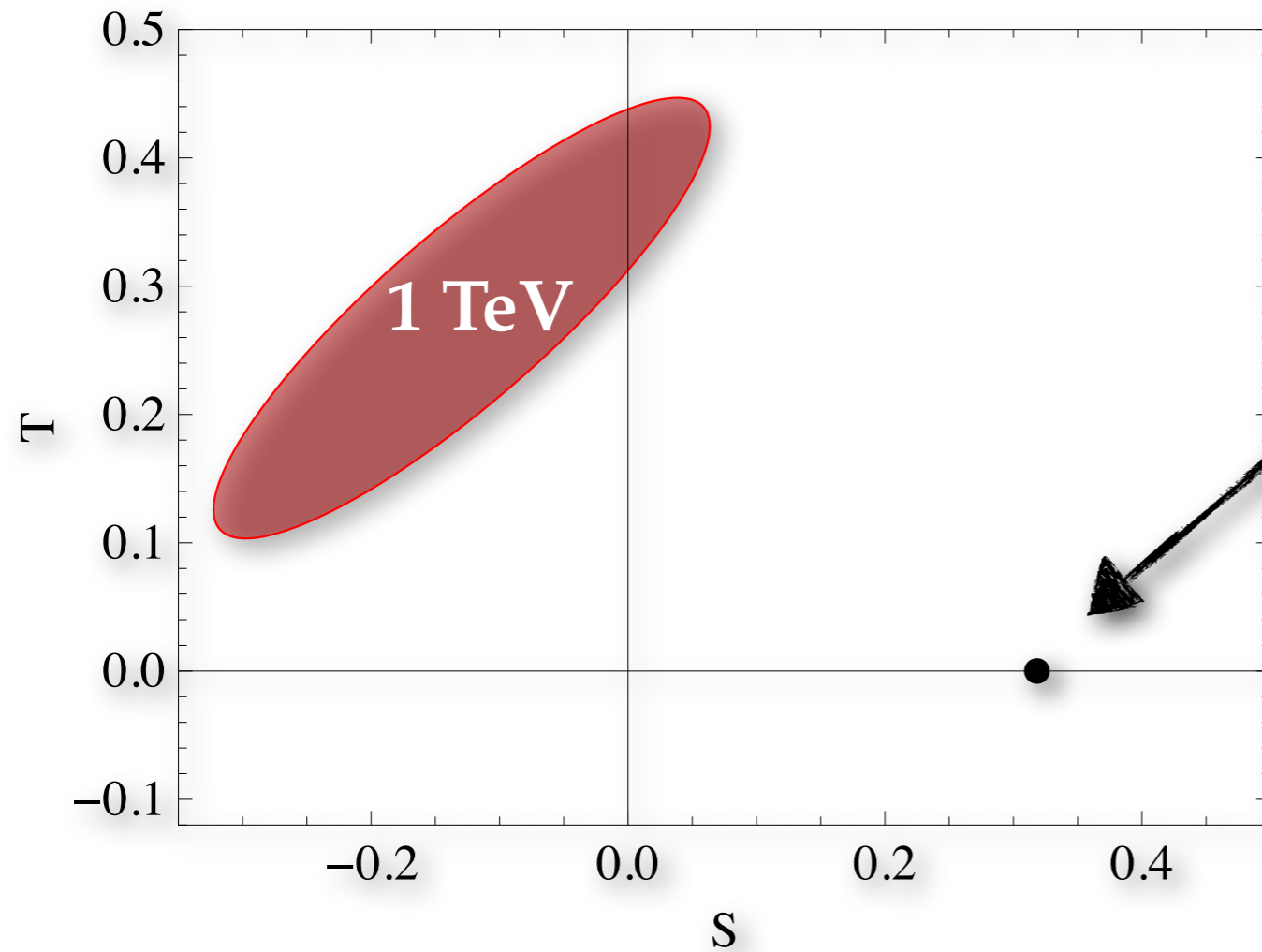
Composite Higgs theory with a 4D underlying theory

- Composite Higgs:

Higgs is a pGB. Need to generate mass and keep it small

If 4D underlying exists probably similar to Technicolor ?

Is “Old” Technicolor dead?

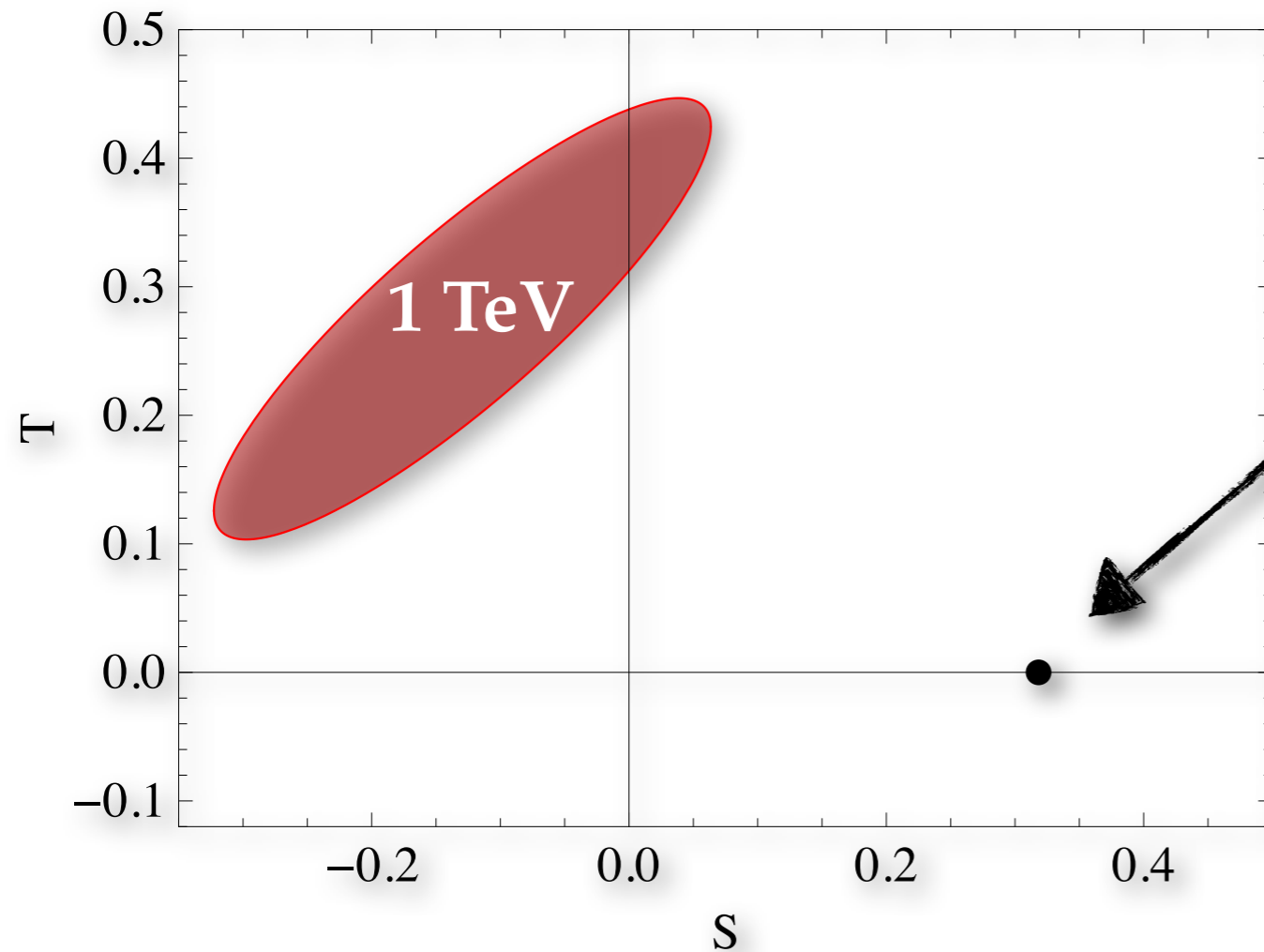


SU(3) + 1 Fund. Doublet

Weinberg, Susskind

$$M_H = \frac{F_{TC}}{F_\pi} M_\sigma \simeq 1.5 \text{ TeV}$$

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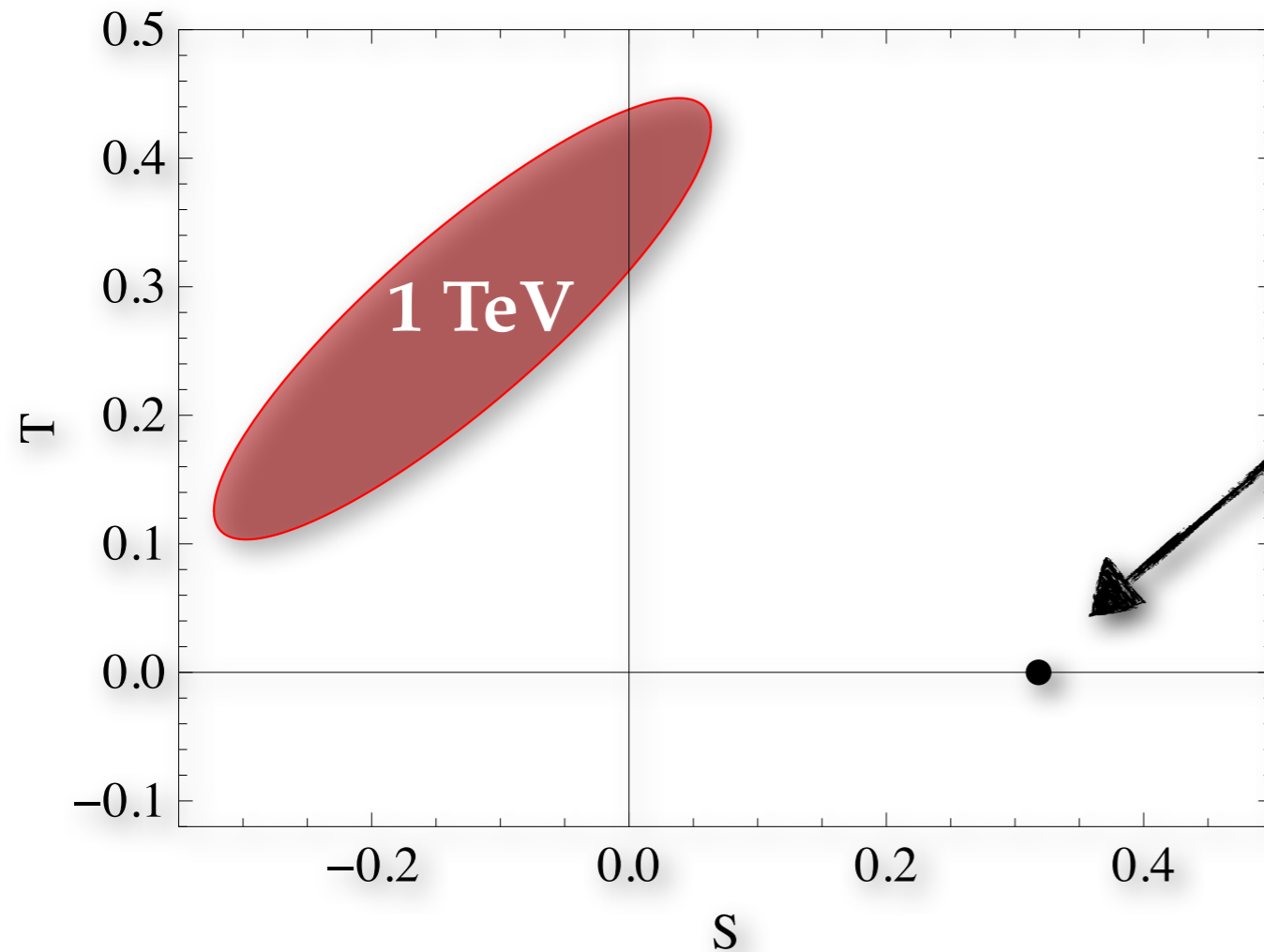
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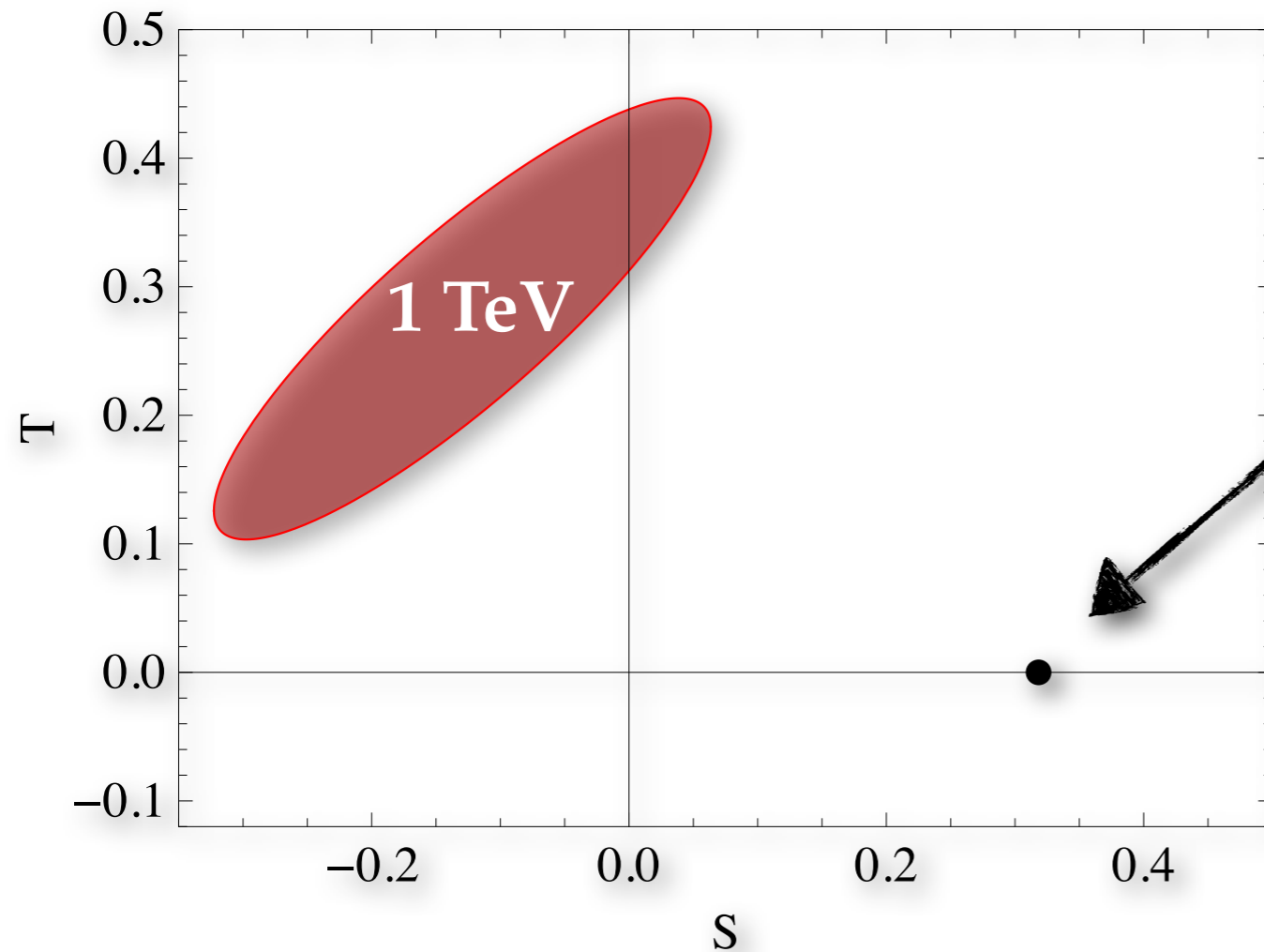
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Extend TC to generate fermion masses [Eichten & Lane]

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Extend TC to generate fermion masses [Eichten & Lane]

Old TC was dead 2 decades ago

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 $\sim 400-550$ 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

Higgs Effective Theory

Higgs Effective Theory

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

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 \end{aligned}$$

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

$$D_\mu U \equiv \partial_\mu U - ig W_\mu^a T^a U + ig' U B_\mu T^3$$

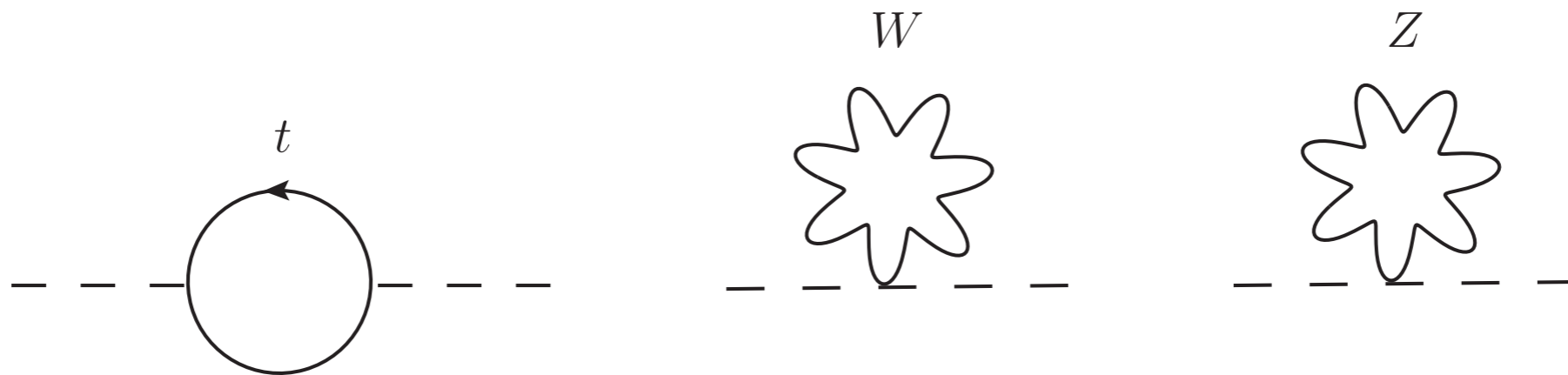
EW - corrections

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

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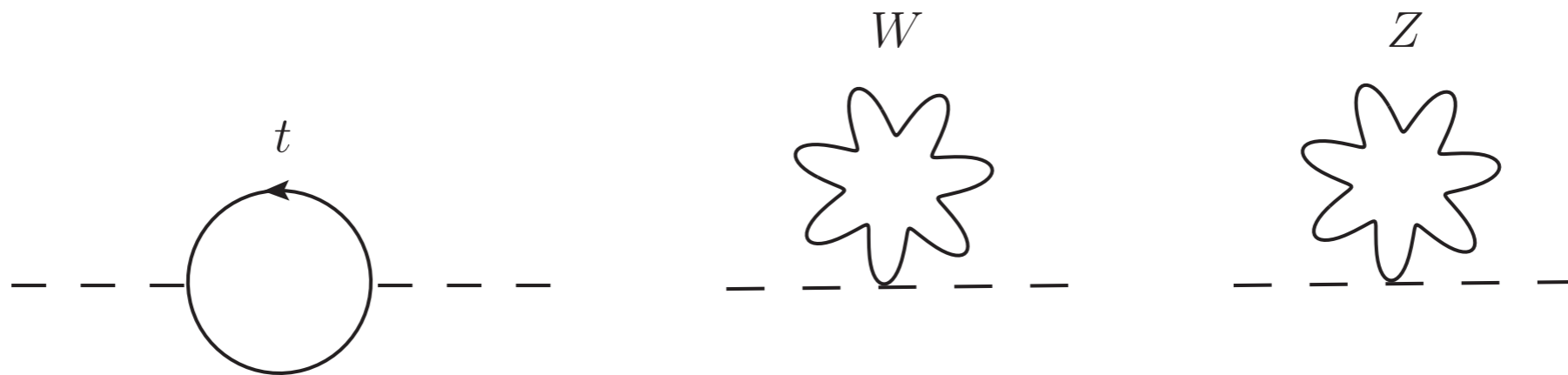
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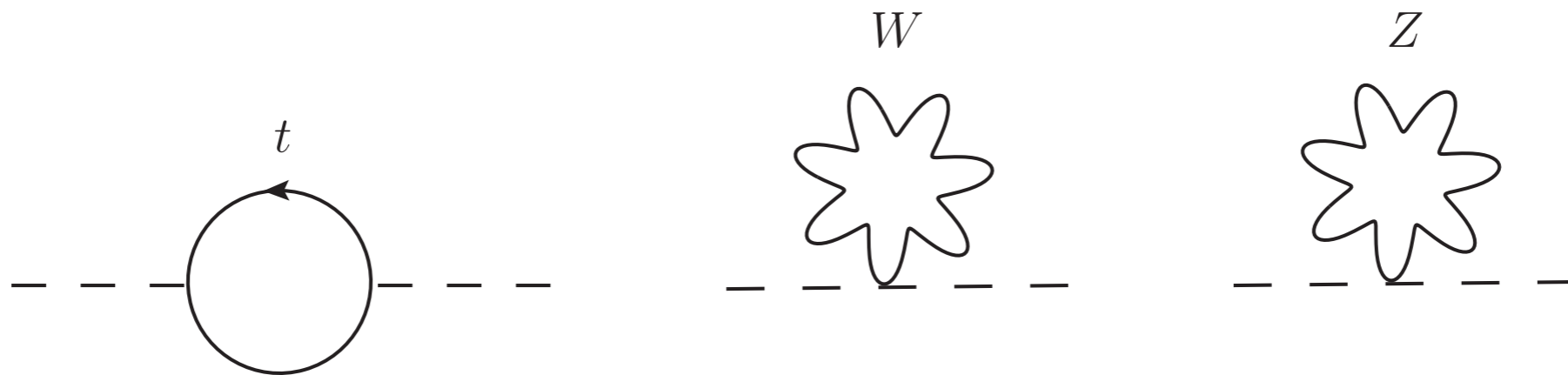


$$M_H^2 = (M_H^{\text{TC}})^2 + \frac{3(4\pi\kappa F_\Pi)^2}{16\pi^2 v^2} \left[-4r_t^2 m_t^2 + 2s_\pi \left(m_W^2 + \frac{m_Z^2}{2} \right) \right] + \Delta_{M_H^2} (4\pi\kappa F_\Pi)$$

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How light is the TC-Higgs ?

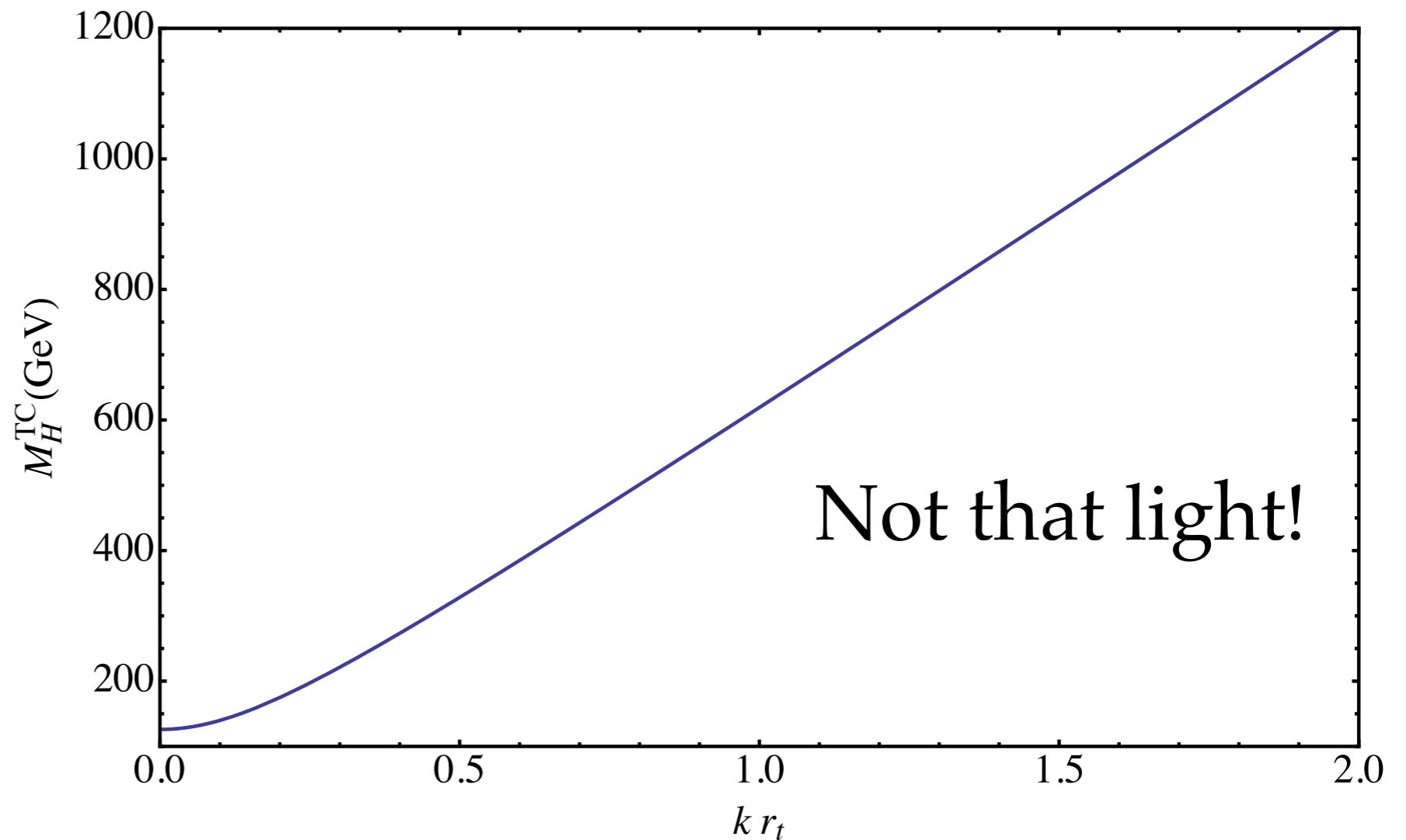
$$(M_H^{\text{TC}})^2 \simeq M_H^2 + 12 \kappa^2 r_t^2 m_t^2 \quad \kappa r_t \sim \text{TC} \times \text{ETC}$$

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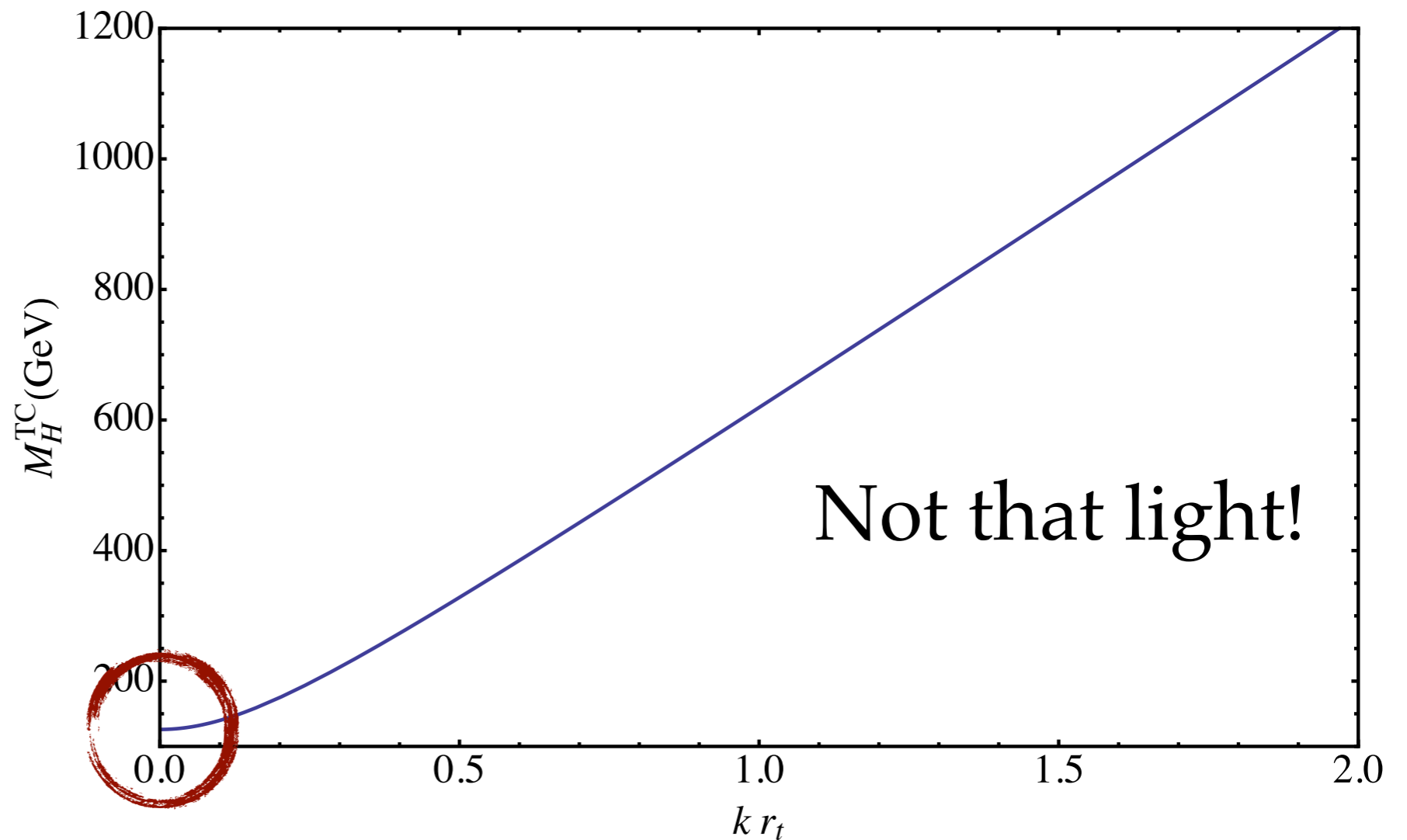
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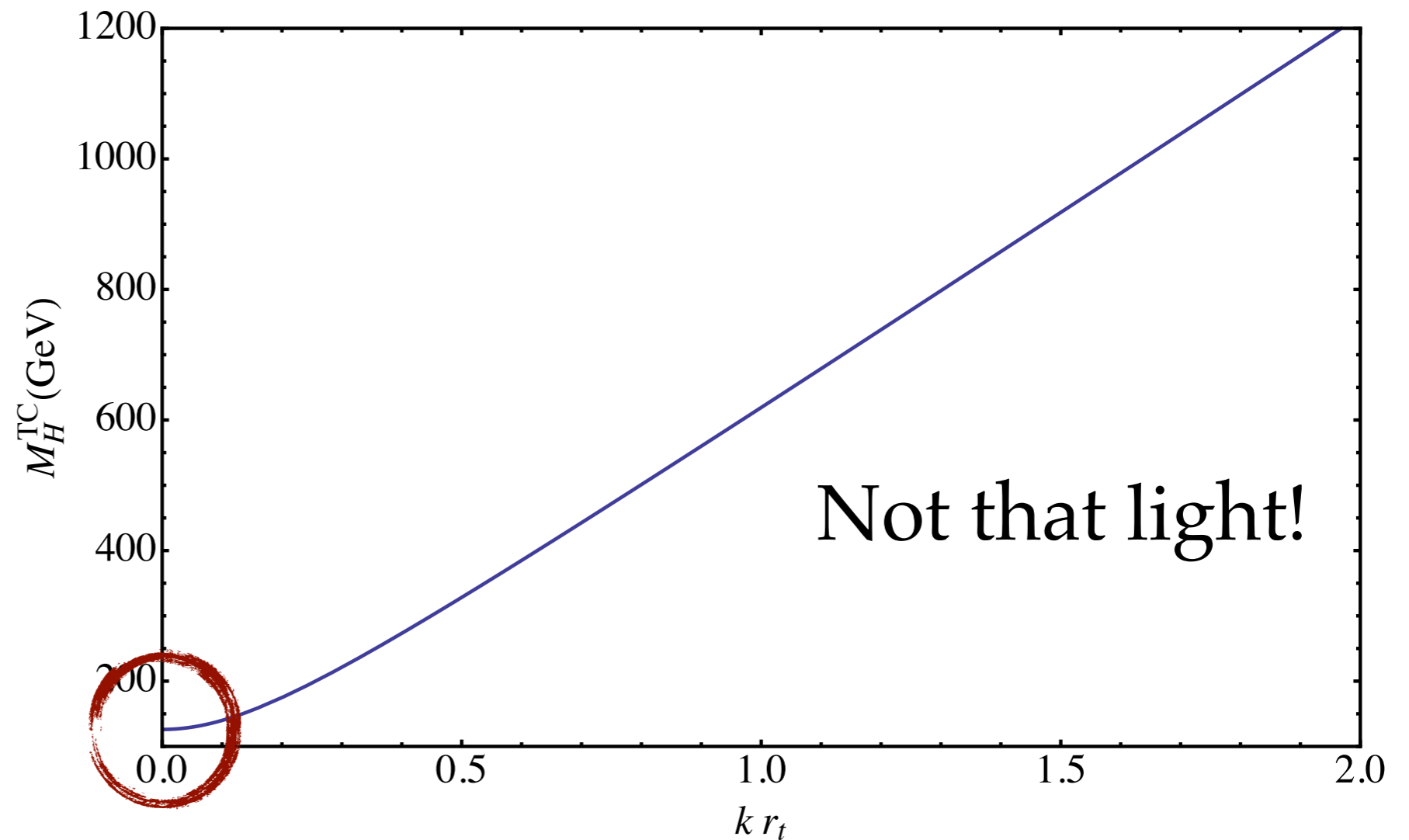
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Narrow due to kinematics [Similar to $f_0(980)$ in QCD]

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

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

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Physical Higgs mass via gauge geometry

Sannino 08

Sannino & Schechter 07

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Realistic theories ?

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

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****Next to Minimal Walking TC**

Sannino & Tuominen hep-ph/0405209

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

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$$M_\rho \simeq 1754 \pm 104 \text{ GeV}$$

$$M_{A_1} \simeq 2327 \pm 121 \text{ GeV}$$

A Minimal TC template

Since 2004 - Minimal WTC is Higgsfull

[Original Name: Light Composite Higgs]

The standard model

Elementary particles

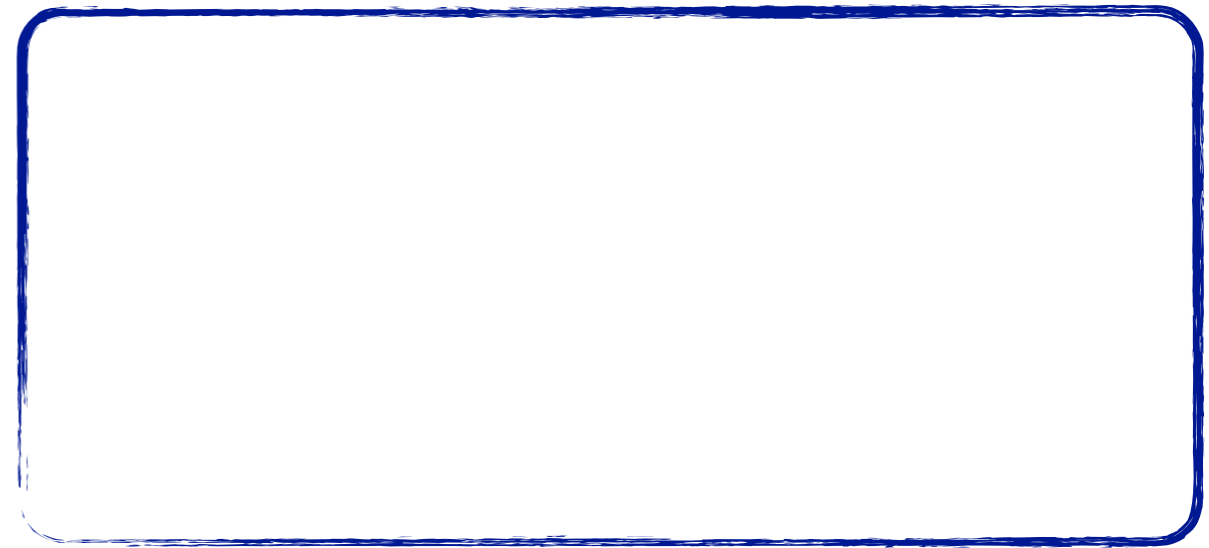
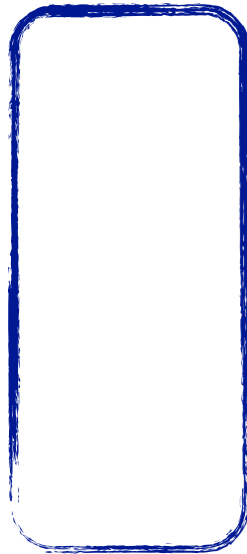
Quarks	u up	c charm	t top	γ photon
	d down	s strange	b bottom	Z Z boson
Leptons	ν_e electron neutrino	ν_μ muon neutrino	ν_τ tau neutrino	W^+ W+ boson
	e electron	μ muon	τ tau	W^- W- boson
			g gluon	
	Higgs			

Source: AAAS *Yet to be confirmed

U(1)

SU(2)

SU(3)



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N

Extra Neutrino

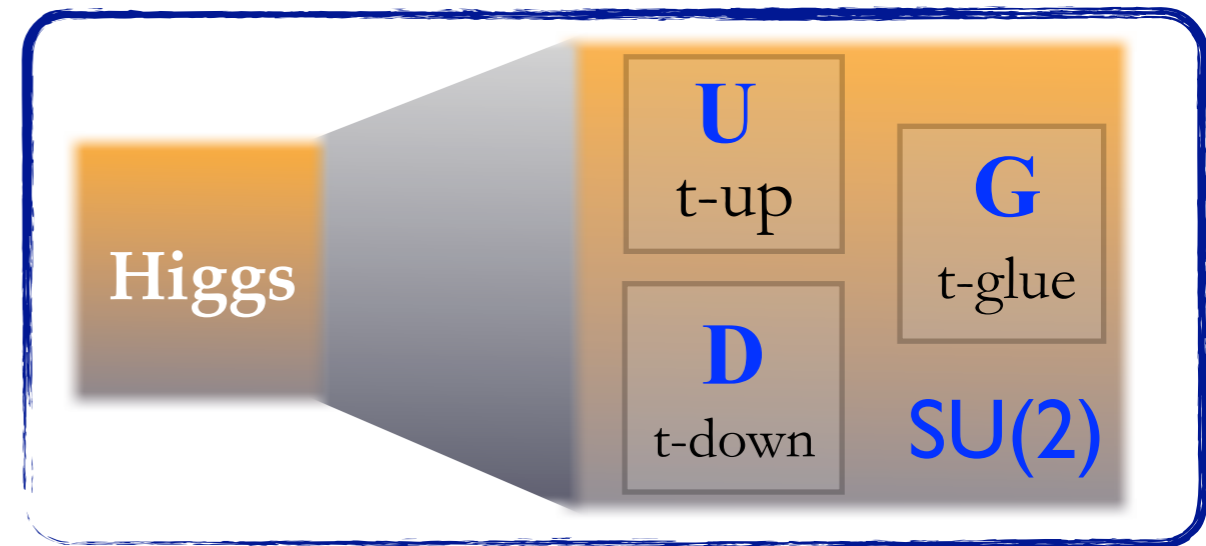
⤵

Extra Electron

U(1)

SU(2)

SU(3)



Sannino, Tuominen 04

Hong, Hsu, Sannino 04

Dietrich, Sannino, Tuominen 05

Since 2004 - Minimal WTC is Higgsfull

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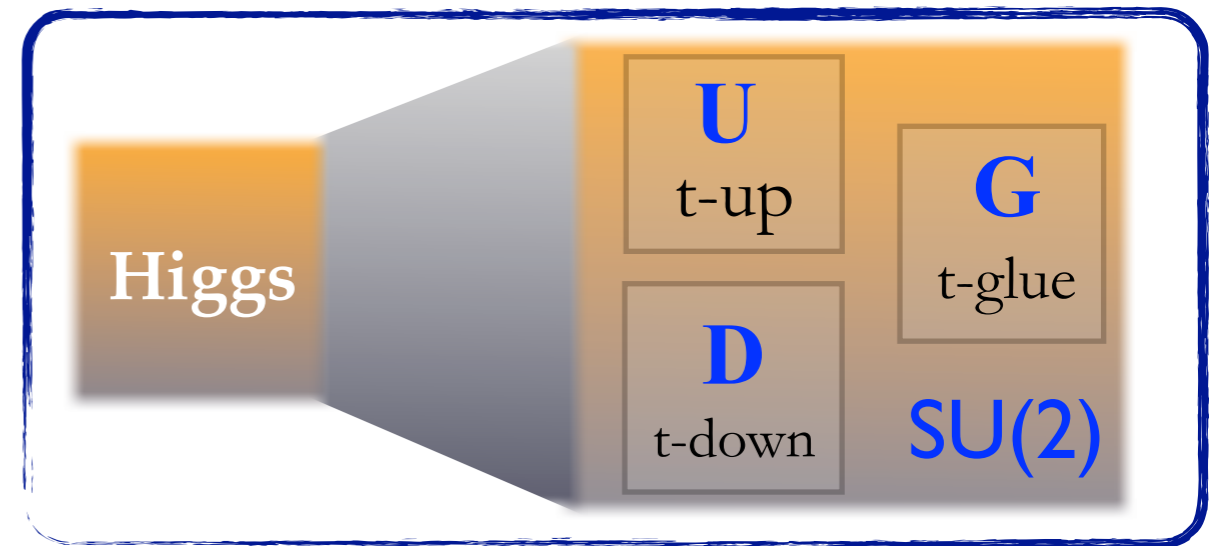
N
Extra Neutrino

e
Extra Electron

U(1)

SU(2)

SU(3)



● Can feature Light TC/Dilaton Higgs

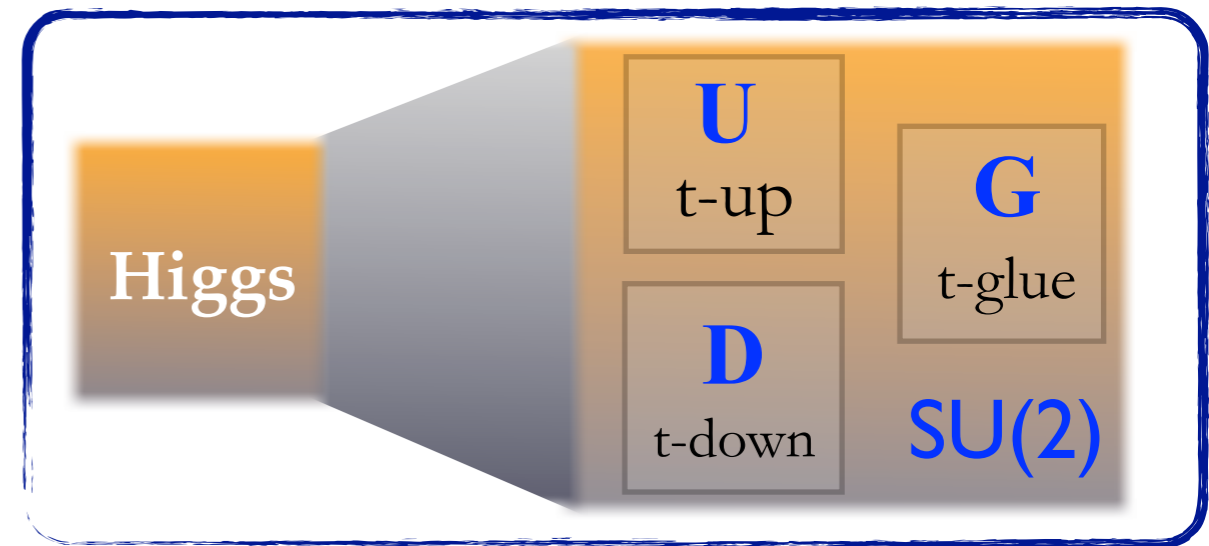
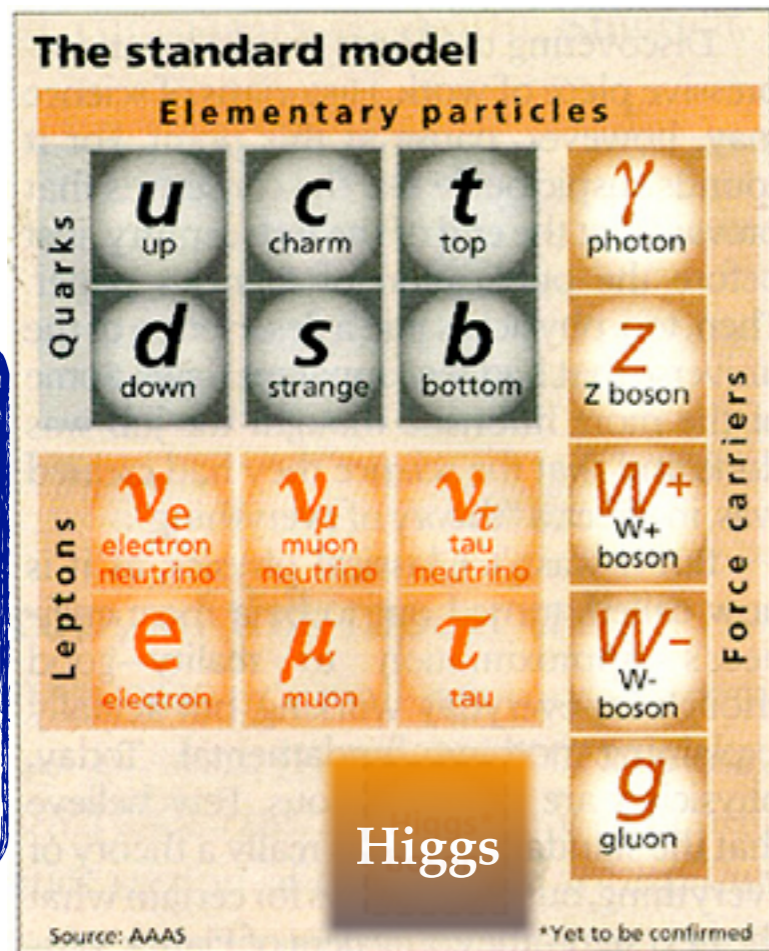
Sannino, Tuominen 04

Hong, Hsu, Sannino 04

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Sannino, Tuominen 04

Hong, Hsu, Sannino 04

Dietrich, Sannino, Tuominen 05

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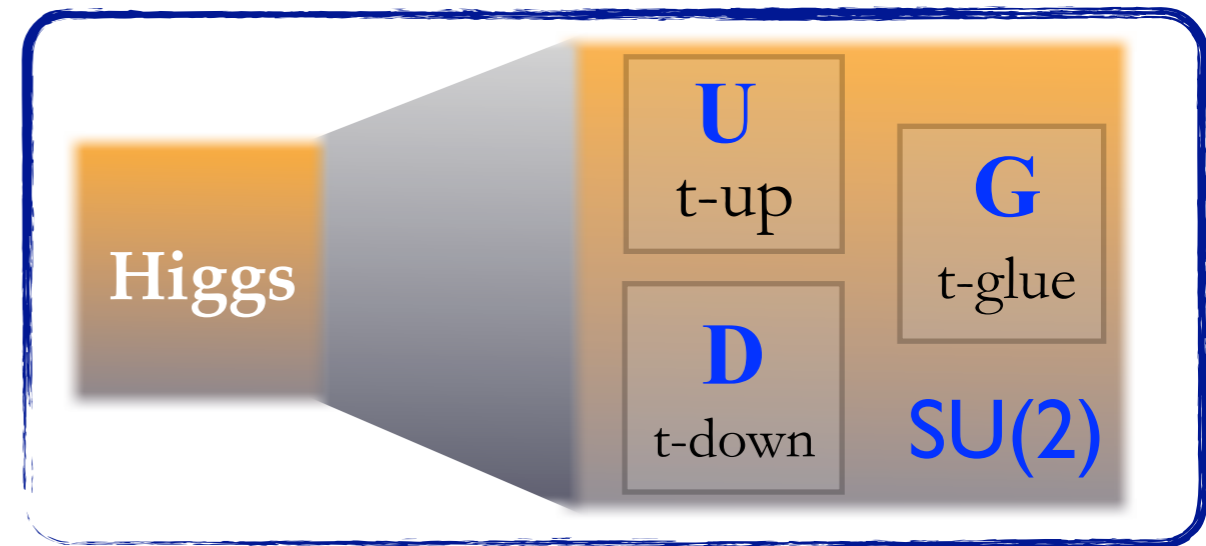
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- Dark matter candidates

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

Minimal TC states to discover

Higgs - like

TC Axial - Vector States



Minimal TC states to discover

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

Higgs to $\gamma\gamma$

Sensitive TC-fermion content

$$\Gamma(H \rightarrow \gamma\gamma) \sim \left(r_t - 7r_W + \frac{3}{4} \sum_{Q_{\text{TC}}} d(R_{\text{TC}}) e_{\text{TC}}^2 \right)^2$$

and to the H-tt coupling r_t (Extended TC)

$$pp \rightarrow H \sim r_t^2$$

H to $\gamma\gamma$ can help discriminate different models

$$\mathcal{L}_H \supset \frac{2 m_W^2 r_W}{v} H W_\mu^+ W^{-\mu} - \frac{m_t r_t}{v} H \bar{t} t$$

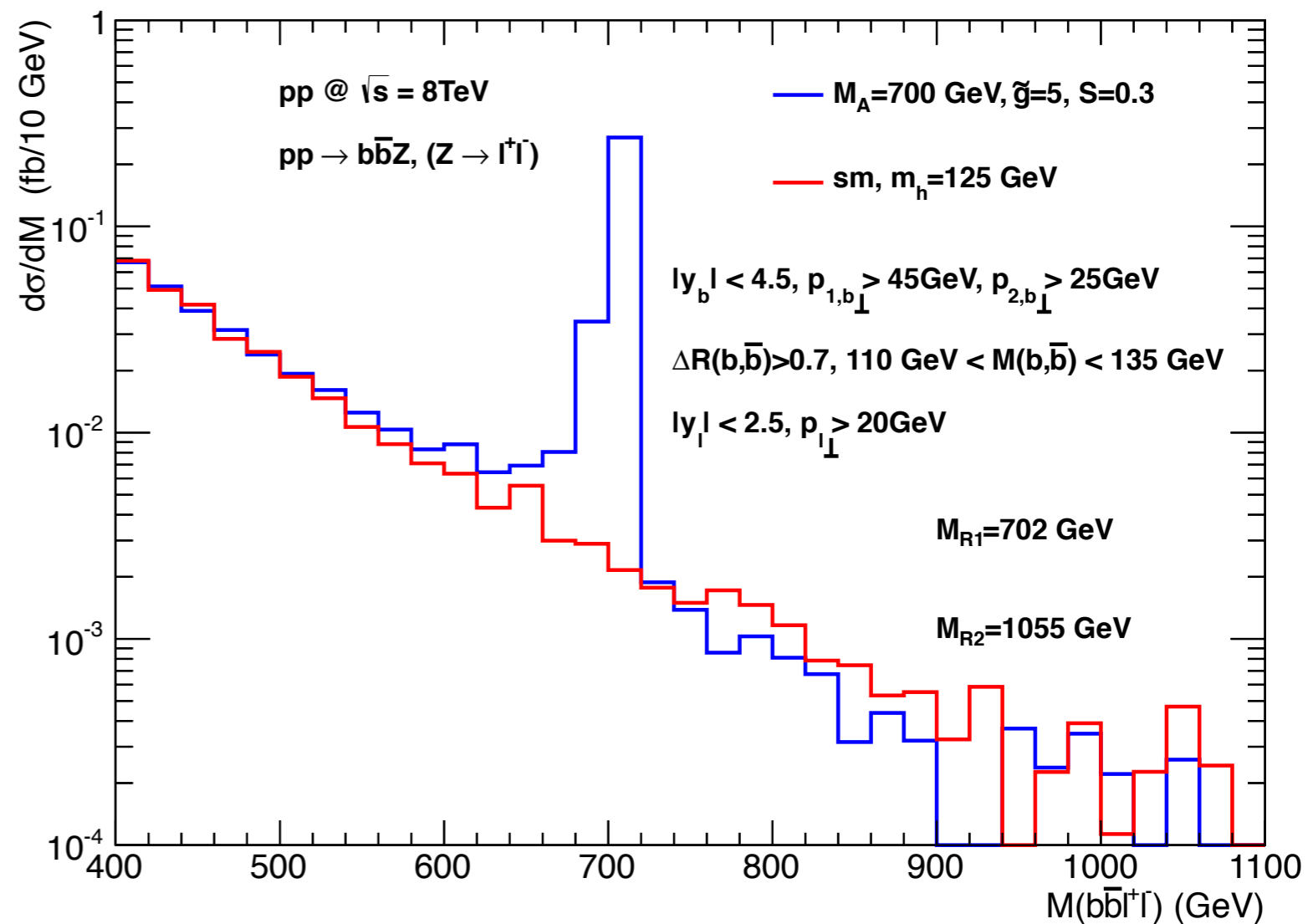
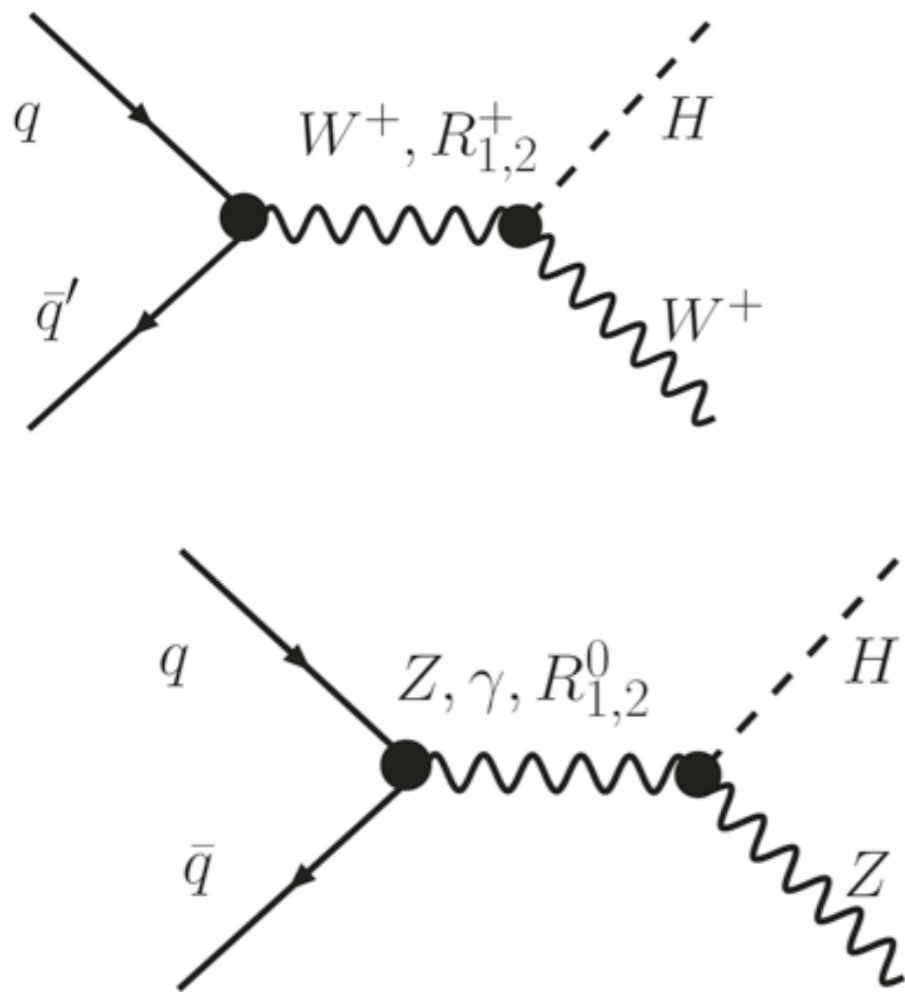
Associate TC-Higgs production

Potential discovery of composite dynamics at the LHC

Composite spin-1 mesons like QCD ρ & a_1

Belyaev, Foadi, Frandsen, Jarvinen & Sannino 08

$$pp \rightarrow HZ \rightarrow \bar{b}b + 2\ell$$



Preliminary MWTC - theoretical updated analysis by T. Hapola

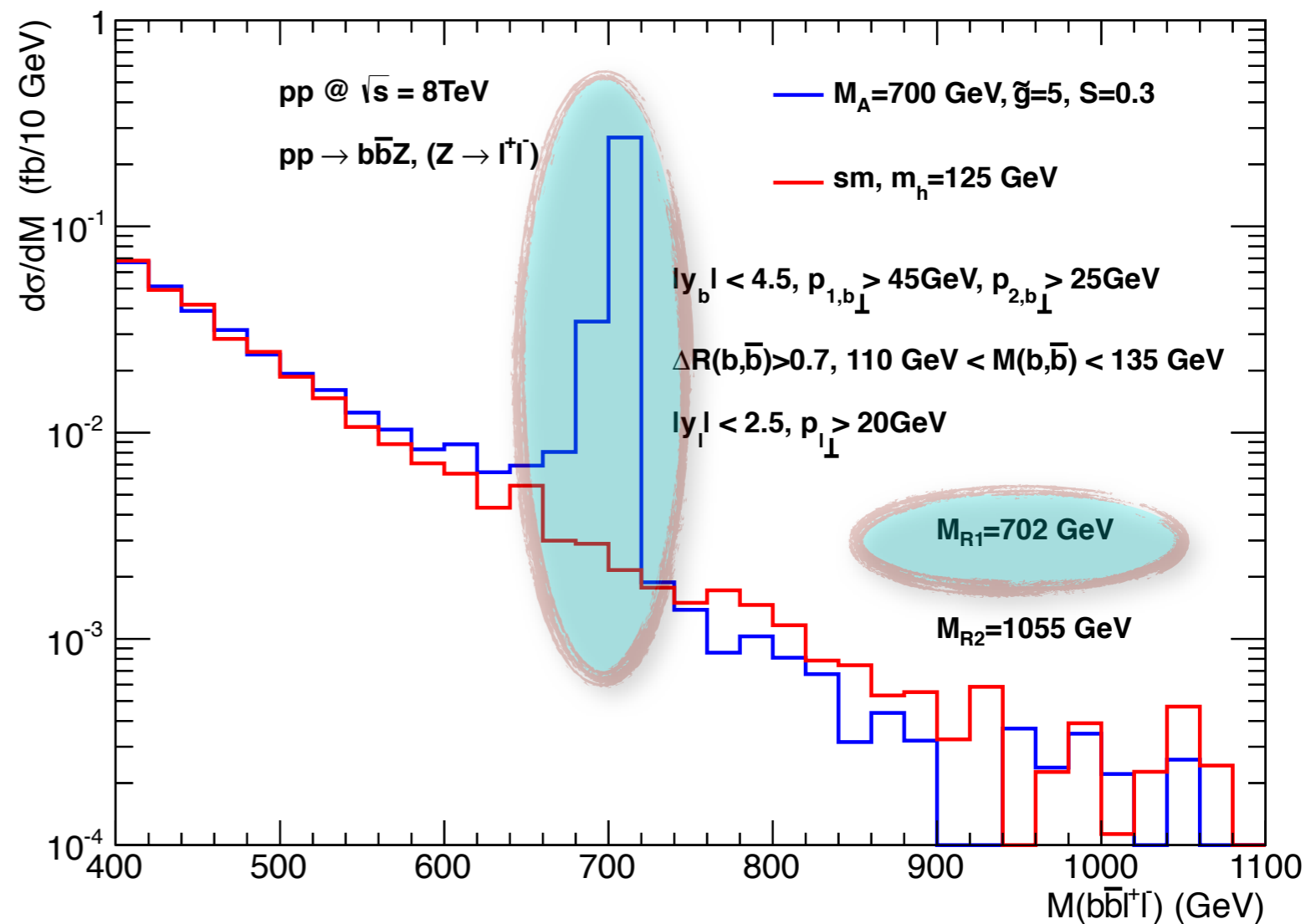
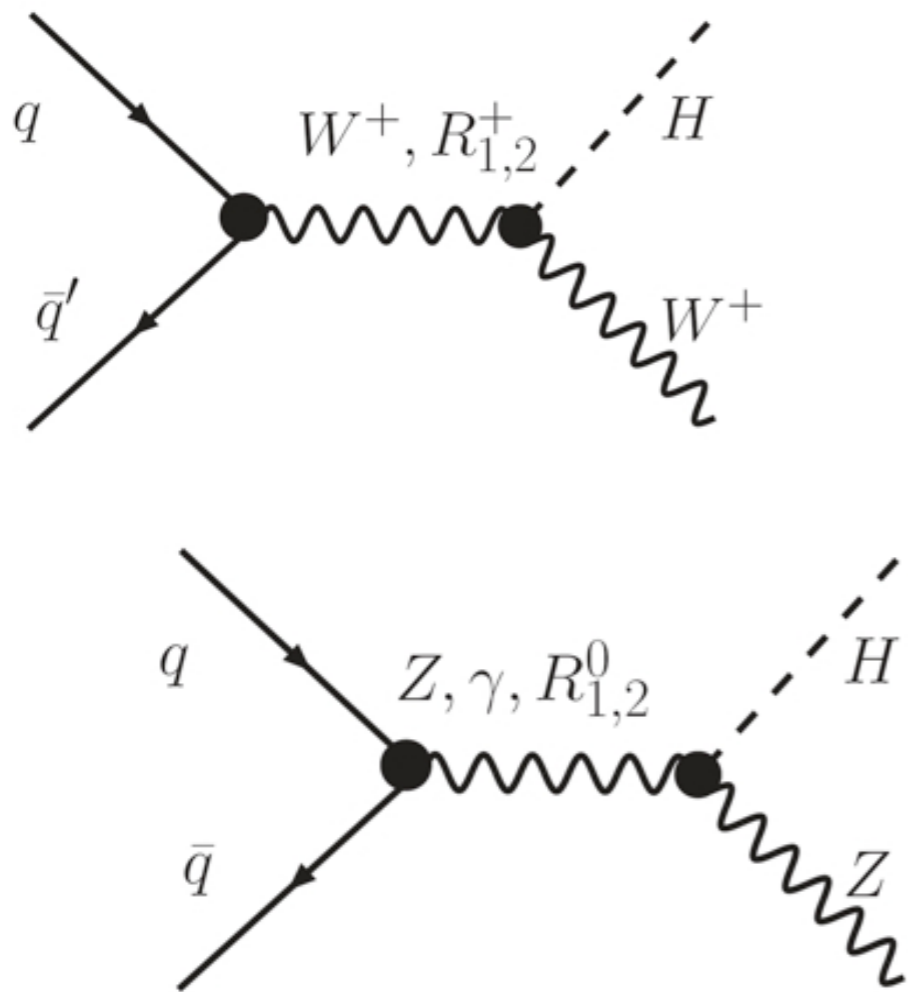
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Conclusions

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

Lots of fun ahead !