Title: Higgs Effective Field Theories for LHC

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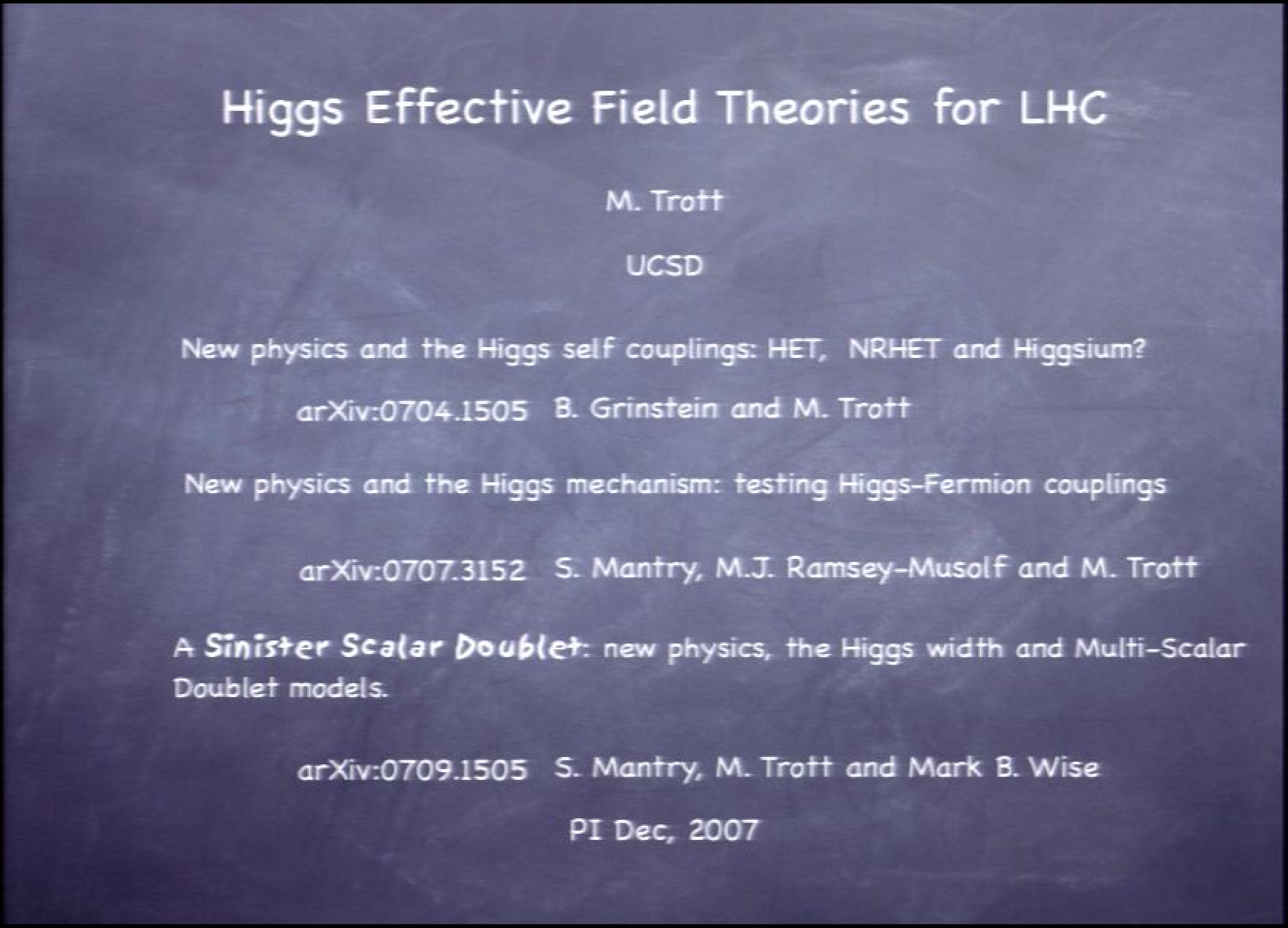
Abstract: We demonstrate a number of effective field theory constructions developed to capture the effects of new physics on the Higgs sector of the standard model. We demonstrate that as the self couplings of the Higgs could be significantly effected by new physics, novel phenomenology such as a two Higgs bound state (Higgsium) may be possible.
We also demonstrate that the effects of new physics on the Higgs fermion couplings, and thus the Higgs width, could be significant.
We show that it is possible this could happen while the new physics cannot be directly detected at LHC. This could lead to an early Higgs discovery or a missing Higgs in the first 100 fb^(-1) of data at LHC.



Higgs Effective Field Theories for LHC

M. Trott

UCSD

New physics and the Higgs self couplings: HET, NRHET and Higgsium?

arXiv:0704.1505 B. Grinstein and M. Trott

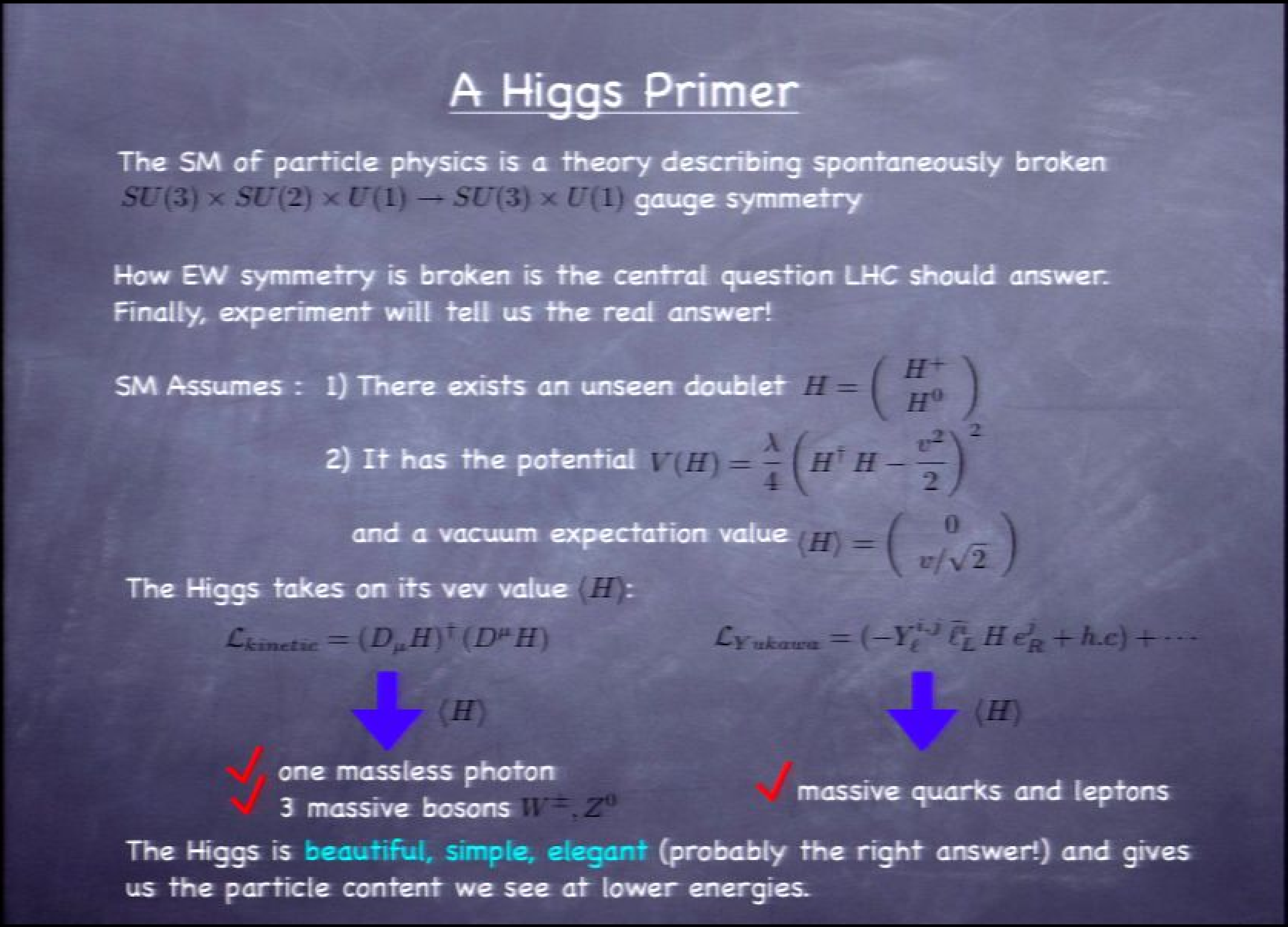
New physics and the Higgs mechanism: testing Higgs-Fermion couplings

arXiv:0707.3152 S. Mantry, M.J. Ramsey-Musolf and M. Trott

A **Sinister Scalar Doublet**: new physics, the Higgs width and Multi-Scalar Doublet models.

arXiv:0709.1505 S. Mantry, M. Trott and Mark B. Wise

PI Dec, 2007



A Higgs Primer

The SM of particle physics is a theory describing spontaneously broken $SU(3) \times SU(2) \times U(1) \rightarrow SU(3) \times U(1)$ gauge symmetry

How EW symmetry is broken is the central question LHC should answer. Finally, experiment will tell us the real answer!

SM Assumes : 1) There exists an unseen doublet $H = \begin{pmatrix} H^+ \\ H^0 \end{pmatrix}$

2) It has the potential $V(H) = \frac{\lambda}{4}\left(H^\dagger H - \frac{v^2}{2}\right)^2$

and a vacuum expectation value $\langle H \rangle = \begin{pmatrix} 0 \\ v/\sqrt{2} \end{pmatrix}$

The Higgs takes on its vev value $\langle H \rangle$:

$$\mathcal{L}_{kinetic} = (D_\mu H)^\dagger (D^\mu H) \qquad\qquad \mathcal{L}_{Yukawa} = (-Y_\ell^{i,j}\, \bar{\ell}^i_L\, H\, e^j_R + h.c) + \cdots$$

$$\Big\Downarrow \langle H \rangle \qquad\qquad\qquad\qquad \Big\Downarrow \langle H \rangle$$

✓ one massless photon

✓ 3 massive bosons $W^\pm, Z^0$

✓ massive quarks and leptons

The Higgs is beautiful, simple, elegant (probably the right answer!) and gives us the particle content we see at lower energies.

A Higgs Problems Primer

The Higgs is indeed beautiful, simple, elegant and probably the right answer!

Looking closer and we have some problems.

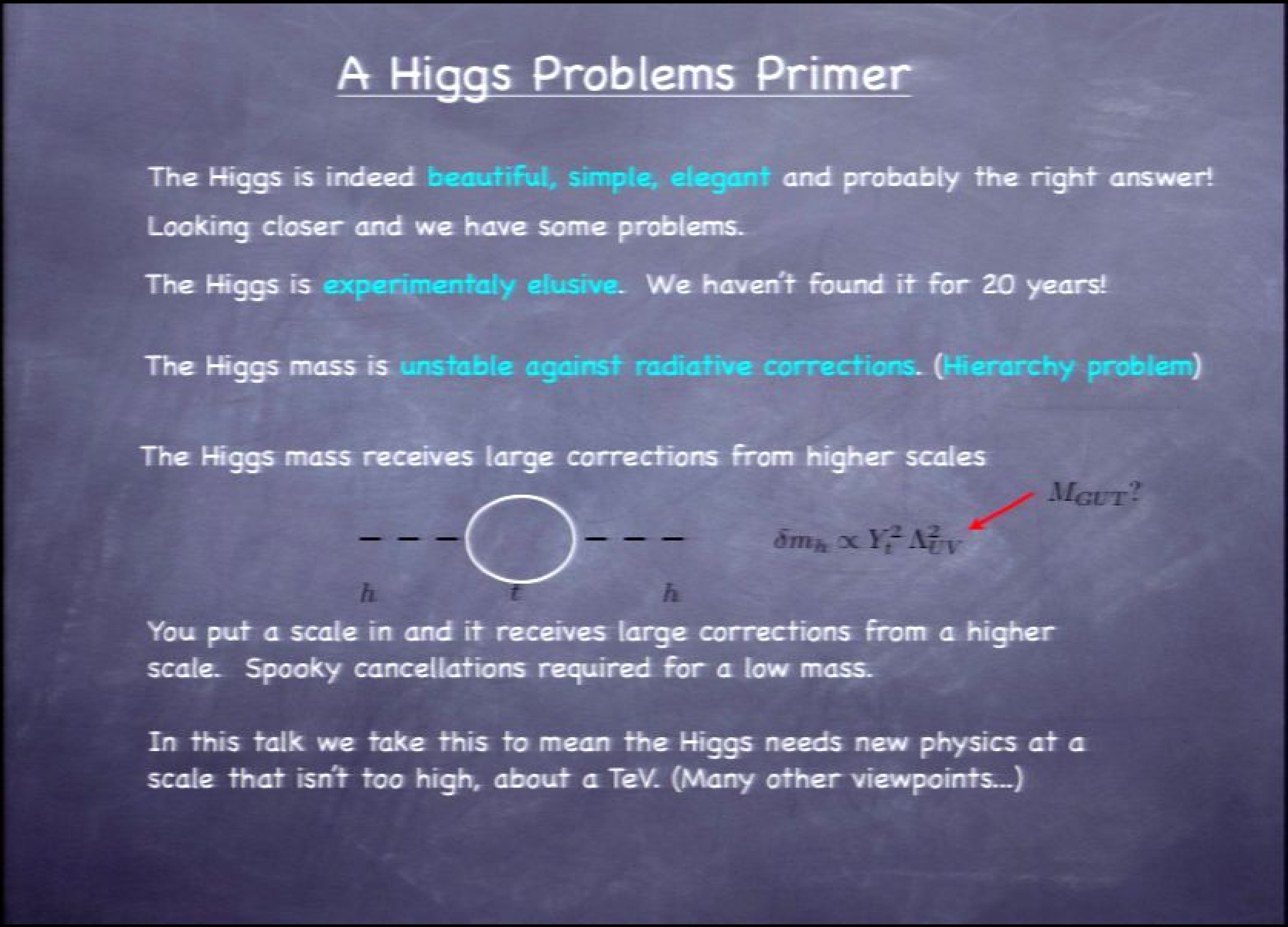
The Higgs is experimentaly elusive. We haven't found it for 20 years!

Where the heck is it? The Higgs is always just around the energy corner.

Indirect tests for the Higgs through EW loops is some evidence

EWPD fit: $m_h = 84^{+33}_{-24}\,\mathrm{GeV}$ LEP2 exclusion: $m_h > 114.4\,\mathrm{GeV}$

BUT you can fit this data with no Higgs, with the chiral EW Lagrangian (see Chanowitz 2004)



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The Higgs mass is unstable against radiative corrections. (Hierarchy problem)

The Higgs mass receives large corrections from higher scales

M_{GUT}?

$$\delta m_h \propto Y_t^2 \Lambda_{UV}^2$$

You put a scale in and it receives large corrections from a higher scale. Spooky cancellations required for a low mass.

In this talk we take this to mean the Higgs needs new physics at a scale that isn't too high, about a TeV. (Many other viewpoints...)

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The SM + Higgs not a UV complete theory. By which I mean the self coupling is driven to vanish without a finite UV cutoff. (Triviality problem)

To deal with this we assume in this talk:

- A Higgs particle will be found once LHC turns on or soon at the TeVatron.
- A Higgs implies new physics with $M \sim \mathrm{TeV}$ that effects the Higgs but also does not cause large FCNC. So focus on the right operators and use MFV when appropriate.

See Guidice et all 2002 for MFV

HET Approach

Even though $\sqrt{s} = 14\,\mathrm{TeV}$ at LHC it can be hard to see the quanta of new physics directly. I will show you an example when things get **sinister** later in the talk.

So construct a low energy EFT of the Higgs to look for NP indirectly
Lets see how NP can effect the properties of the Higgs (its self couplings, its couplings to fermions, etc...)

We extend the SM with higher dimension operators:

$$\mathcal{L} = \mathcal{L}_{SM} + \frac{1}{\mathcal{M}}\mathcal{L}_5 + \frac{1}{\mathcal{M}^2}\mathcal{L}_6$$

Buchmuller and Wyler (1986)

- There are dimension 6 operators NOT constrained by precision EW to have a high scale in the Higgs sector.
- They preserve custodial symmetry and do not lead to shifts in the ρ parameter from 1
- You can have in mind some strong physics of some form at a TeV involved in EWSB to set the scale and the Higgs is a Goldstone boson of this sector. We take the Wilson coefficients of our ops $C \sim 1$

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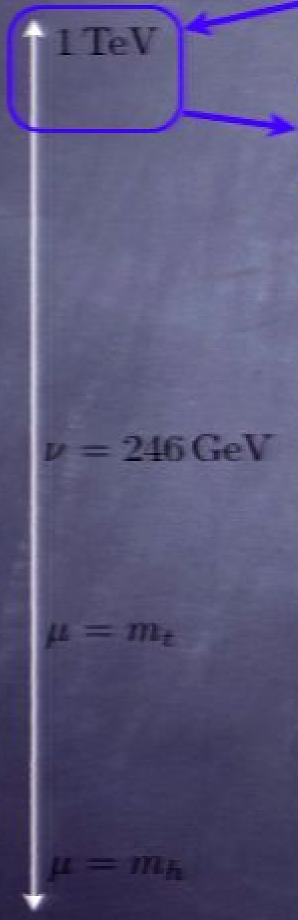
$$\boxed{\frac{C_\phi^1}{\mathcal{M}^2}\partial^\mu(\phi^\dagger\phi)\partial_\mu(\phi^\dagger\phi) + \frac{C_\phi^2}{\mathcal{M}^2}(\phi^\dagger\phi)\,(D^\mu\phi)^\dagger\,(D_\mu\phi) - \frac{\lambda_2}{3!\,\mathcal{M}^2}(\phi^\dagger\phi)^3} + \cdots$$

Lets see how these effect the Higgs self couplings.

Higgs Effective Field Theory

Scales:



$1\,\mathrm{TeV}$

$v = 246\,\mathrm{GeV}$

$\mu = m_t$

$\mu = m_h$

Exciting new physics! Integrated out as it is hard to see at LHC directly.

$$\boxed{\frac{\mathcal{L}^6_\phi}{\mathcal{M}^2} = \frac{C^1_\phi}{\mathcal{M}^2}\,\partial^\mu(\phi^\dagger\phi)\,\partial_\mu(\phi^\dagger\phi) + \frac{C^2_\phi}{\mathcal{M}^2}\,(\phi^\dagger\phi)\,(D_\mu\phi)^\dagger\,(D^\mu\phi) - \frac{\lambda_2}{3!\,\mathcal{M}^2}\,(\phi^\dagger\phi)^3}$$

We use Unitary Gauge $\phi(x) = \frac{U(x)}{\sqrt{2}}\begin{pmatrix} 0 \\ v + h(x) \end{pmatrix}$

This gives us a non-canonically normalized Lagrangian. We address this by the field redefinition

$$h(x) \to \frac{h'(x)}{(1+2C^K_h)^{1/2}} \quad \text{where } C^K_h = \frac{v^2}{4\,\mathcal{M}^2}\,(4C^1_\phi + C^2_\phi)$$

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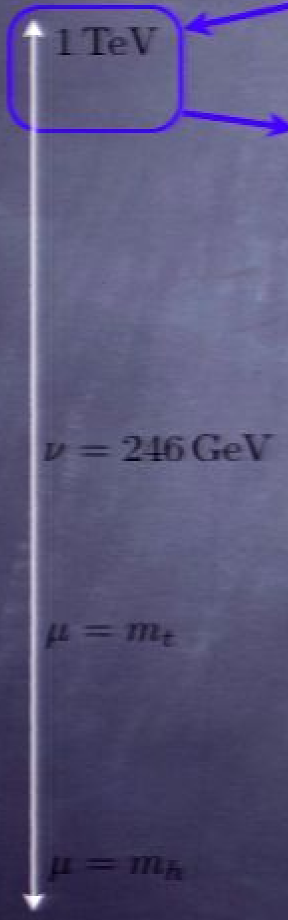

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$$\boxed{\frac{\mathcal{L}_\phi^6}{\mathcal{M}^2} = \frac{C_\phi^1}{\mathcal{M}^2}\partial^\mu(\phi^\dagger\phi)\,\partial_\mu(\phi^\dagger\phi) + \frac{C_\phi^2}{\mathcal{M}^2}(\phi^\dagger\phi)\,(D_\mu\phi)^\dagger\,(D^\mu\phi) - \frac{\lambda_2}{3!\,\mathcal{M}^2}\,(\phi^\dagger\phi)^3}$$

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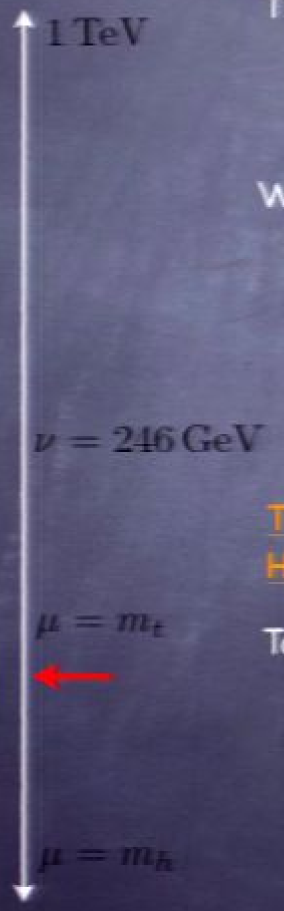
Note that $v^2/\mathcal{M}^2 \sim 1/16$ for $\mathcal{M} \sim 1\,\mathrm{TeV}$, small enough to justify an effective theory but not so small as it is hopeless to see anything.

We neglect the effect of running.

We match onto the theory without a top quark, this is ok for our phenomenology.

Higgs Effective Field Theory

Scales:



The induced effective potential is given by:

$$V_{eff}(h') = \frac{1}{2} m_h^2 h'^2 + \frac{v\,\lambda_3^{eff}}{3!} h'^3 + \frac{\lambda_4^{eff}}{4!} h'^4 + \frac{30\,\lambda_2}{5!\,\mathcal{M}^2} v\,h'^5 + \frac{30\,\lambda_2}{6!\,\mathcal{M}^2} h'^6,$$

Where the mass and coupling are now

$$\frac{m_h^2}{v^2} = \lambda_1\,(1 - 2C_h^K) + \frac{\lambda_2}{2}\frac{v^2}{\mathcal{M}^2} + \frac{N_c}{4\pi^2}\frac{m_t^4}{v^4} + \mathcal{O}(\frac{v^4}{\mathcal{M}^4}),$$

$$\lambda_3^{eff} = 3\lambda_1\,(1 - 3C_h^K) + \frac{5}{2}\lambda_2\frac{v^2}{\mathcal{M}^2} - \frac{N_c}{\pi^2}\frac{m_t^4}{v^4} + \mathcal{O}(\frac{v^4}{\mathcal{M}^4}),$$

$$\lambda_4^{eff} = 3\lambda_1\,(1 - 4C_h^K) + \frac{15}{2}\lambda_2\frac{v^2}{\mathcal{M}^2} - \frac{4\,N_c}{\pi^2}\frac{m_t^4}{v^4} + \mathcal{O}(\frac{v^4}{\mathcal{M}^4}),$$

The relationship between the Higgs mass and the self coupling of the Higgs is starting to break down.

To get an idea of how big the shifts could be we use

$$m_h = v/2\,\mathrm{GeV} \quad m_t = 174\ \mathrm{GeV} \quad v = 246\ \mathrm{GeV} \qquad \mathcal{M} = 1\,\mathrm{TeV}$$

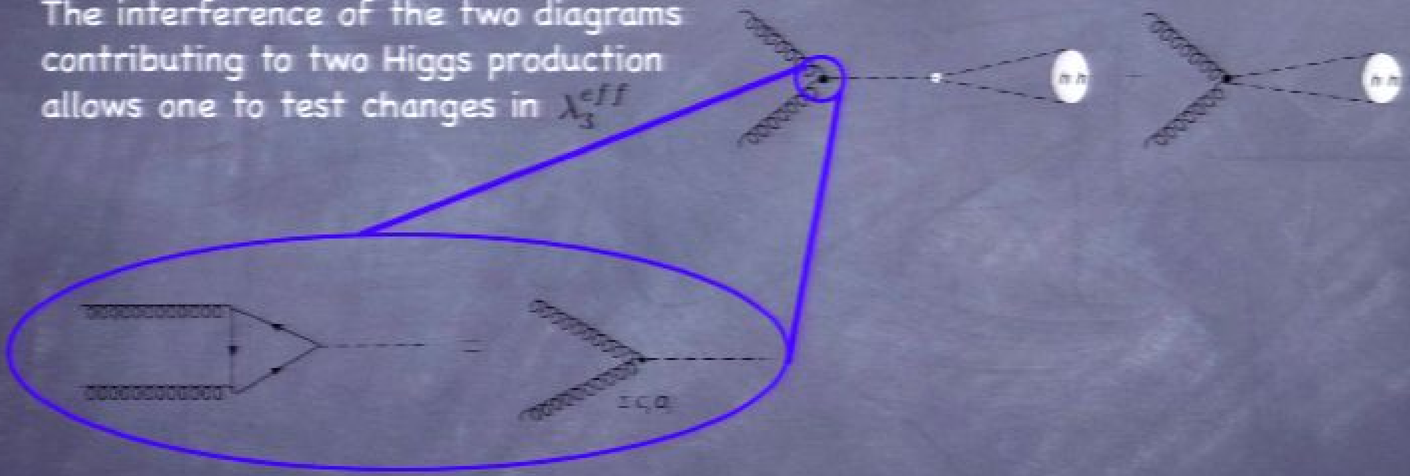
$$\lambda_3^{eff} = 0.62 - 0.05\left(C_\phi^1 + \frac{1}{4}C_\phi^2\right) + 0.06\,\lambda_2$$

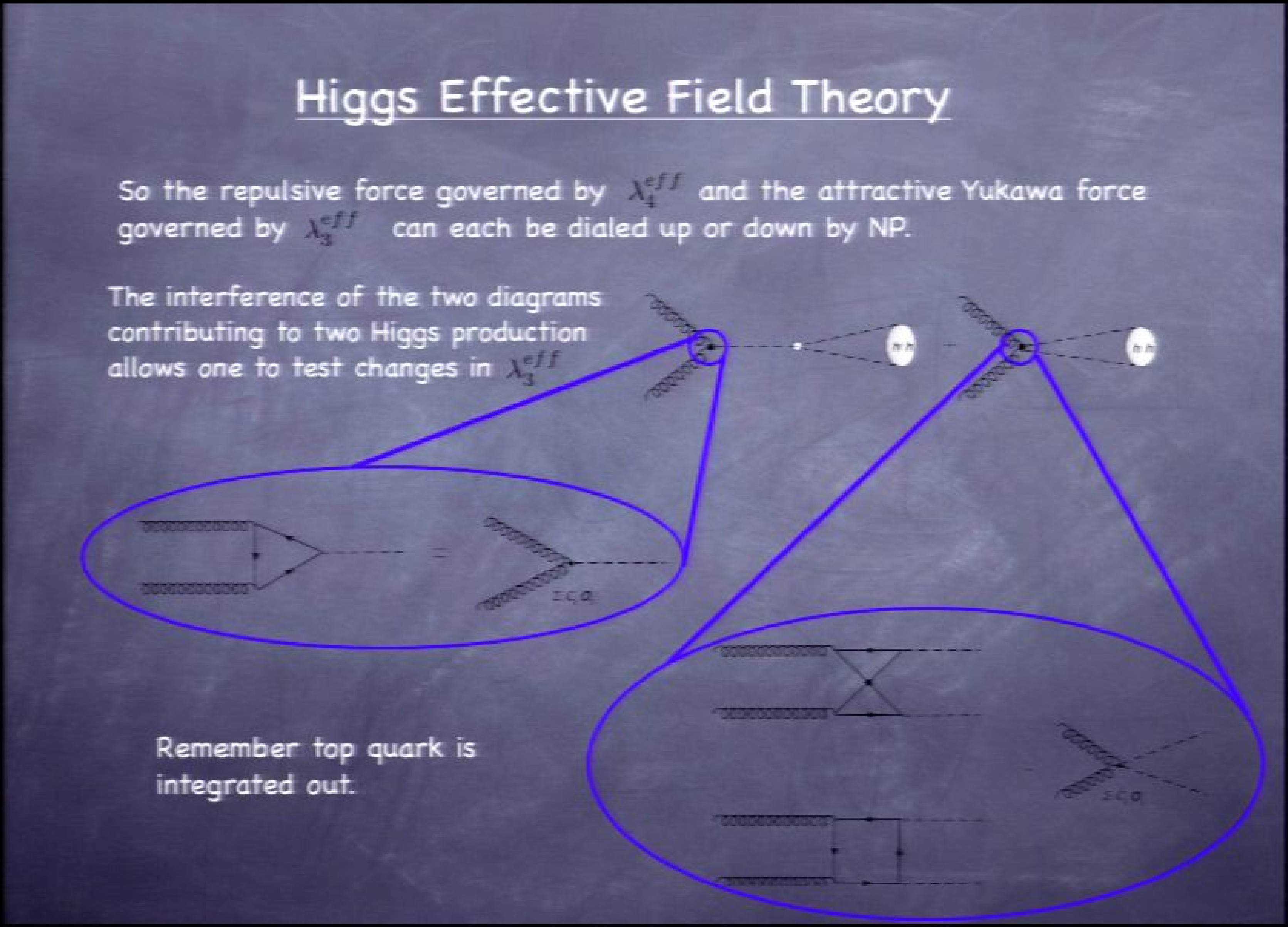
$$\lambda_4^{eff} = 0.39 - 0.09\left(C_\phi^1 + \frac{1}{4}C_\phi^2\right) + 0.36\,\lambda_2$$

Higgs Effective Field Theory

So the repulsive force governed by λ_4^{eff} and the attractive Yukawa force governed by λ_3^{eff} can each be dialed up or down by NP.

The interference of the two diagrams contributing to two Higgs production allows one to test changes in λ_3^{eff}





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Remember top quark is integrated out.

Higgs Effective Field Theory

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Such a two Higgs signal is (marginally) possible to observe at LHC.

For $m_h < 200\,\mathrm{GeV}$ (in the SM) the cross section falls from 50 to about 10 fb.
This leads to about 1000 events for 100 fb^(-1) of data.

Dawson, Dittmaier, Spira hep-ph/9805244

One experimental signal that deviates from the SM would be exciting but it isn't enough.... too many parameters

If the 2 Higgs production signal is off from its SM value we
NEED MORE INFORMATION (and ILC).

Bound States = More Information

We have investigated the possibility of a Higgs-Higgs bound state.

- A Higgs-Higgs bound state can form in the standard model alone. (Cohn-Suzuki 84)
  It does require a Higgs of mass $m_h > 1.2\,\mathrm{TeV}$, how low can the mass be in the HET NP context?

Bound States in Field Theory

(see Bethe's papers and Sterman's book)

A bound state is described by the Greens function satisfying the Dyson-Schwinger equation

$$H(K,k) = \frac{i}{(\frac{1}{2}K+k)^2 - m_h^2 + i\epsilon}\,\frac{i}{(\frac{1}{2}K-k)^2 - m_h^2 + i\epsilon}\left(1 + \int \frac{d^4q}{(2\pi)^4}\,V(K,k,q)\,H(K,q)\right)$$

- Once V is approximated, the self consistent solution to this equation "sums an infinite set of diagrams" and the pole in H is the bound state pole.

NRHET

To construct NRHET we take the $c \to \infty$ limit of the Higgs Lagrangian density.

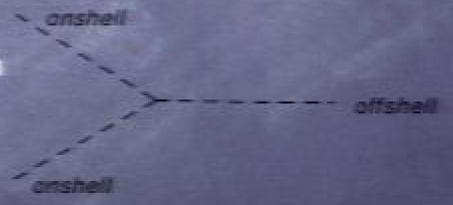
Making the factors of c explicit while keeping $\hbar = 1$ one finds

$$\mathcal{L} = \frac{1}{2}\left[1 + c_1^{eff}\frac{h}{v} + c_2^{eff}\frac{h^2}{v^2}\right]\partial^\mu h\,\partial_\mu h - \frac{1}{2}m_h^2 c^2 h^2 - \frac{v\,\lambda_3^{eff}}{3!\,c}h^3 - \frac{\lambda_4^{eff}}{4!\,c}h^4 + \mathcal{O}\left(\frac{v^2}{\mathcal{M}^2}\right)$$

We also have to remove the large energy scale $m_h c^2$ from the Higgs field with the field redefinition in terms of the creation and annihilation operators of the field

$$h(x) = \frac{1}{\sqrt{2}}e^{-i m_h c^2 t}h_+(x) + \frac{1}{\sqrt{2}}e^{i m_h c^2 t}h_-(x)$$

Physically one can see what is going to happen by realizing that the Higgs trilinear coupling has to vanish



$$\mathcal{L}_{\rm NR} = h_-\left(i\frac{\partial}{\partial t} + \frac{\nabla^2}{2m_h}\right)h_+ + \frac{C_{NR}}{4c}h_-^2 h_+^2.$$

The coefficient C_{NR} is undetermined but can be obtained by the matching of HET onto NRHET

Matching onto NRHET

The matching is accomplished by taking the non relativistic limit of $h\,h \rightarrow h\,h$ scattering

The momenta in this NR limit are given by $p_i = m_h v + \tilde{p}_i$ where the residual momenta is given by $\tilde{p}_i \sim m_h\,(k^2, k)$

Just expand in k for the leading order matching, we find

$$C_{NR} = 12\,\lambda_1 + 10\,\lambda_2\,\frac{v^2}{M^2} - 64\,\lambda_1\,C_h^K - \frac{39}{4\pi^2}\left(\frac{m_t^4}{v^4}\right)$$

In NRHET the contact interaction is attractive and the V in the Dyson-Schwinger eqn is given by a delta function.

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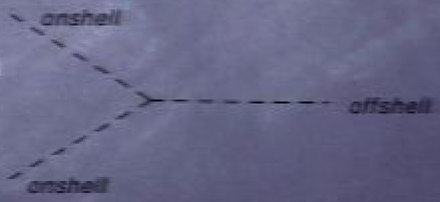

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In NRHET the contact interaction is attractive and the V in the Dyson-Schwinger eqn is given by a delta function.

NRHET Bound State

As V is now approximated by simply a contact interaction it is easy to see that H is given by

This expression is easy to determine. The bubbles all give the same factor.

$$iA_{1-loop} = -i\frac{m_h(C_{NR})^2}{4\pi}(-m_h E)^{1/2}.$$

So the geometric sum of bubbles gives H, the Greens function

$$iC_{NR}\left[1-\frac{m_h C_{NR}}{4\pi}(-m_h E)^{1/2}+\left(\frac{m_h C_{NR}}{4\pi}(-m_h E)^{1/2}\right)^2+\cdots\right] = \frac{iC_{NR}}{1+\frac{m_h C_{NR}}{4\pi}(-m_h E)^{1/2}}.$$

When the denominator vanishes the solution is the bound state energy. Rescale back to physical units one finds the binding energy for the NR bound state

$$E_b = m_h\left(\frac{16\pi}{\bar{C}_{NR}}\right)^2.$$

NRHET Bound State

This is an NRHET calculation so we require that $|E_b| < m_h$

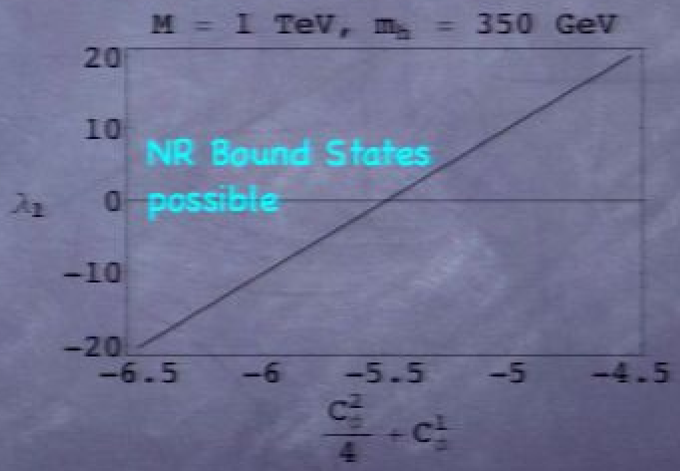
$$12\,\lambda_1 + 10\,\lambda_2\,\frac{v^2}{\mathcal{M}^2} - 64\,\lambda_1\,C_h^K - \frac{39}{4\,\pi^2}\left(\frac{m_t^4}{v^4}\right) > 16\,\pi$$

Illustrating this condition and using

$$C_h^K = \frac{v^2}{4\,\mathcal{M}^2}\left(4C_\phi^1 + C_\phi^2\right)$$

The line gives the critical coupling for a NR bound state for a given Higgs mass

We see a bound state could exist for much lower Higgs masses. EXCITING!



There is also another situation in which it is VERY likely that a bound state can form.

NRHET Bound State

2. Non-Linear realization of the EWSB, with a Higgs singlet:

$$\mathcal{L}_{NL} = \frac{v^2}{4}\,\mathrm{Tr} D_\mu U^\dagger\, D^\mu U + \frac{1}{2}\partial_\mu h\, \partial^\mu h - V(h)$$

The goldstone boson fields $\xi^a(x)$ appear through the matrix $U(x) = e^{i\xi^a(x)\sigma_a/v}$
Again you can think of some strong interaction that preserves $SU(2)_C$

The potential of the theory is $V(h) = \mathcal{M}^4 f(h/\mathcal{M})$.

The mass and self interactions of the Higgs fields are given by derivatives.

$$m_h^2 = \mathcal{M}^2 f^{(ii)}(0). \longleftarrow$$

small
(Goldstone boson)

$$v\lambda_3^{eff} = \mathcal{M} f^{(iii)}(0).$$

$$\lambda_4^{eff} = f^{(iv)}(0).$$

Unless the mechanism that keeps the Higgs mass small also suppresses λ_3^{eff} naturally we expect $\lambda_3^{eff} \sim \mathcal{M}/v \gg 1$

The Higgs sector of the Lagrangian is given by

$$\mathcal{L} = \frac{1}{2}\left[1 + c_1^{eff}\frac{h}{v} + c_2^{eff}\frac{h^2}{v^2}\right]\partial^\mu h\,\partial_\mu h - \frac{1}{2}m_h^2 h^2 - \frac{v\lambda_3^{eff}}{3!}h^3 - \frac{\lambda_4^{eff}}{4!}h^4 + \cdots$$

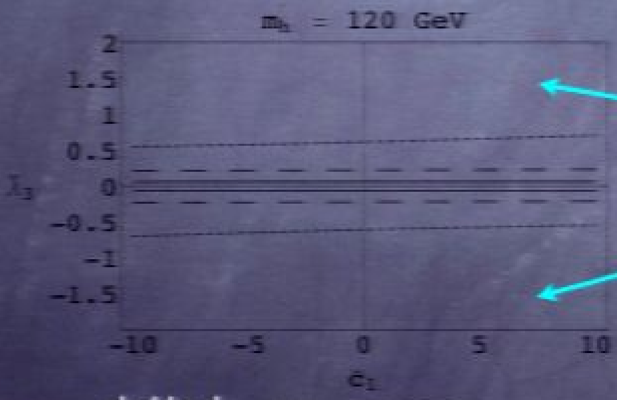
NRHET Bound State

NRHET is still the right low energy effective theory the only difference will be that the matching gives

$$\hat{C}_{NR}^{NL} = \frac{5}{3}\frac{v^2}{m_h^2}(\lambda_3^{eff})^2 - \lambda_4^{eff} - 2c_1^{eff}\lambda_3^{eff} + \left(4c_2^{eff} - (c_1^{eff})^2\right)\frac{m_h^2}{v^2}.$$

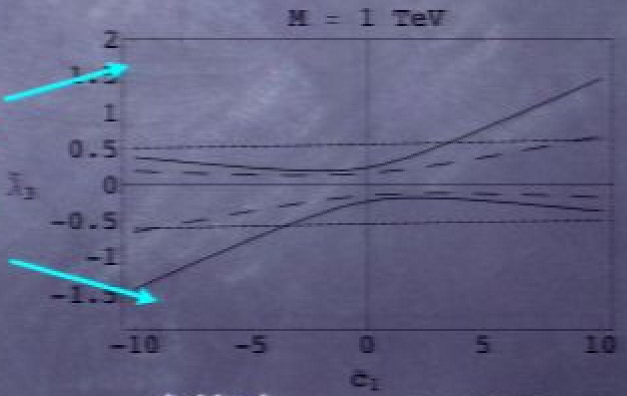
The bound state condition gives $\frac{5}{3}\frac{\mathcal{M}^2}{m_h^2}(\bar{\lambda}_3^{eff})^2 - 2\bar{c}_1^{eff}\bar{\lambda}_3^{eff} - \frac{m_h^2}{\mathcal{M}^2}(\bar{c}_1^{eff})^2 > 16\pi + \lambda_4.$

Where we have used the rescaled variables $\lambda_3^{eff} = \left(\frac{\mathcal{M}}{v}\right)\bar{\lambda}_3^{eff},\ c_1^{eff} = \left(\frac{v}{\mathcal{M}}\right)\bar{c}_1^{eff}.$



dotted $\mathcal{M} = 1\,\mathrm{TeV}$
dashed $\mathcal{M} = 3\,\mathrm{TeV}$
solid $\mathcal{M} = 10\,\mathrm{TeV}$

NR bound states are possible for a wide range of parameters



dotted $m_h = 100\,\mathrm{GeV}$
dashed $m_h = 200\,\mathrm{GeV}$
solid $m_h = 300\,\mathrm{GeV}$

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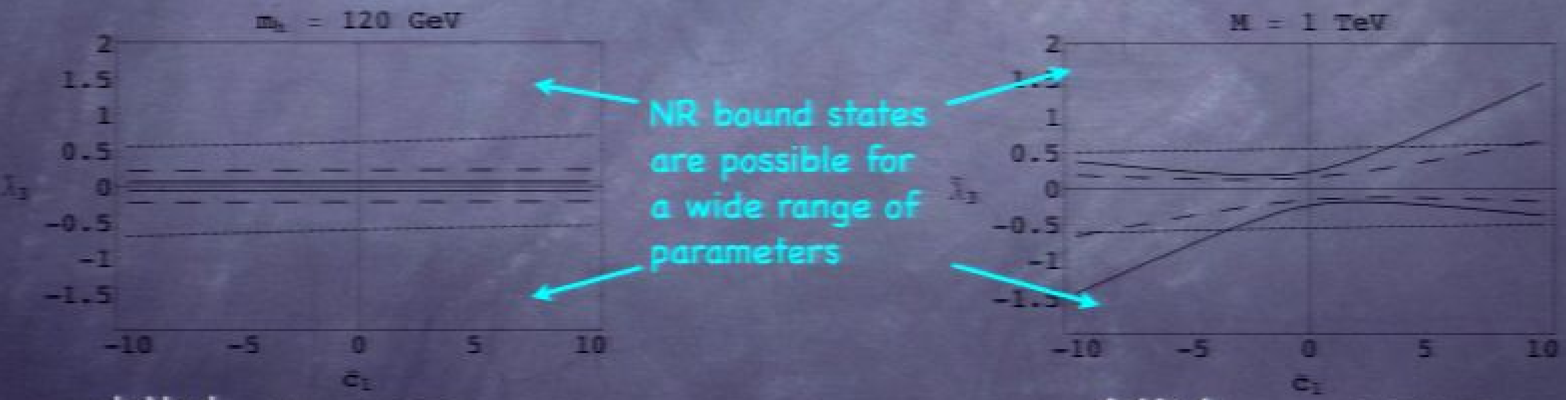
$$\hat{C}_{NR}^{NL} = \frac{5}{3}\frac{v^2}{m_h^2}(\lambda_3^{eff})^2 - \lambda_4^{eff} - 2c_1^{eff}\lambda_3^{eff} + \left(4c_2^{eff} - (c_1^{eff})^2\right)\frac{m_h^2}{v^2}.$$

The bound state condition gives $\frac{5}{3}\frac{\mathcal{M}^2}{m_h^2}(\bar{\lambda}_3^{eff})^2 - 2\bar{c}_1^{eff}\bar{\lambda}_3^{eff} - \frac{m_h^2}{\mathcal{M}^2}(\bar{c}_1^{eff})^2 > 16\pi + \lambda_4.$

Where we have used the rescaled variables $\lambda_3^{eff} = \left(\frac{\mathcal{M}}{v}\right)\bar{\lambda}_3^{eff}, \quad c_1^{eff} = \left(\frac{v}{\mathcal{M}}\right)\bar{c}_1^{eff}.$



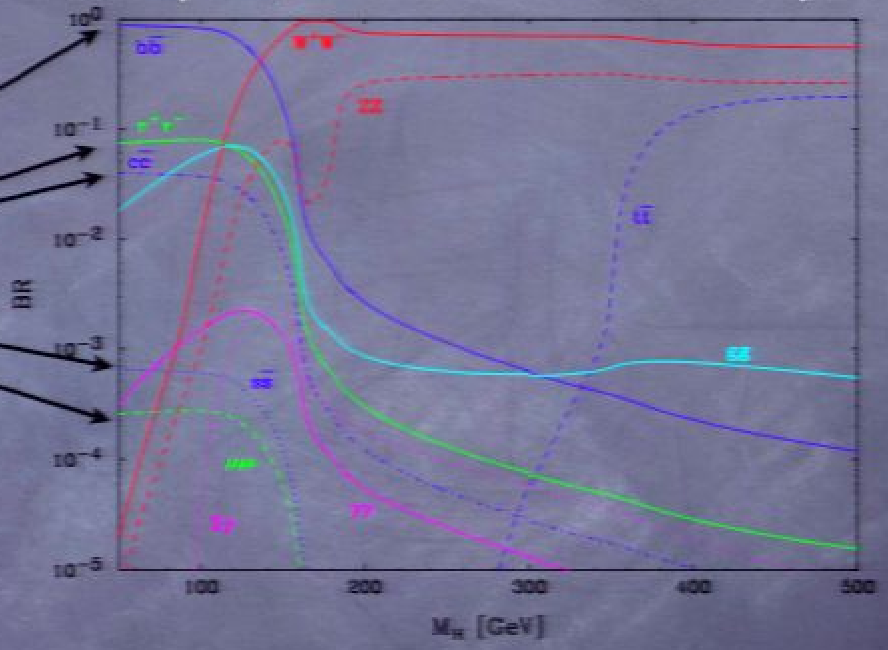
NR bound states are possible for a wide range of parameters

dotted $\mathcal{M} = 1\,\mathrm{TeV}$
dashed $\mathcal{M} = 3\,\mathrm{TeV}$
solid $\mathcal{M} = 10\,\mathrm{TeV}$

dotted $m_h = 100\,\mathrm{GeV}$
dashed $m_h = 200\,\mathrm{GeV}$
solid $m_h = 300\,\mathrm{GeV}$

The Sinister Scalar Doublet (SSD)

The width of the light Higgs is dictated by small Yukawas sensitive to New Physics.



Small Yukawas.
Naturalness says
they can be
sensitive to NP.

see S. Mantry, M.J. Ramsey-Musolf and M. Trott arXiv:0707.3152

A two scaler doublet model, using MFV (so no FCNC) the second doublet can be nearly invisible at LHC but can cause large effects on Yukawas.

- It could be **sinister** because not only is it hard to see the second doublet in this model, the existence of the second doublet can make it hard to see the Higgs itself at LHC.

The Sinister Scalar Doublet (SSD)

In particular the decay $h \to b\bar{b}$ is sensitive to new physics and even though we can't see this decay directly if it changes:

- The width of light higgs changes. If $h \to b\bar{b}$ changes by f but everything else contributing to the width remains the same, then IMPORTANT Higgs discovery signals like: $h \to \gamma\gamma$
  $h \to \tau\tau$

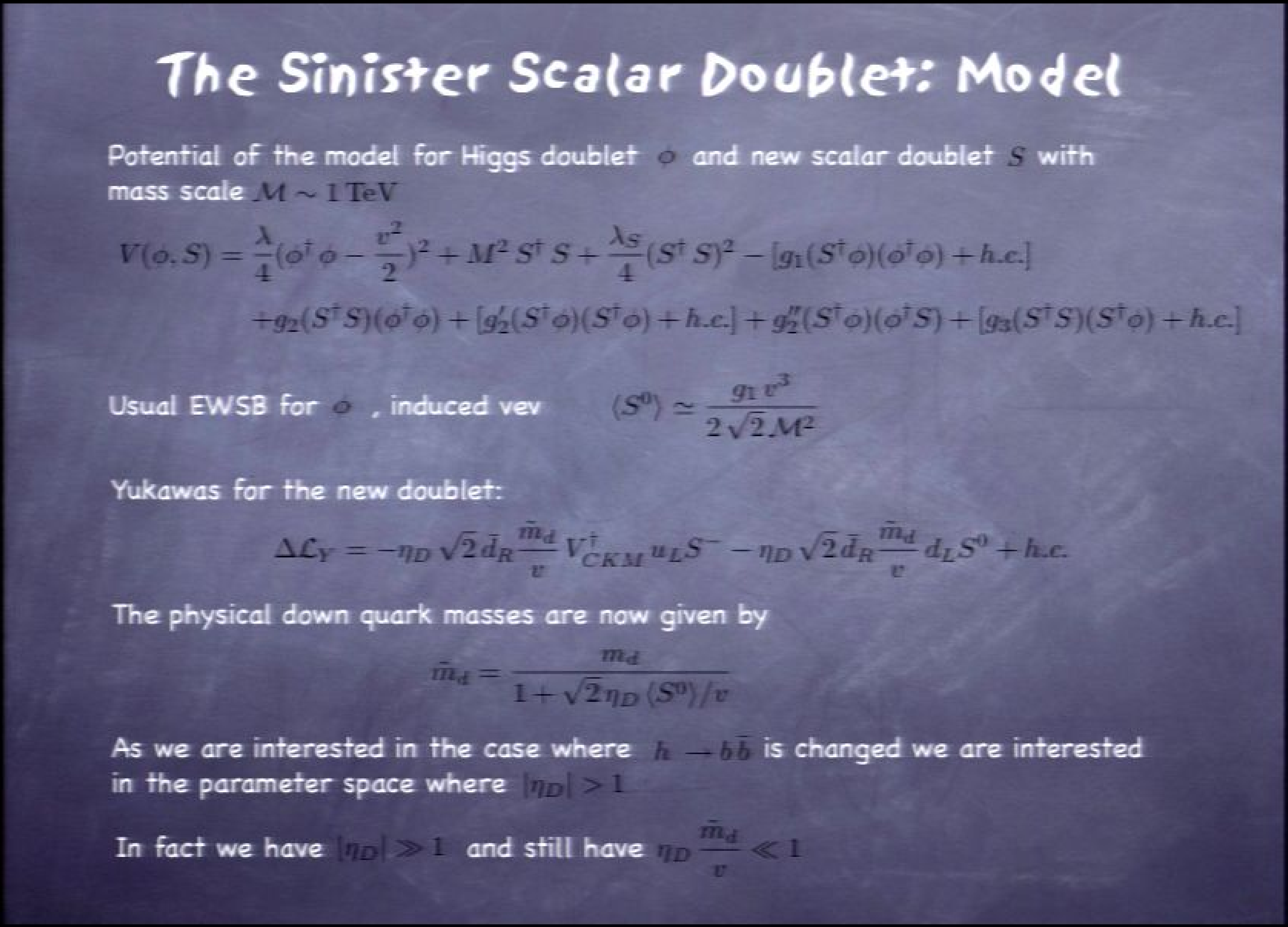
  change by $\xi = \dfrac{1}{1-(f-1)\mathrm{BR}(h \to b\bar{b})_{SM}}$

- Depending on the parameters in the potential and in the extended Yukawa sector we could have :

  $\xi = 3$ fantastic early Higgs discovery!

  $\xi = 1/80$ the Higgs is missing at LHC!

Now lets talk about the model a bit, remember this is just one way this could happen. Note that the parameter choices you will see is consistent and natural with large $\tan(\beta)$ supersymmetry.
(Just shown by Lisa Randall last week 0711.4369)



The Sinister Scalar Doublet: Model

Potential of the model for Higgs doublet ϕ and new scalar doublet S with mass scale $\mathcal{M} \sim 1\,\mathrm{TeV}$

$$V(\phi, S) = \frac{\lambda}{4}(\phi^\dagger \phi - \frac{v^2}{2})^2 + M^2 S^\dagger S + \frac{\lambda_S}{4}(S^\dagger S)^2 - [g_1 (S^\dagger \phi)(\phi^\dagger \phi) + h.c.]$$

$$+ g_2 (S^\dagger S)(\phi^\dagger \phi) + [g_2' (S^\dagger \phi)(S^\dagger \phi) + h.c.] + g_2'' (S^\dagger \phi)(\phi^\dagger S) + [g_3 (S^\dagger S)(S^\dagger \phi) + h.c.]$$

Usual EWSB for ϕ , induced vev $\langle S^0 \rangle \simeq \dfrac{g_1 v^3}{2\sqrt{2}\mathcal{M}^2}$

Yukawas for the new doublet:

$$\Delta\mathcal{L}_Y = -\eta_D \sqrt{2}\, \bar{d}_R \frac{\bar{m}_d}{v} V^\dagger_{CKM} u_L S^- - \eta_D \sqrt{2}\, \bar{d}_R \frac{\bar{m}_d}{v} d_L S^0 + h.c.$$

The physical down quark masses are now given by

$$\bar{m}_d = \frac{m_d}{1 + \sqrt{2}\eta_D \langle S^0 \rangle / v}$$

As we are interested in the case where $h \to b\bar{b}$ is changed we are interested in the parameter space where $|\eta_D| > 1$

In fact we have $|\eta_D| \gg 1$ and still have $\eta_D \dfrac{\bar{m}_d}{v} \ll 1$

The Sinister Scalar Doublet: Constraints

We have checked that for the $|\eta_D| \gg 1, |\eta_U| \ll 1$ parameter space that is particularly interesting is viable by checking against $\bar{B} \to X_s \gamma$ constraints

We find: $$\mathcal{H}_{eff} = \frac{e}{96\,\pi^2}\,\eta_D^2\,\frac{m_t^2}{\mathcal{M}^2}\,\frac{G_F}{\sqrt{2}}\,V_{ts}^{*}\,V_{tb}\left(\frac{\bar{m}_b}{m_b}\right)\bar{m}_s\,\bar{s}_R\,\sigma_{\mu\nu}\,F^{\mu\nu}\,b_L$$

This gives: $$\frac{\Gamma(b \to s\gamma)}{\Gamma(b \to s\gamma)_{SM}} \simeq 1 + \left(\frac{\eta_D^2\,\bar{m}_s\,\bar{m}_b\,m_t^2}{24\,C_7(m_b)\,m_b^2\,\mathcal{M}^2}\right)^2$$

Integrate the new doublet S out as it is heavy and you induce the operator that naturalness says can have a big effect on the $hb\bar{b}$ coupling

$$\mathcal{L}_{eff} = -\sqrt{2}\,\eta_D(\phi^\dagger\,\phi)\,\frac{g_1}{\mathcal{M}^2}\,\frac{\bar{m}_b}{v}\bar{b}_R\,\phi^\dagger Q_L + h.c.$$

Production of The Sinister Scalar Doublet

The change in $h \to b\bar{b}$ due to this operator is

$$\frac{\Gamma(h \to b\bar{b})}{\Gamma(h \to b\bar{b})_{SM}} = \left[\frac{1+3v^2 g_1 \eta_D/2\mathcal{M}^2}{1+v^2 g_1 \eta_D/2\mathcal{M}^2}\right]^2$$

Remember WE CAN"T SEE $h \to b\bar{b}$ at LHC for a lot of data. (ttbb background)

Can we see S ? Nope.

Dominant production mechanisms:

$\eta_D = 10, g_1 = 0.5$

$b\bar{b} \to S^0$

$gg \to S^0$

Where: $S^0 = \langle S^0 \rangle + \frac{S_R^0 + iS_I^0}{\sqrt{2}}$

Not that many S^0 produced in the parameter space where it can have a big indirect effect on the production of the Higgs.

Production of the $S^{\pm}$ suppressed compared to S^0

Pseudo-scalar production not suppressed but it is harder to see.

Detection of The Sinister Scalar Doublet

Same quantum numbers as the Higgs so it mixes with the Higgs:

$$h \simeq h^0 + \frac{3\, g_1\, v^2}{2\,\mathcal{M}^2}\, S_R^0 \qquad S_R \simeq S_R^0 - \frac{3\, g_1\, v^2}{2\,\mathcal{M}^2}\, h^0$$

Mass Spectrum is given by:

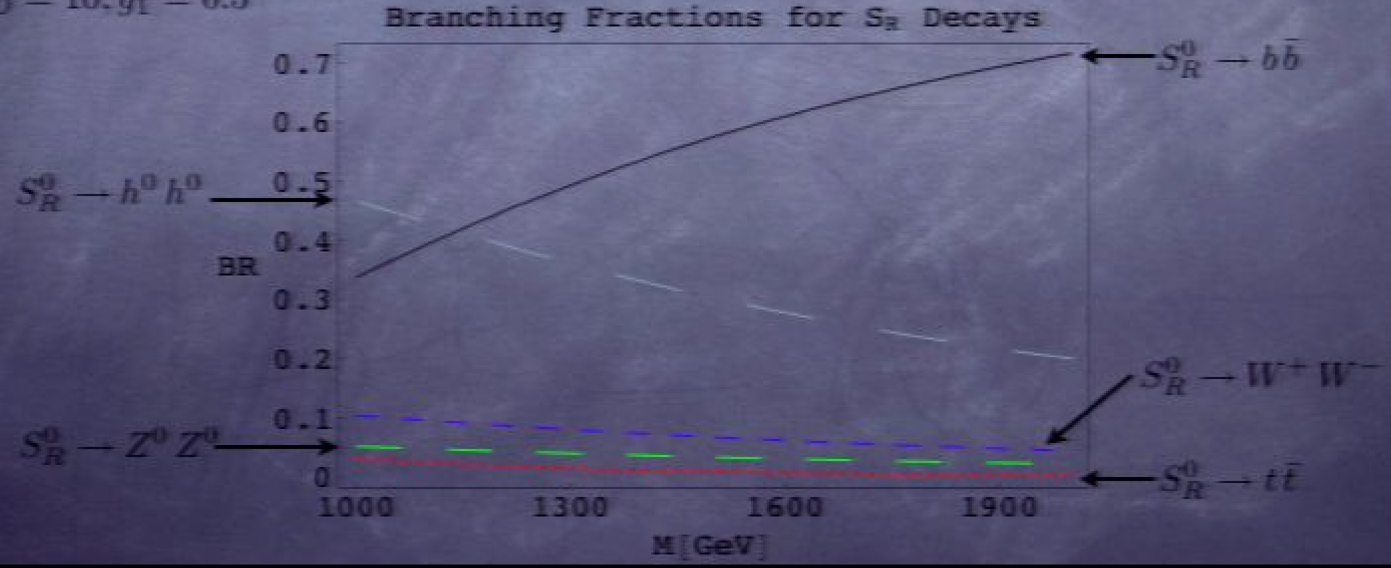
$$m^2_{S^\pm} = \mathcal{M}^2 + g_2\, v^2$$

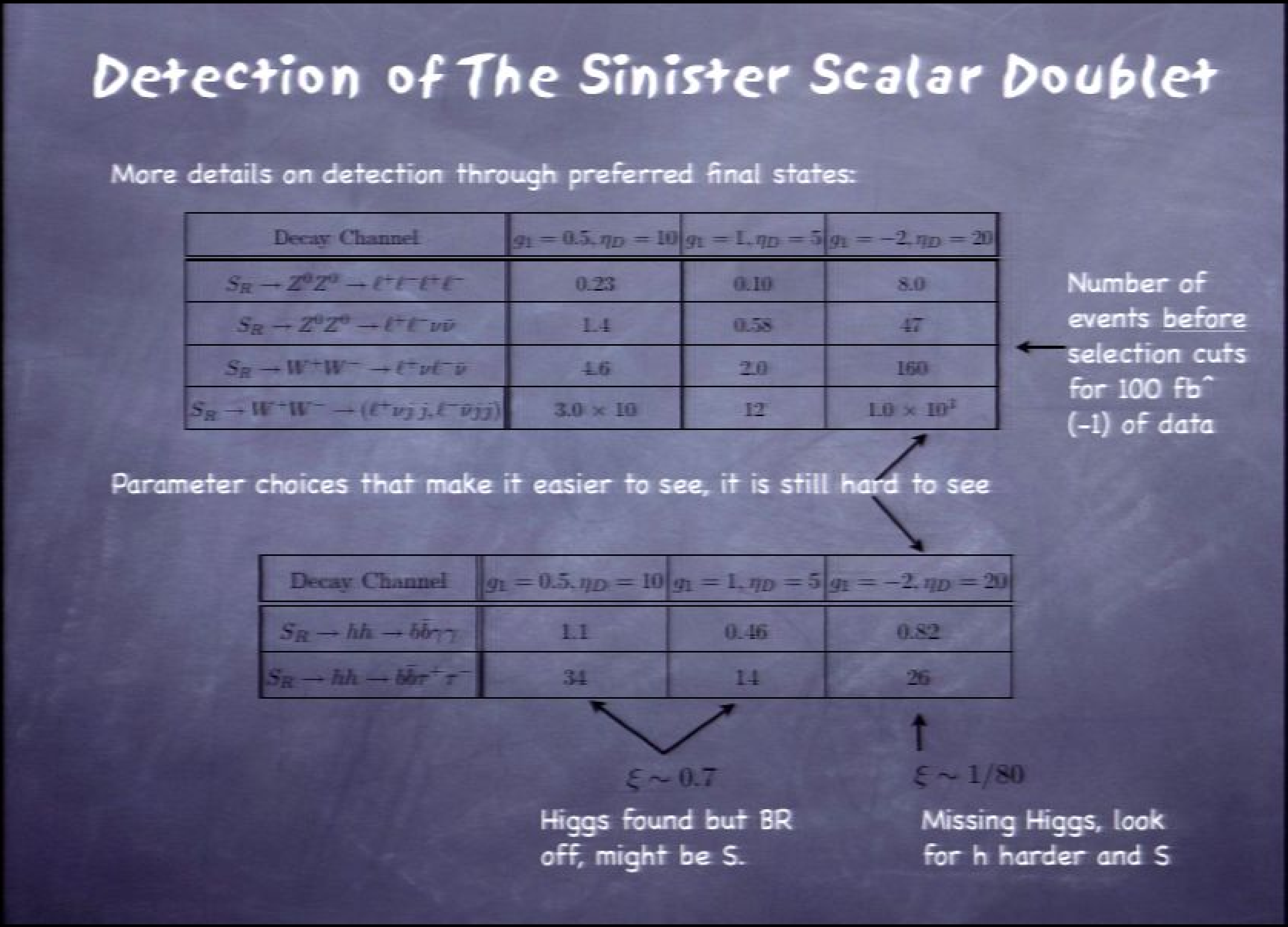
$$m^2_{S_I^0} = \mathcal{M}^2 + (g_2 - g_2' + g_2''/2)\, v^2$$

$$m^2_{S_R^0} = \mathcal{M}^2 + (g_2 + g_2' + g_2''/2)\, v^2$$

For the region of parameter space where $m^2_{S_R^0} < m^2_{S_I^0}, m^2_{S^\pm}$

$\eta_D = 10, g_1 = 0.5$





Detection of The Sinister Scalar Doublet

More details on detection through preferred final states:

Decay Channel	$g_1 = 0.5, \eta_D = 10$	$g_1 = 1, \eta_D = 5$	$g_1 = -2, \eta_D = 20$
$S_R \to Z^0 Z^0 \to \ell^+ \ell^- \ell^+ \ell^-$	0.23	0.10	8.0
$S_R \to Z^0 Z^0 \to \ell^+ \ell^- \nu \bar{\nu}$	1.4	0.58	47
$S_R \to W^+ W^- \to \ell^+ \nu \ell^- \bar{\nu}$	4.6	2.0	160
$S_R \to W^+ W^- \to (\ell^+ \nu j j, \ell^- \bar{\nu} j j)$	3.0×10	12	1.0×10^3

Number of events before selection cuts for 100 fb^ (-1) of data

Parameter choices that make it easier to see, it is still hard to see

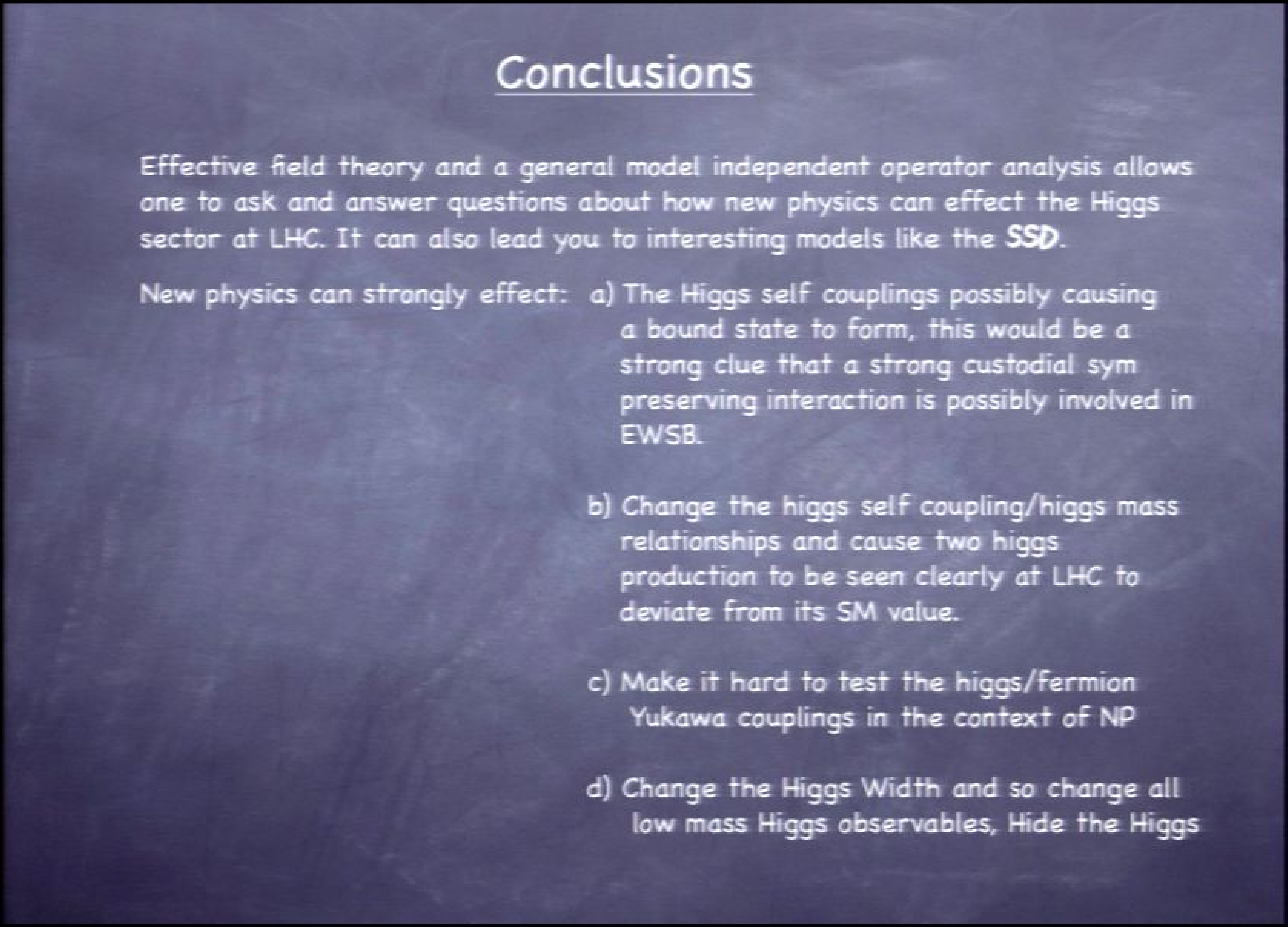
Decay Channel	$g_1 = 0.5, \eta_D = 10$	$g_1 = 1, \eta_D = 5$	$g_1 = -2, \eta_D = 20$
$S_R \to hh \to b\bar{b}\gamma\gamma$	1.1	0.46	0.82
$S_R \to hh \to b\bar{b}\tau^+\tau^-$	34	14	26

$\xi \sim 0.7$

Higgs found but BR off, might be S.

$\xi \sim 1/80$

Missing Higgs, look for h harder and S



Conclusions

Effective field theory and a general model independent operator analysis allows one to ask and answer questions about how new physics can effect the Higgs sector at LHC. It can also lead you to interesting models like the **SSD**.

New physics can strongly effect:

a) The Higgs self couplings possibly causing a bound state to form, this would be a strong clue that a strong custodial sym preserving interaction is possibly involved in EWSB.

b) Change the higgs self coupling/higgs mass relationships and cause two higgs production to be seen clearly at LHC to deviate from its SM value.

c) Make it hard to test the higgs/fermion Yukawa couplings in the context of NP

d) Change the Higgs Width and so change all low mass Higgs observables, Hide the Higgs