A* HIGGS
-OR-
*THE* HIGGS

[A Bottom-Up Theory Perspective on LHC Higgs Searches]

PLHC 2012
UNIVERSITY OF BRITISH COLUMBIA

Jamison Galloway
Based on arXiv:1202.3415 with A. Azatov and R. Contino;
arXiv:1206.1058 with A. Azatov, S. Chang, and N. Craig
Both camps weighing in...

Experimentalists:

Not enough data to conclude the existence or non-existence of the Higgs boson

from A. Falkowski @ Planck 2012
Theorists:

*Come on... it’s 125 GeV*

from A. Falkowski @ Planck 2012
Some are already taking a bolder stance...

Higgs weights 125 GeV!
Now what?

2) SM vacuum (in)stability (http://arxiv.org/abs/1205.6497)
3) Higgs & SUSY (http://arxiv.org/abs/1108.6077)

Alessandro Strumia
Talk at CERN, IFAE, Princeton and Planck2012
updated to May 31, 2012

from A. Strumia @ Planck 2012
Some are already taking a bolder stance...

Higgs weights 125 GeV!

Now what?

1) Is Higgs standard?  
2) SM vacuum (in)stability  
3) Higgs & SUSY

Alessandro Strumia
Talk at CERN, IFAE, Princeton and Planck2012
updated to May 31, 2012

from A. Strumia @ Planck 2012
Outline:

I. How can we tell? (i.e. going from data to models as an outsider)

II. Contextual Answer One: Compositeness

III. Contextual Answer Two: Supersymmetry
Primary difference between cases one and two: flavor-universal vs. non-universal Yukawa rescalings
Primary commonality between cases one and two: Deviations from “the-ness” imply additional low energy states associated with EWSB sector
Part One: From Data to Models
Part One: From Data to Models

Question to answer: how can we use searches -- and data presentation -- that are optimized for a SM Higgs to constrain generic Higgs-like parameter spaces?
Our handle: construct everything from two critical pieces of information, the expected and observed exclusion limits (from each channel/subchannel)

- We have this certainly for each channel...
- ...and each subchannel when we’re lucky
- Gives necessary information over whole mass range
What do we know (thanks to the LHC)?

Answer:
We know the amount by which we can rescale production/branching -- all in the same proportions -- and still be consistent with observation.

Said another way, we know what’s going on in a one-dimensional parameter space: adequate in some cases, but in several others we’d like to push this information a bit further...

How do we proceed?
Moving on: Comparison to RECONSTRUCTED Likelihood

(Three variables, only two constraints: we need to be slightly clever)

Assume asymptotic limit, i.e. Poisson $\rightarrow$ Gaussian:

\[ P(n_B + \mu n_S | n_{\text{obs}}) = \pi(\mu) \times \exp \left[ \frac{-(n_B + \mu n_S - n_{\text{obs}})^2}{2n_{\text{obs}}} \right] \]

\[ \Rightarrow \hat{\mu}^{95\%} = 1.96 \times \frac{\sqrt{n_B}}{n_S} \]
Assume asymptotic limit, i.e. Poisson $\rightarrow$ Gaussian:

$$P(n_B + \mu n_S | n_{\text{obs}}) = \pi(\mu) \times \exp \left[ \frac{-(n_B + \mu n_S - n_{\text{obs}})^2}{2n_{\text{obs}}} \right]$$

$$\Rightarrow \tilde{\mu}_{\text{exp}}^{95\%} = 1.96 \times \frac{\sqrt{n_B}}{n_S}$$

For observed exclusion, use a simple rewriting:

$$P(n_B + \mu n_S | n_{\text{obs}}) = \pi(\mu) \times \exp \left[ -\frac{1}{2} \left( \mu \frac{n_S}{\sqrt{n_B}} \frac{\sqrt{n_B}}{\sqrt{n_{\text{obs}}}} + \delta \right)^2 \right]; \quad \delta \equiv \frac{n_B - n_{\text{obs}}}{\sqrt{n_{\text{obs}}}}$$

with a simple assumption $\frac{n_{\text{obs}} - n_B}{n_{\text{obs}}} \ll 1$
Moving on: Comparison to RECONSTRUCTED Likelihood

(Three variables, only two constraints: we need to be slightly clever)

Assume asymptotic limit, i.e. Poisson $\rightarrow$ Gaussian:

$$P(n_B + \mu n_S | n_{obs}) = \pi(\mu) \times \exp \left[ -\left( \frac{n_B + \mu n_S - n_{obs}}{2n_{obs}} \right)^2 \right]$$

$$\Rightarrow \tilde{\mu}_{95\%}^\text{exp} = 1.96 \times \frac{\sqrt{n_B}}{n_S}$$

For observed exclusion, use a simple rewriting:

$$P(n_B + \mu n_S | n_{obs}) = \pi(\mu) \times \exp \left[ -\frac{1}{2} \left( \mu \frac{n_S}{\sqrt{n_B}} \frac{\sqrt{n_B}}{\sqrt{n_{obs}}} + \delta \right)^2 \right] ; \quad \delta \equiv \frac{n_B - n_{obs}}{\sqrt{n_{obs}}}$$

with a simple assumption $\frac{n_{obs} - n_B}{n_{obs}} \ll 1$
Moving on: Comparison to \textit{RECONSTRUCTED} Likelihood

\[ P(\mu) = N \times \exp \left[ -\frac{1}{2} \left( \frac{1.96 \times \mu}{\tilde{\mu}_{\text{exp}}^{(95\%)} + \delta} \right)^2 \right] \]
Moving on: Comparison to RECONSTRUCTED Likelihood

\[ P(\mu) = N \times \exp \left[ -\frac{1}{2} \left( \frac{1.96 \times \mu}{\tilde{\mu}_{\text{exp}}^{(95\%)} + \delta} \right)^2 \right] \]

Solve for remaining parameter using observed exclusion limit:

\[ 0.95 = \int_{\tilde{\mu}_{\text{obs}}^{(95\%)}}^{\infty} d\mu P(\mu) \]
Moving on: Comparison to *RECONSTRUCTED* Likelihood

\[
P(\mu) = N \times \exp \left[ -\frac{1}{2} \left( \frac{1.96 \times \mu}{\tilde{\mu}_{\text{exp}}^{(95\%)} + \delta} \right)^2 \right]
\]

Solve for remaining parameter using observed exclusion limit:

\[
0.95 = \int_{0}^{\tilde{\mu}_{\text{obs}}^{(95\%)}} d\mu \, P(\mu)
\]

RECAP:
- Expected exclusion tells us about s/b
- Observed tells us delta, completes determination of (AL) likelihood
- Good news: can be done over whole mass range, not just at ‘peaks’ where information on best fit is available
How well does this method do?

One possible check: the total combination

![Graph showing the comparison of different methods against CMS data. The x-axis represents $m_h$ (GeV), and the y-axis represents the value being checked. The graph includes lines for the Official Combination, Gaussian, and Inverse Quadrature.]
How well does this method do?

One possible check: the total combination

- ACCURATE WITHIN 10% BELOW 300 GeV; within 20% at high masses
- Compare to "naive graphical analysis" (adding in inverse quadrature) which errs by 40% or more
- Looks good: let's apply the method and run with it
Part Two: Compositeness

Assumption here: the ‘Higgs’ emerges as a pseudo Nambu-Goldstone boson of a spontaneously broken global symmetry
The Big Picture

Setup

- Some new dynamics confines at a scale $\Lambda \sim 4\pi f$
- EW is embedded in the global symmetry such that the Higgs develops a VEV, $v = f \sin \theta$, with vacuum angle determined by symmetry-breaking spurions (top Yukawa, gauge coupling, ...)

$$\Lambda \sim 4\pi f$$
The Big Picture

Setup

- Some new dynamics confines at a scale \( \Lambda \sim 4\pi f \)
- EW is embedded in the global symmetry such that the Higgs develops a VEV, \( v = f \sin\theta \), with vacuum angle determined by symmetry-breaking spurions (top Yukawa, gauge coupling, ...)

\[
\sin\theta \to 0 \quad \Rightarrow \quad \text{SM Limit (} f \to \infty \text{);
}\]

\[
\sin\theta \to 1 \quad \Rightarrow \quad \text{Technicolor (‘Higgsless’) Limit}
\]
The Big Picture

Setup
- Some new dynamics confines at a scale $\Lambda \sim 4\pi f$
- EW is embedded in the global symmetry such that the Higgs develops a VEV, $v = f \sin \theta$, with vacuum angle determined by symmetry-breaking spurions (top Yukawa, gauge coupling, ...)

Implications: Higgs couplings interpolate between two limits

\[
\begin{align*}
g_{hVV} &= \sqrt{1 - \xi} \times g_{hVV}^{\text{SM}}; \quad \xi \equiv v^2/f^2 \\
\Rightarrow g_{hf f} &= \sqrt{1 - \xi} \times g_{hf f}^{\text{SM}} \\
\Rightarrow g_{hf f} &= \frac{1 - 2\xi}{\sqrt{1 - \xi}} \times g_{hf f}^{\text{SM}}
\end{align*}
\]

Model-dependent, e.g.
- $SO(5)/SO(4); \quad f \in 4$
  \[
  \Rightarrow g_{hf f} = \sqrt{1 - \xi} \times g_{hf f}^{\text{SM}}
  \]
- $SO(5)/SO(4); \quad f \in 5$
  \[
  \Rightarrow g_{hf f} = \frac{1 - 2\xi}{\sqrt{1 - \xi}} \times g_{hf f}^{\text{SM}}
  \]
The Big Picture

Setup
- Some new dynamics confines at a scale $\Lambda \sim 4\pi f$
- EW is embedded in the global symmetry such that the Higgs develops a VEV, $v = f \sin \theta$, with vacuum angle determined by symmetry-breaking spurions (top Yukawa, gauge coupling, ...)

Implications: Additional new physics at low scales

Many new states could be within reach!

- Non-minimal symmetry structure => additional scalars (PNGBs)
- Vector mesons (analogue of $\rho_{\text{QCD}}$)

$$m_\rho \sim \frac{\Lambda}{\sqrt{N}}$$

$$\sim \frac{4\pi v}{\sqrt{N}} \times \sqrt{\frac{1}{1 - \left(\frac{g_{hVV}}{g_{hVV}^{\text{SM}}}\right)^2}}$$
The Big Picture

Setup

- Some new dynamics confines at a scale $\Lambda \sim 4\pi f$
- EW is embedded in the global symmetry such that the Higgs develops a VEV, $v = f \sin \theta$, with vacuum angle determined by symmetry-breaking spurions (top Yukawa, gauge coupling, ...)

Implications: Additional new physics at low scales

Many new states could be within reach!

\[ m_\rho \sim \frac{\Lambda}{\sqrt{N}} \]
\[ \sim \frac{4\pi v}{\sqrt{N}} \times \sqrt{\frac{1}{1 - \left(g_{hVV}/g_{hVV}^{\text{SM}}\right)^2}} \]

- Non-minimal symmetry structure $\Rightarrow$ additional scalars (PNGBs)
- Vector mesons (analogue of $\rho_{QCD}$)
The Big Picture

Setup

- Some new dynamics confines at a scale \( \Lambda \sim 4\pi f \)
- EW is embedded in the global symmetry such that the Higgs develops a VEV, \( v = f \sin \theta \), with vacuum angle determined by symmetry-breaking spurions (top Yukawa, gauge coupling, ...)

Implications

- Non-minimal symmetry structure \( \Rightarrow \) additional scalars (PNGBs)
- Vector mesons (analogue of \( \rho_{QCD} \))

\[
\begin{align*}
\text{Very Model-Dependent} \\
\text{Many new states could be within reach!}
\end{align*}
\]

\[
\begin{align*}
m_{\rho} & \sim \frac{\Lambda}{\sqrt{N}} \\
& \sim \frac{4\pi v}{\sqrt{N}} \times \sqrt{\frac{1}{1 - \left(\frac{g_{hVV}}{g_{hVV}^{\text{SM}}}\right)^2}}
\end{align*}
\]

See explicitly how new physics scale depends on deviation from SM
Status report for the Higgs at 125(?)(!)

CMS Likelihoods \([\leq 4.9 \, \text{fb}^{-1} \, @ \, 7 \, \text{TeV}]\)

Peak likelihood falls nearly on top of SM point...
Status report for the Higgs at 125(?)(!)

(Preliminary) Conclusions:
- Exclusive analyses suggest that couplings in this framework ~ SM
- Therefore compositeness scale would be quite high...
- ...other states from EWSB (vectors) typically heavy

Peak likelihood falls nearly on top of SM point...
Part Three:
Supersymmetry
First: U and D Yukawa Rescalings differ (Type-II 2HDM)

Conventions: \( H_u = 2_{1/2}, \ H_d = 2_{-1/2}, \langle \text{Re} H_u^0 \rangle / \langle \text{Re} H_d^0 \rangle \equiv \tan \beta \)

\[
\begin{pmatrix} h \\ H \end{pmatrix} = \sqrt{2} \begin{pmatrix} -\sin \alpha & \cos \alpha \\ \cos \alpha & \sin \alpha \end{pmatrix} \begin{pmatrix} \text{Re} H_d^0 \\ \text{Re} H_u^0 \end{pmatrix}
\]

Implications: (Again) Additional new physics at low scales

\[
\sum_i g^2_{VVh_i} = g^2_{VVh_{SM}}; \quad \text{e.g.} \quad \frac{g^2_{VVh}}{g^2_{VVh_{SM}}} + \frac{g^2_{VVH}}{g^2_{VVh_{SM}}} = 1
\]
First: U and D Yukawa Rescalings differ (Type-II 2HDM)

Conventions: \( H_u = 2_{1/2}, \ H_d = 2_{-1/2}, \ \langle \text{Re} H_u^0 \rangle / \langle \text{Re} H_d^0 \rangle \equiv \tan \beta \)

\[
\begin{pmatrix}
 h \\
 H
\end{pmatrix} = \sqrt{2} \begin{pmatrix}
 -\sin \alpha & \cos \alpha \\
 \cos \alpha & \sin \alpha
\end{pmatrix} \begin{pmatrix}
 \text{Re} H_d^0 \\
 \text{Re} H_u^0
\end{pmatrix}
\]

Implications: (Again) Additional new physics at low scales

\[
\sum_i g_{VVh_i}^2 = g_{VVh_{SM}}^2; \quad \text{e.g.} \quad \frac{g_{VVh}^2}{g_{VVh_{SM}}^2} + \frac{g_{VVH}^2}{g_{VVh_{SM}}^2} = 1
\]

Heavy Higgs in the low-energy spectrum \(\Rightarrow\) Deviations from SM couplings
First: U and D Yukawa Rescalings differ (Type-II 2HDM)

Conventions: $H_u = 2_{1/2}, H_d = 2_{-1/2}, \langle \text{Re}H_u^0 \rangle / \langle \text{Re}H_d^0 \rangle \equiv \tan \beta$

$$\begin{pmatrix} h \\ H \end{pmatrix} = \sqrt{2} \begin{pmatrix} -\sin \alpha & \cos \alpha \\ \cos \alpha & \sin \alpha \end{pmatrix} \begin{pmatrix} \text{Re}H_d^0 \\ \text{Re}H_u^0 \end{pmatrix}$$

Implications: (Again) Additional new physics at low scales

$$\sum_i g_{VV}^2 h_i = g_{VV}^2 h_{SM}; \quad \text{e.g.} \quad \frac{g_{VV}^2 h}{g_{VV}^2 h_{SM}} + \frac{g_{VV}^2 H}{g_{VV}^2 h_{SM}} = 1$$

Heavy Higgs in the low-energy spectrum $\Rightarrow$ Deviations from SM couplings

$$c_u \equiv \frac{g_{hQuc}}{SM} = \frac{\cos \alpha}{\sin \beta}$$

$$c_d \equiv \frac{g_{hQdc}}{SM} = -\frac{\sin \alpha}{\cos \beta}$$

$$a \equiv \frac{\text{gauge}}{SM} = \sin(\beta - \alpha)$$

What is the data telling us about this space?
First: what does the accessible space of Yukawas look like?
And for the MSSM?

The *very constrained* quartic structure of the MSSM (all coming from D terms) forbids it from entering the down-suppressed region whenever tan beta > 1.
Status...

We can construct the likelihood in the full 3D space, then project the gauge direction onto the 2D Yukawa plane:

While gauge coupling currently prefers decoupling (couplings = SM), other channels slide shallowly into a region inaccessible for MSSM!
How does the (loop-level) MSSM fare?

\[ \Delta V_{\text{generic}} = \lambda_1 |H_u|^4 + \lambda_2 |H_d|^4 - 2\lambda_3 |H_u|^2 |H_d|^2 \]

(+ non-minimal terms)

MSSM for neutral CP-even fields: \( \lambda_{1,2,3} = \frac{1}{8} (g^2 + g'^2) \)

with potentially lifesaving quantum corrections to \( \lambda_1 \), but for “down-suppression” we need

\[ v_u^2 \times (\lambda_1 + \lambda_3) < v_d^2 \times (\lambda_2 + \lambda_3) \]

i.e. big quantum-level correction to \( \lambda_{2,3} \) when \( \tan \beta > 1 \), tough for the MSSM!
How does the (loop-level) MSSM fare?

$$\Delta V_{\text{generic}} = \lambda_1 |H_u|^4 + \lambda_2 |H_d|^4 - 2\lambda_3 |H_u|^2 |H_d|^2$$

$$\text{(} + \text{ non-minimal terms)}$$

MSSM for neutral CP-even fields: \( \lambda_{1,2,3} = \frac{1}{8} (g^2 + g'^2) \)

with potentially lifesaving quantum corrections to \( \lambda_1 \), but for “down-suppression” we need

$$v_u^2 \times (\lambda_1 + \lambda_3) < v_d^2 \times (\lambda_2 + \lambda_3)$$

i.e. big quantum-level correction to \( \lambda_{2,3} \) when \( \tan \beta > 1 \), tough for the MSSM!

Two potential strikes against minimality:

- Higgs mass;
- Higgs couplings.

Natural to consider non-minimal dynamics (left as an exercise*)
How does the (loop-level) MSSM fare?

$$
\Delta V_{\text{generic}} = \lambda_1 |H_u|^4 + \lambda_2 |H_d|^4 - 2\lambda_3 |H_u|^2 |H_d|^2
$$

(\text{+ non-minimal terms})

MSSM for neutral CP-even fields: \( \lambda_{1,2,3} = \frac{1}{8} (g^2 + g'^2) \)

with potentially lifesaving quantum corrections to \( \lambda_1 \), but for “down-suppression” we need

$$
\nu_u^2 \times (\lambda_1 + \lambda_3) < \nu_d^2 \times (\lambda_2 + \lambda_3)
$$

i.e. big quantum-level correction to \( \lambda_2,3 \) when \( \tan \beta > 1 \), tough for the MSSM!

Two potential strikes against minimality:

- Higgs mass;
- Higgs couplings.

Natural to consider non-minimal dynamics (left as an exercise*)

*But the answer is in the back of the book (backup slides)
(Way too early for any) Conclusions

I. Composite Higgs: Fairly SM-like couplings indicate strong dynamics preferred at a high scale, if at all

II. SUSY: Hints of non-minimality in some channels so far; non-SM couplings indicate that some new states could show up soon

III. Generally: Couplings provide crucial indirect hints and consistency checks for BSM physics...
I. Composite Higgs: Fairly SM-like couplings indicate strong dynamics preferred at a high scale, if at all

II. SUSY: Hints of non-minimality in some channels so far; non-SM couplings indicate that some new states could show up soon

III. Generally: Couplings provide crucial indirect *hints* and *consistency checks* for BSM physics...

Spectra may make headlines, but couplings serve as fact-checkers. Establishing consistency of new physics requires collaboration between theorists and experimentalists; let’s be ready for it!
Backups
Status report for unpopular mass points

![CMS Exclusions graph](image)

CMS Exclusions [$\sqrt{s} = 7$ TeV; $\leq 4.8$ fb$^{-1}$]

- $m_h$ [95% CL]
  - Black: 120 GeV
  - Blue dotted: 130 GeV
  - Green: 160 GeV
  - Red: 200 GeV

Star denotes SM point.
A Cautionary tale: **Need Exclusive** Searching and Reporting

**ALL INCLUSIVE vs. ALL EXCLUSIVE** subchannels:

![CMS Likelihoods](image)
*The* space of the MSSM Higgs

![CMS Combined Likelihoods](image-url)
*The* space of the MSSM Higgs

Decoupling:

\[ H^0, H^\pm, A^0 \to \infty; \]

\[ \Rightarrow a, c_u, c_d \to 1 \]

Supported here by couplings, but also by Higgs mass!

\[ m_h \to m_Z \text{ as } m_{A^0} \to \infty \]
The space of the MSSM Higgs

Decoupling:

\[ H^0, H^\pm, A^0 \to \infty; \]

\[ \Rightarrow a, c_u, c_d \to 1 \]

Supported here by couplings, but also by Higgs mass!

\[ m_h \to m_Z \text{ as } m_{A^0} \to \infty \]

- Peak likelihood lies close to the decoupling limit contour
- Consistency of this requires ALL couplings to revert to SM
- To check this, we can examine a 3D space...
Down-Suppression from New Perturbative Dynamics

I. Singlets (e.g. NMSSM)

$$v_u^2 \times (\lambda_1 + \lambda_3) < v_d^2 \times (\lambda_2 + \lambda_3)$$

II. Doublets (Superconformal TC = “The Seiberg Higgs”)

III. Triplets
Down-Suppression from New Perturbative Dynamics

\[ v_u^2 \times (\lambda_1 + \lambda_3) < v_d^2 \times (\lambda_2 + \lambda_3) \]

I. Singlets (e.g. NMSSM)

\[ \Delta W = \lambda S H_u H_d + \kappa S^3 \quad \Rightarrow \quad \delta \lambda_3 = -|\lambda|^2 \]

II. Doublets (Superconformal TC = “The Seiberg Higgs”)

III. Triplets
Down-Suppression from New Perturbative Dynamics

I. Singlets (e.g. NMSSM)

\[ \Delta W = \lambda S H_u H_d + \kappa S^3 \implies \delta \lambda_3 = -|\lambda|^2 \]

II. Doublets (Superconformal TC = “The Seiberg Higgs”)
Down-Suppression from New Perturbative Dynamics

\[ v_u^2 \times (\lambda_1 + \lambda_3) < v_d^2 \times (\lambda_2 + \lambda_3) \]

I. Singlets (e.g. NMSSM)

\[ \Delta W = \lambda_S H_u H_d + \kappa S^3 \Rightarrow \delta \lambda_3 = -|\lambda|^2 \]

II. Doublets (Superconformal TC = “The Seiberg Higgs”)

\[ \Delta W = \lambda_u H_u O_d + \lambda_d H_d O_u \]

\[ \Rightarrow \Delta \mathcal{L} \sim \frac{\lambda_{u,d} \Lambda^3}{16\pi^2} H_{u,d}; \ v_{u,d} \sim \frac{\lambda_{u,d} \Lambda^3}{16\pi^2 m_{H_{u,d}}^2} \]

⇒ Tadpoles ⇒ \beta
Masses ⇒ \alpha
INDEPENDENT ANGLES!

III. Triplets
Down-Suppression from New Perturbative Dynamics

\[ v_u^2 \times (\lambda_1 + \lambda_3) < v_d^2 \times (\lambda_2 + \lambda_3) \]

I. Singlets (e.g. NMSSM)

\[ \Delta W = \lambda S H_u H_d + \kappa S^3 \quad \Rightarrow \quad \delta \lambda_3 = -|\lambda|^2 \]

II. Doublets (Superconformal TC = “The Seiberg Higgs”)

\[ \Delta W = \lambda_u H_u O_d + \lambda_d H_d O_u \]

\[ \Rightarrow \Delta L \sim \frac{\lambda_{u,d} \Lambda^3}{16\pi^2} H_{u,d}; \quad v_{u,d} \sim \frac{\lambda_{u,d} \Lambda^3}{16\pi^2 m_{H_{u,d}}^2} \]

\[ \Rightarrow \text{Tadpoles} \Rightarrow \beta \quad \text{Masses} \Rightarrow \alpha \quad \text{INDEPENDENT ANGLES!} \]

III. Triplets

\[ \Delta W = \lambda_T T H_u H_u + \lambda_{\bar{T}} \bar{T} H_d H_d \quad \Rightarrow \quad \delta \lambda_{1,2} = |\lambda_{T,\bar{T}}|^2 \]
Down-Suppression from New Perturbative Dynamics

\[ v_u^2 \times (\lambda_1 + \lambda_3) < v_d^2 \times (\lambda_2 + \lambda_3) \]

I. Singlets (e.g. NMSSM)

\[ \Delta W = \lambda S H_u H_d + \kappa S^3 \quad \Rightarrow \quad \delta \lambda_3 = -|\lambda|^2 \]

II. Doublets (Superconformal TC = “The Seiberg Higgs”)

\[ \Delta W = \lambda_u H_u \mathcal{O}_d + \lambda_d H_d \mathcal{O}_u \]

\[ \Rightarrow \Delta \mathcal{L} \sim \frac{\lambda_{u,d} \Lambda^3}{16\pi^2} H_{u,d}; \quad v_{u,d} \sim \frac{\lambda_{u,d} \Lambda^3}{16\pi^2 m^2_{H_{u,d}}} \]

\[ \text{Tadpoles} \Rightarrow \beta \quad \text{Masses} \Rightarrow \alpha \quad \text{INDEPENDENT ANGLES!} \]

III. Triplets

\[ \Delta W = \lambda_T T H_u H_u + \lambda_{\bar{T}} \bar{T} H_d H_d \quad \Rightarrow \quad \delta \lambda_{1,2} = |\lambda_T, \bar{T}|^2 \]