The Dilaton/Radion and the 125 GeV Resonance

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Introduction

The discovery of a new Higgs-like particle with mass close to 125 GeV is a watershed in high energy physics!

The All-Important Question:

Is the new particle the SM Higgs, a close relative or a rank impostor?

Difficult to answer in general. Focus instead on two more specific questions.

- **Could the 125 GeV resonance be a dilaton/radion rather than a Higgs?**
- **Could the 125 GeV resonance be a SM-like Higgs, but with an admixture of dilaton/radion?**

What is the dilaton?

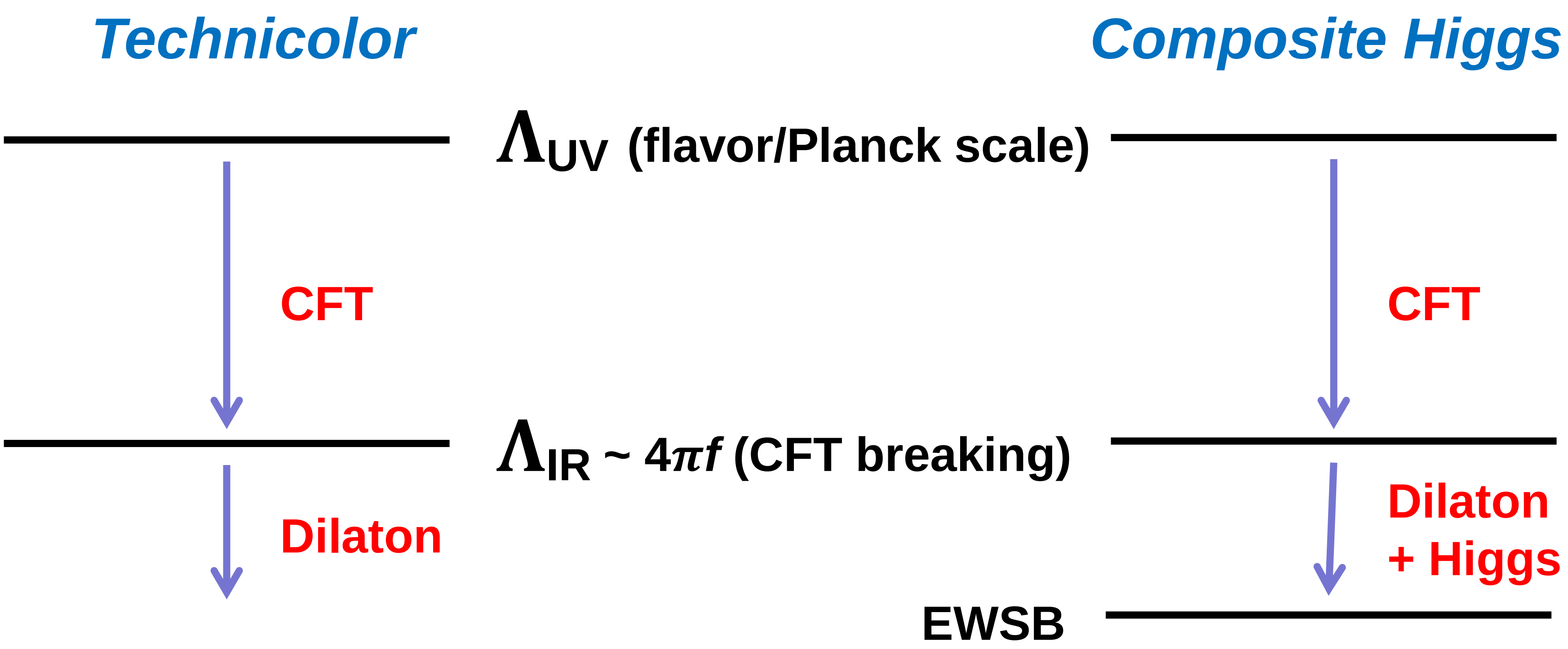
In theories where an exact conformal symmetry is spontaneously broken, the low energy effective theory contains a massless scalar, the dilaton.

The dilaton can be thought of as the NGB asociated with the breaking of conformal invariance. (Just 1 NGB, not 5, because conformal invariance is a space-time symmetry.)

The form of the dilaton couplings is fixed by the requirement that conformal symmetry be realized non-linearly ➔ very predictive!

Strong conformal dynamics plays an important role in many theories of electroweak symmetry breaking. Can help address the flavor problem in technicolor and composite Higgs models.

When this (approximate) conformal symmetry is broken, the low energy spectrum of composite states may contain a light dilaton, a light Higgs doublet, or both.



How does the dilaton couple?

Below the breaking scale the conformal symmetry is realized non-linearly. Under scale transformations,

$$x^\mu \to x'^\mu = e^{-\omega} x^\mu$$

the dilaton $\sigma(x)$ transforms as

$$\sigma(x) \to \sigma'(x') = \sigma(x) + \omega f$$

where f is the symmetry breaking scale.

It is convenient to define the object $\chi(x)$, which transforms linearly under scale transformations.

$$\chi(x) = f e^{\sigma(x)/f}$$

Under the scale transformation

$$x^\mu \rightarrow x'^\mu = e^{-\omega} x^\mu$$

$$\chi(x) \rightarrow \chi'(x') = e^{\omega}\, \chi(x)$$

The low energy effective theory will in general contain all terms consistent with this transformation.

The object χ(x) couples as a conformal compensator.

This can be used to obtain, for example, the dilaton couplings to massive gauge bosons,

$$\left(\frac{\chi}{f}\right)^2 m_W^2 W_\mu^+ W^{\mu-} \longrightarrow 2\sigma \frac{m_W^2}{f} W_\mu^+ W^{\mu-}$$

The coupling to SM fermions can be obtained in the same way.

For massless gauge bosons, the photon and gluon

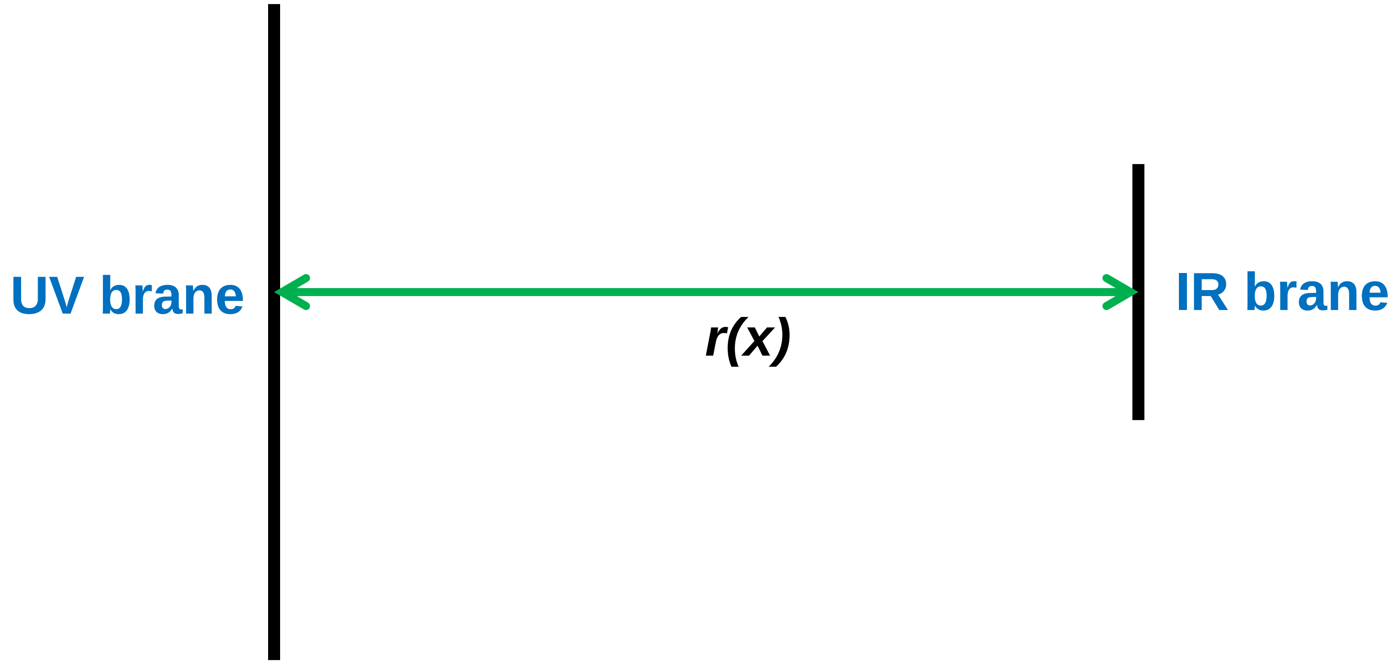
$$\frac{\mathrm{d}}{\mathrm{d}\,\log\mu}\frac{1}{g^2} = \frac{b_<}{8\pi^2}$$

This leads to a loop suppressed dilaton coupling,

$$\frac{b_<}{32\pi^2}\frac{\chi}{f}F_{\mu\nu}F^{\mu\nu} \longrightarrow \frac{b_<}{32\pi^2}\frac{\sigma}{f}F_{\mu\nu}F^{\mu\nu}$$

What is the radion?

Consider the 2 brane Randall-Sundrum model. The spacing between the branes corresponds to a dynamical field, the radion.



Holography maps the radion on AdS side of the correspondence to the dilaton on the CFT side.

The dilaton and radion are equivalent in the limit of a large-*N* CFT.

Could the 125 GeV Resonance Be a Dilaton/Radion?

Why is it easy to mistake the dilaton for a Higgs?

Consider the SM in the classical limit, with the parameters in the Higgs potential set to zero .

In this limit the SM exhibits conformal symmetry (at the classical level). Also, any value of the Higgs VEV constitutes a minimum.

For any non-zero value of the Higgs VEV, the conformal symmetry is spontaneously broken. Therefore, in this limit, the SM Higgs is itself a dilaton, its couplings determined by the non-linearly realized conformal symmmetry !

Goldberger, Grinstein & Skiba

It follows from this that the couplings of the dilaton to the SM fermions, and to the *W* and *Z*, are proportional to those of the Higgs.

The branching ratios for dilaton decays to these particles are the same as for the Higgs!

The constant of proportionality is (v/f) , where v is the electroweak VEV and f the scale of CFT breaking.

The only interactions of the Higgs that differ at lowest order from those of a dilaton are

- **the couplings to gluons and photons, which are generated at loop level in the SM (quantum effect)**

- **the Higgs trilinear and quartic self-interaction terms, which depend on the form of the potential for the Higgs doublet**

A determination of these couplings would be particularly useful in distinguishing the SM Higgs from a dilaton.

A Complication

In any realistic model where EWSB arises from strong conformal dynamics, the couplings of the dilaton are modified by effects that explicitly violate conformal symmetry.

It is these effects that generate a mass for the dilaton.

Predictive power is lost!

The Resolution

The mass of the resonance (dilaton) ~ 125 GeV is small compared to the strong coupling scale $\Lambda_{IR} \sim 4\pi f \gtrsim 1$ TeV.

This is an indication that conformal symmetry violation is small!

Corrections to the form of the dilaton couplings to SM particles are suppressed by the square of the ratio of the dilaton mass to the strong coupling scale, $\Lambda_{IR} \sim 4\pi f$.

ZC & Mishra

Although these corrections are small in the case of a light dilaton, they can still significantly affect the dilaton couplings to photons and gluons, which are a quantum effect.

Dilaton Meets Data

ZC, Franceschini and Mishra

Let us first understand the main features of the (Fall 2012) data.

ATLAS $\tau\tau$ 2011	0.2 ± 1.8
ATLAS bb AP 2011	$0.5 \pm 2.$
ATLAS WW 2011+2012	1.4 ± 0.5
ATLAS ZZ 2011+2012	1.3 ± 0.6
ATLAS $\gamma\gamma$ 2011+2012	1.4 ± 0.5
ATLAS $\gamma\gamma$ dijet 2011	2.7 ± 1.8
ATLAS $\gamma\gamma$ dijet 2012	2.6 ± 1.7
CMS WW VBF 2011+2012	0.2 ± 1.5
CMS $\gamma\gamma$ Dijet Loose 2012	$-0.6 \pm 2.$
CMS $\gamma\gamma$ Dijet Tight 2012	1.3 ± 1.6
CMS $\gamma\gamma$ Dijet 2011	$4.2 \pm 2.$
CMS WW AP 2011	$-2.8 \pm 3.$
CMS $\tau\tau$ 2011+2012	-0.2 ± 0.8
CMS bb AP 2011+2012	0.5 ± 0.8
CMS WW 2011+2012	0.6 ± 0.4
CMS ZZ 2011+2012	0.8 ± 0.4
CMS $\gamma\gamma$ 2011+2012	1.35 ± 0.44

These are signal strength best fits.

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Significant excesses in $\gamma\gamma$ and ZZ* final states.

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Significant excesses in $\gamma\gamma$ + dijet final states.

Not to forget the Tevatron!

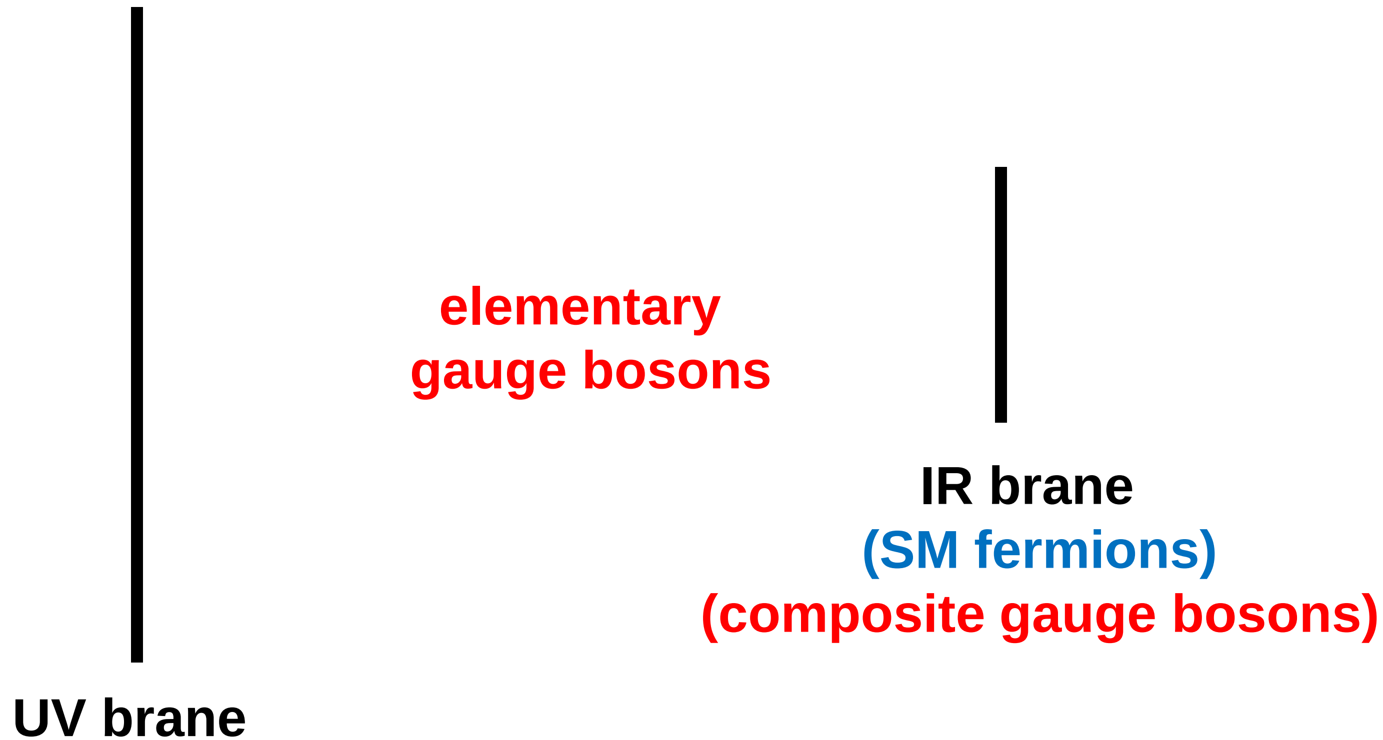
TeVatron $\gamma\gamma$	3.6 ± 2.8
TeVatron WW	0.3 ± 1.1
TeVatron bb AP	$2. \pm 0.7$ ←

Significant excess in bb + W/Z final states.

First study case when (3rd generation) fermions are composite.

The SM gauge bosons could be elementary or composite.

This class of theories can be realized as RS models.



Denote the scale at which conformal symmetry is broken by *f*, where *f* $\gtrsim$ *v*, where *v* is the electroweak VEV.

Define the parameter $\xi = (v/f)^2$. In general all the dilaton couplings are suppressed relative to those of the SM Higgs by powers of $(v/f) \equiv \sqrt{\xi}$.

Introduce the ratio η, which parametrizes the strength of the dilaton couplings relative to those of the SM Higgs.

$$\eta_{XX} \equiv \left(\frac{g_{\sigma XX}}{g_{hXX}} \right)^2$$

	Elementary Fermions	Composite Fermions
η_{bb}	$(\epsilon+1)^2\xi$	ξ
η_{WW}	ξ	ξ
$\eta_{\tau\tau}$	$(\epsilon+1)^2\xi$	ξ
η_{ZZ}	ξ	ξ
η_{gg}	$(\epsilon+1)^2\xi$	$\xi\psi$
$\eta_{\gamma\gamma}$	$\xi\phi$	$\xi\phi$

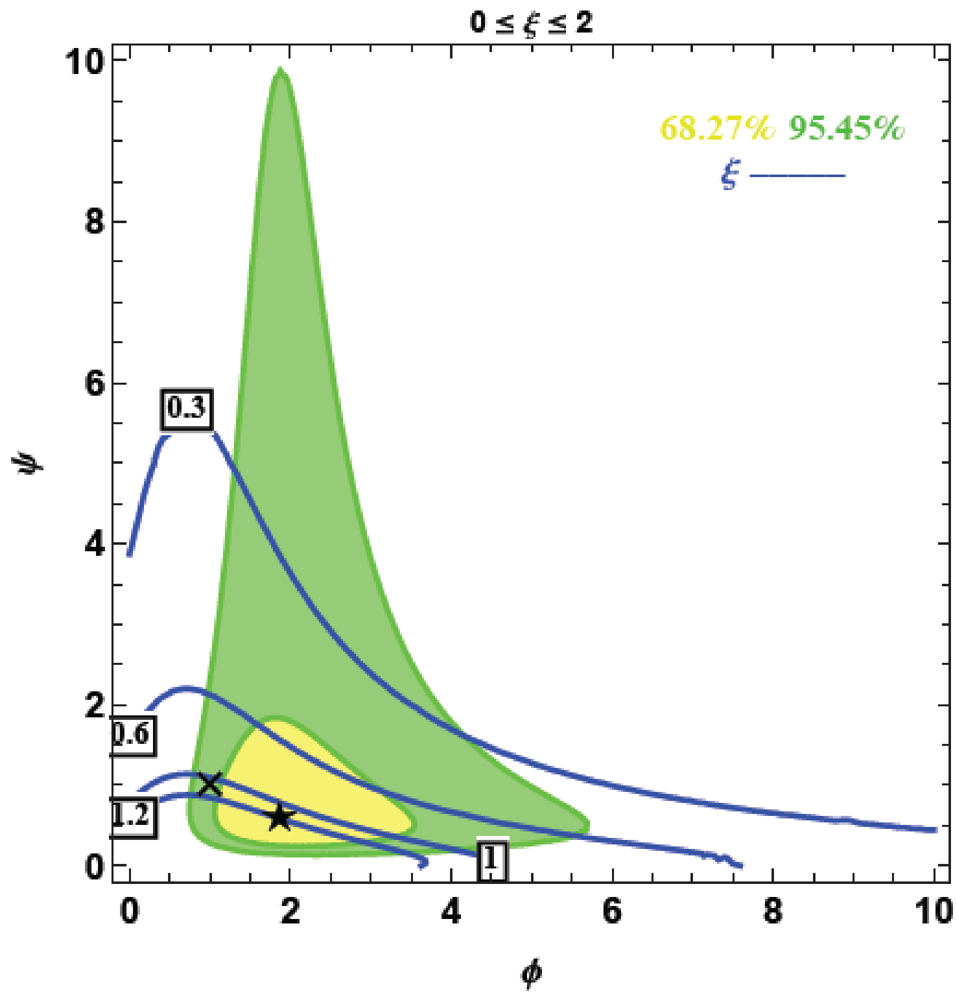
The dilaton couplings to the SM fields in the case of composite fermions are parametrized by the three parameters ξ, ψ, and ϕ.

ψ controls dilaton couplings to gluons, and ϕ to photons.

In the case when SM gauge bosons are composite, corresponding to all the SM fields on the IR brane in RS, ψ and ϕ are predicted:

$$\psi \simeq 132\,, \qquad \phi \simeq 2.4$$

However, prediction does not survive symmetry violating effects.



The dilaton is a good fit to the data, comparable to SM Higgs.

However, given the range over which ξ, ψ, and ϕ can vary, the best fit point is suspiciously close to the SM.

Why are the parameters forced towards the SM?

The Tevatron is seeing associated production, ➔ $\xi \approx 1$.

Then to match the number of ZZ events at LHC, ➔ $\psi \approx 1$.

Then, for agreement with number of $\gamma\gamma$ events at LHC, ➔ $\phi \approx 1$.

We could have reached the same conclusion without Tevatron data, by using $\gamma\gamma$ + dijet data from the LHC.

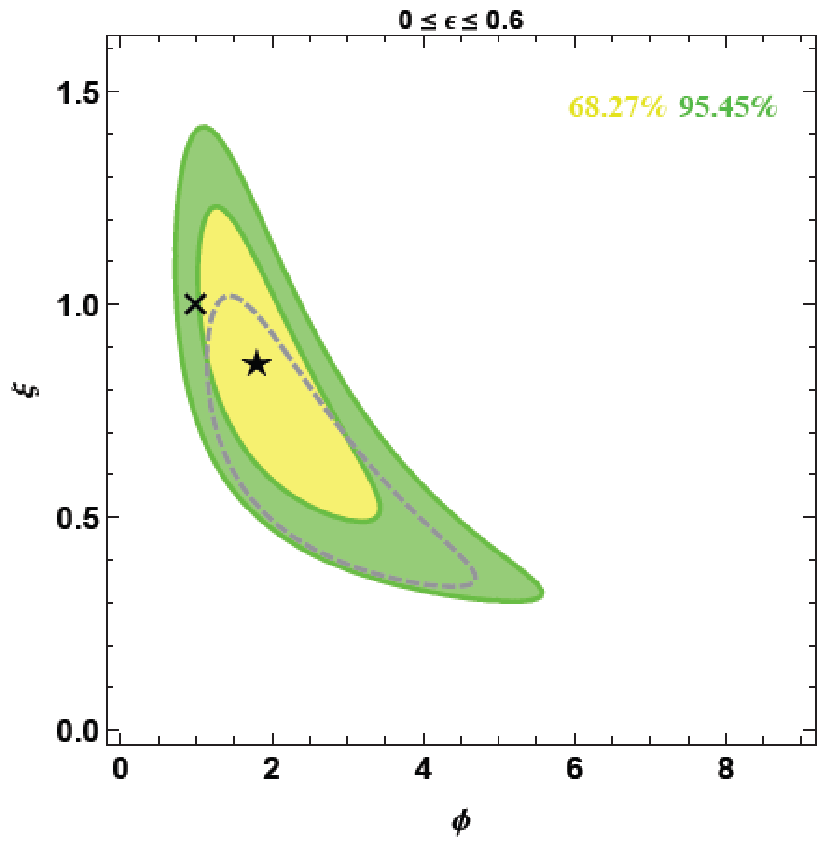
All these conspire to shrink the dilaton parameter space.

Next consider scenario when SM fermions and gauge bosons are all elementary, and CFT contains no colored states.

This class of theories do not possess a realistic RS (large *N*) limit.

	Elementary Fermions	Composite Fermions
$\eta_{\rm bb}$	$(\epsilon+1)^2\xi$	ξ
$\eta_{\rm WW}$	ξ	ξ
$\eta_{\tau\tau}$	$(\epsilon+1)^2\xi$	ξ
$\eta_{\rm ZZ}$	ξ	ξ
$\eta_{\rm gg}$	$(\epsilon+1)^2\xi$	$\xi\psi$
$\eta_{\gamma\gamma}$	$\xi\phi$	$\xi\phi$

The dilaton couplings to the SM fermions now arise from a conformal symmetry violating effect. Parametrized by ε .



Superficially a good fit to the data. Milder coincidence problem.

However, the preferred range of ε is constrained. Require ε < 0.55 from flavor, and ε > 0.35 from fine-tuning.

Rattazzi, Rychkov & Vichi,
…. , Poland & Vichi

With these additional constraints, no 1 sigma points survive.

What Next?

So far, analyses have focused on the dilaton couplings to SM fields.

However, the dilaton trilinear and quartic self couplings are in general completely different from those of a SM Higgs.

Goldberger, Grinstein & Skiba

As a consequence, the rates for di-dilaton production can be very different from SM di-Higgs production.

Dolan, Englert & Spannowsky

This will provide an additional handle on these theories.

Could the 125 GeV Resonance Be a Higgs/Dilaton Admixture?

In general, if the low energy theory contains both a dilaton and a Higgs, they mix. The mass eigenstates are linear combinations.

Mixing can occur through terms involving derivatives

$$\frac{\partial_\mu \chi}{f} \partial^\mu \left(H^\dagger H \right)$$

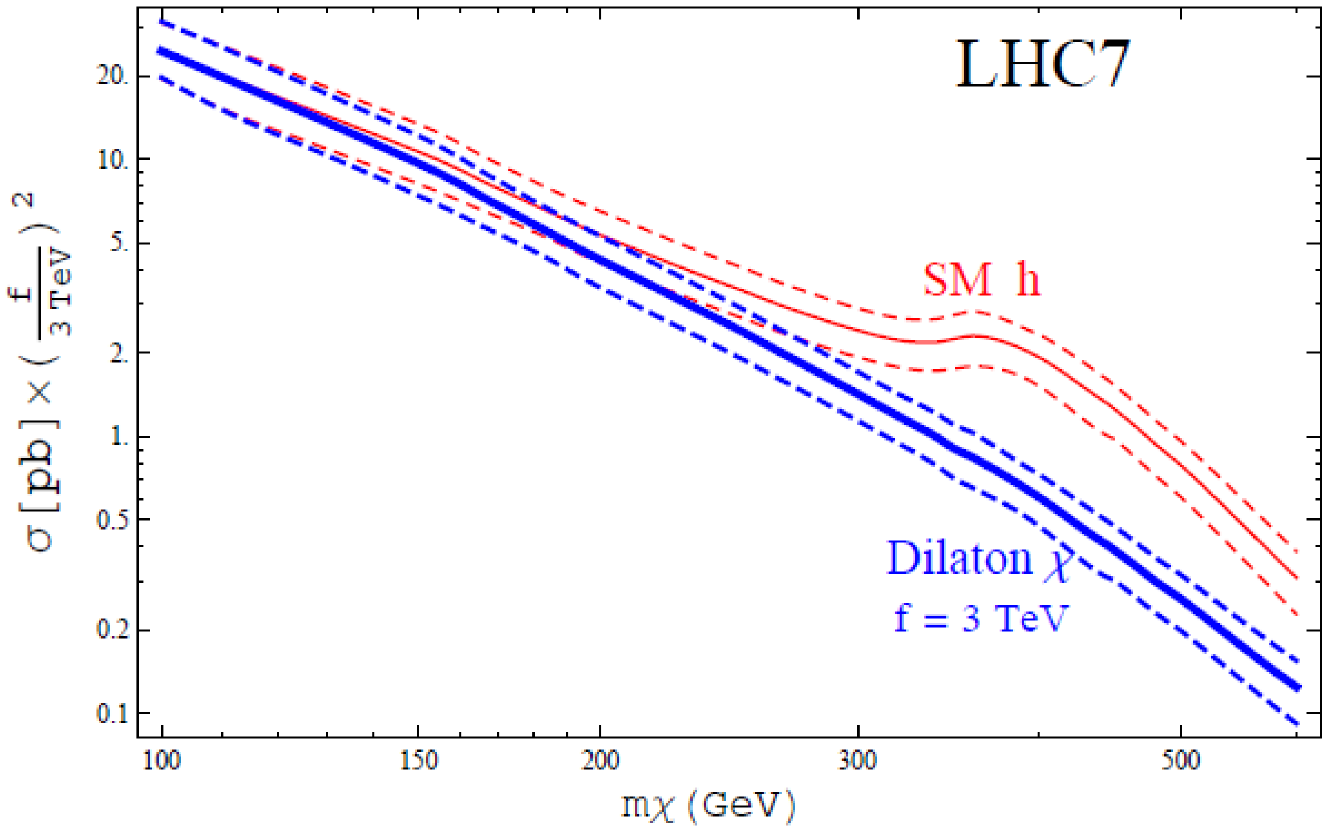
It can also occur through the potential.

$$V \supset \chi^4 \mathcal{F}\left(\frac{H^\dagger H}{\chi^2} \right)$$

Most analyses of mixing have been done in RS using the radion description. Directly applicable to the case of composite tops.

Giudice, Rattazzi & Wells
Dominici, Grzadkowski, Gunion & Toharia
. . . .

Only one eigenstate has been observed. This puts limits on the allowed parameter space.



Barger, Ishida & Keung

In general f ≳ 3 TeV or the other eigenstate is heavy (~ TeV).

In a large part of parameter space the mixing is parametrically

$$\theta \sim v/f$$

This is too small to generate observable effects.

However, there are regions of parameter space where the mixing is large enough for the rates to $\gamma\gamma$ and *ZZ* to receive observable corrections.

Kubota & Nojiri

The limits on the other eigenstate are not significantly affected by mixing.

The bounds have improved. An updated analysis is badly needed.

Conclusions

In theories where the breaking of electroweak symmetry is driven by strong conformal dynamics, there may be a light dilaton in the low energy spectrum.

The dilaton is a particularly dangerous Higgs impostor, because many of its couplings have exactly the same form.

At present the dilaton is a good fit to the data, comparable to the SM Higgs. More data is needed to distinguish between them.

However the best-fit parameters in the dilaton case are already quite close to the SM values (coincidence problem).

If the 125 GeV resonance is a SM-like Higgs but with a dilaton admixture, the rates to $\gamma\gamma$ etc. can receive large corrections.