BSM Higgs Properties

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(Karlsruhe Institute of Technology)

LHCP14
Columbia University
June 2-7, 2014
BSM Higgs Properties - Not SUSY

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LHC Discovery of New Scalar Particle

ATLAS-CONF-2013-12

CMS-PAS-HIG-13-002

ATLAS Preliminary

\[ \text{Data S/B Weighted} \]

\[ \text{Sig+Bkg Fit (} m_\gamma = 126.8 \text{ GeV)} \]

\[ \text{Bkg (4th order polynomial)} \]

\[ \sqrt{s} = 7 \text{ TeV, } \int L dt = 4.8 \text{ fb}^{-1} \]

\[ \sqrt{s} = 8 \text{ TeV, } \int L dt = 20.7 \text{ fb}^{-1} \]

\[ H \rightarrow \gamma \gamma \]

\[ \Sigma \text{weights} / \text{GeV} \]

\[ \Sigma \text{weights - Bkg} \]

\[ m_{\gamma \gamma} [\text{GeV}] \]

\[ \text{Events} / 3 \text{ GeV} \]

\[ m_{4\ell} [\text{GeV}] \]

Data

\( Z+X \)

\( Z\gamma^*, ZZ \)

\( m_H = 126 \) GeV

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It is the Higgs Boson

- Investigation of properties of scalar particle:
It is the Higgs Boson

- Investigation of properties of scalar particle: \( \sim \) Higgs Boson
It is the Higgs Boson

The Nobel Prize in Physics 2013

François Englert
Université Libre de Bruxelles, Belgium

Peter W. Higgs
University of Edinburgh, UK

"Für den theoretiska upptäckten av en mekanism som bidrar till förståelsen av massans ursprung hos subatomära partiklar, och som nyligen, genom upptäckten av den förutsagda fundamentals partikeln, bekräftats av ATLAS- och CMS-experimenten vid CERN:s accelerator LHC."

"For the theoretical discovery of a mechanism that contributes to our understanding of the origin of mass of subatomic particles, and which recently was confirmed through the discovery of the predicted fundamental particle, by the ATLAS and CMS experiments at CERN's Large Hadron Collider."
It is the Higgs Boson
The Menu

◊ Introduction

◊ Composite Higgs Boson
  * Phenomenological Implications

◊ Effective Lagrangian Approach
  * Relevant Operators

◊ Specific Models
  * Coupling Measurements

◊ Summary
Introduction
Open Problems

- What is the mechanism beyond EWSB? Weak or strong dynamics?
- Huge Higgs mass corrections - finetuning?
- Do the gauge couplings unify?
- Incorporation of gravity?
- Puzzling spectrum of fermion masses and mixings
- What is the nature of Dark Matter?
- Origin of matter-antimatter asymmetry?
- New sources of CP violation?
- ...
Big Questions - Big Ideas

◊ What is the mechanism beyond EWSB? Weak or strong dynamics?

◊ Huge Higgs mass corrections - finetuning? Supersymmetry

◊ Do the gauge couplings unify? Compositeness

◊ Incorporation of gravity? Extra Dimensions

◊ Puzzling spectrum of fermion masses and mixings Extended Higgs Sectors

◊ What is the nature of Dark Matter? Top Partner $W'/Z'$

◊ Origin of matter-antimatter asymmetry? Minimal Dark Matter

◊ New sources of CP violation? Hidden Sector ...

◊ ...

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Big Questions - Big Ideas

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Big Questions - Big Ideas

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- What is the nature of Dark Matter? Top Partner $W'/Z'$
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- New sources of CP violation? Hidden Sector ...
- Naturalness: New Physics just around the corner
- ...

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What Can We Learn From Higgs Physics?

Test of the Higgs mechanism

- Mass, Total Width \( m, \Gamma \)
- Interaction with a scalar Higgs \( g_{HXX} \sim m_X \) with \( v \approx 246 \text{ GeV} \neq 0 \)
- Spin and parity quantum numbers \( J^{PC} \)
- EWSB requires Higgs potential \( \lambda_{HHH}, \lambda_{HHHH} \)

Is it the Standard Model Higgs boson?

Is it the harbinger of New Physics?
What is the Dynamical Origin of EWSB?

Is the Higgs boson Elementary or Composite?

**Weakly coupled models**

- SM, SUSY, ...
- SUSY Partner \( \sim 1 \) TeV
- New particles necessary to stabilise the Higgs boson mass

**Strongly-interacting dynamics**

- Composite Higgs
- top partners \( \gtrsim 700 \) GeV
- Resonances for unitarity
- Higgs boson composite object

Cartoon from R.Contino [1005.4269]
**Composite Higgs Boson**

- **Bound state from a Strongly Interacting Sector not much above weak scale**

- **How can we obtain a light composite Higgs?**
  
  Higgs: Pseudo-Goldstone boson of strongly interacting sector

  Global symmetry of strong sector $\mathcal{G}$ spontaneously broken at $f$ subgroup $\mathcal{H}_1$

  $\mathcal{G}/\mathcal{H}_1$: contains Higgs boson as Nambu-Goldstone Boson

- **SM Gauge Group**
  
  - $\mathcal{H}_0 \subset \mathcal{G}$ gauged by external vector bosons
  - Identify $\mathcal{H}_0 = G_{SM} = SU(2)_L \times U(1)_Y$; $\mathcal{G} \to \mathcal{H}_1 \supset G_{SM}$
  - $\mathcal{H}_1$ contains 'custodial' $SO(4) \cong SU(2)_L \times SU(2)_R$ (protect $T$ parameter)
  - SM fields are external to strong sector $\sim$ elementary
Composite Higgs Boson

- Possible symmetry patterns
  - Examples:
    - $SO(5)/SO(4)$: 4 PGBs = $W^\pm_L, Z_L, h \rightarrow$ Minimal Comp. Higgs Model
      Agashe, Contino, Pomarol
    - $SO(6)/SO(5)$: 5 PGBs = $W^\pm_L, Z_L, h, a \rightarrow$ Next MCHM
      Gripaios, Pomarol, Riva, Serra
    - ...

- Higgs Boson Mass protected $\leftarrow$ quantum corrections saturated at composite scale

- Higgs Potential generated radiatively
  - By gauge boson and top quark loops
  - EWSB triggered by top loops
Partial Compositeness

- Partial Compositeness

  - Elementary fermions couple linearly to heavy states of strong sector w/ same quantum numbers

    \[ \mathcal{L}_{pc} = -\Delta_L \bar{q}_L Q_R - \Delta_R \bar{T}_L t_R + h.c. \]

  - Fermions acquire mass through mixing with new vector-like strong sector fermions

  - Linear couplings violate \( G \) explicitly \( \leadsto \) Higgs potential induced

  - Large top Yukawa couplings \( \leadsto \) top largely composite

  - Light Higgs boson requires light top partners
Phenomenological Implications?

- Modified Higgs couplings to SM gauge bosons and fermions
  - Unitarity not restored any more in $V_L V_L$ scattering
Implications of Higgs Coupling Deviations

- Longitudinal $W$ boson scattering

\[ \mathcal{A} = \frac{s}{v^2} \]
Implications of Higgs Coupling Deviations

- Longitudinal $W$ boson scattering

\[ A = \frac{1}{v^2} \left( S - \frac{\kappa_V^2 s^2}{s - m_h^2} \right) \]
Implications of Higgs Coupling Deviations

- Longitudinal $W$ boson scattering

$$\mathcal{A} = \frac{1}{v^2} \left( S - \frac{k_V^2 s^2}{s-m_h^2} \right)$$

$k_V = 1$ perturbative unitarity in $WW \rightarrow WW$

- Higgs couplings deviate from SM couplings $\Rightarrow VV \rightarrow VV$ and $VV \rightarrow hh$ grow with $E^2$

Giudice, Grojean, Pomarol, Rattazzi; Contino et al '10, '13
Phenomenological Implications?

- Modified Higgs couplings to SM gauge bosons and fermions
  - Unitarity not restored any more in $V_L V_L$
  - Higgs production and decay rates changed
  - Influences compatibility with EWPT

- New couplings
  - Compatibility with Flavour Constraints
    Agashe, Perez, Soni; Csaki eal; Blanke eal; Bauer eal; Redi, Weiler; Keren-Zur eal; Barbieri eal; Redi; Vignaroli; Da Rold eal; Delaunay eal
  - Influences Double Higgs Production

- New Resonances
  - Compatibility with LHC searches
    Gillioz, Grober, Kapuvari, MMM

- Partial Compositeness
  - Compatibility with Flavour Constraints
  - Modified Higgs Yukawa couplings
  - New particles in Loop induced processes
  - Compatibility with direct LHC Searches for new fermions, with EWPT
**Higgs Anomalous Couplings**

- **SILH effective Lagrangian** (SILH = strongly interacting light Higgs) expansion for small \( \xi \equiv v^2/f^2 \)

SM limit for \( \xi \rightarrow 0 \)

Giudice, Grojean, Pomarol, Rattazzi
**Higgs Anomalous Couplings**

- **Large $\xi$?** The 5D MCHM ($SO(5)/SO(4)$) provides completion for large $\xi$. Contino eal; Agashe eal

- **Gauge couplings**

$$g_{HVV} = g_{HV}^{SM} \sqrt{1 - \xi}$$

- **Fermion couplings** depend on embedding into representations of the bulk symmetry

  spinorial representations of $SO(5)$
  
  MCHM4

  $$g_{Hff} = g_{Hff}^{SM} \sqrt{1 - \xi} \equiv g_{Hff}^{SM} c$$

  universal shift of couplings
  no modifications of BRs

  fundamental representations of $SO(5)$
  
  MCHM5

  $$g_{Hff} = g_{Hff}^{SM} \frac{1 - 2\xi}{\sqrt{1 - \xi}} \equiv g_{Hff}^{SM} c$$

  BRs depend on $\xi = v^2/f^2$

- **Higgs self-couplings** also model-dependent

  Contino eal; Gröber, MMM; Bock eal; Barger eal
Higgs Anomalous Couplings

- **Implementation for Higgs BRs:** eHDECAY
  
  URL: [http://www.itp.kit.edu/~maggie/eHDECAY/](http://www.itp.kit.edu/~maggie/eHDECAY/)

- **Gluon Fusion Production:**
  - NNLO corrections
  - Two-loop Yukawa corrections in top partner singlet model
Constraints on the Oblique Parameters

Grojean, Matsedonskyi, Panico
Heavy Quark Partners and LHC Searches

- **Decay Channels:**
  
  **Top Partners:** $T \rightarrow Wb, Zt, ht$
  
  **Bottom Partners:** $B \rightarrow Wt, Zb, hb$
  
  **Charge-5/3 Fermions:** $\chi \rightarrow Wt$

- **Limits from LHC Experiments:**
  
  The ATLAS Collaboration: ATLAS-CONF-2013-018, 051, 056, 060
  
Heavy Quark Partners and LHC Searches

Gillioz, Gröber, Kapuvari, MMM

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• Compatibility with ATLAS Moriond’13 data, EWPD, $|V_{tb}|$, direct searches, w/ top&bottom partners ($\xi_{\text{best fit}} = v^2/f^2 = 0.096$)
• Compatibility with ATLAS Moriond'13 data, EWPD, $|V_{tb}|$, direct searches, w/ top&bottom partners ($\xi_{\text{best fit}} = v^2/f^2 = 0.096$)
• Compatibility with CMS Moriond’13 data, EWPD, $|V_{tb}|$, direct searches, w/ top&bottom partners ($\xi_{\text{best fit}} = v^2/f^2 = 0.055$)
Loop Processes: Sensitivity to the Top Partners?

- **Single Higgs production through gluon fusion:** dominant production process at LHC

  ![Diagram](image)

  - Mediated by top and bottom loops and heavy quark loops; here heavy top partners
  - Sensitivity to details of heavy composite sector?
**Loop Processes: Sensitivity to the Top Partners?**

- **Single Higgs production through gluon fusion:** via Low-Energy Theorem (LET)

\[
g g \rightarrow \text{Higgs} H
\]

- Gluon fusion computed within LET is insensitive to details of the couplings and masses of strong sector
  - Falkowski; Low, Vichi; Azatov, Galloway; Furlan; Gillioz et al; Delaunay et al; Montull et al

- **Reason:** Cancellation between

  * Correction of top Yukawa coupling due to mixing with heavy resonances and
  * Loops of extra fermions

- **⇒** Cross section depends only on Higgs non-linearities \( \xi = \frac{v^2}{f^2} \), mixing effects drop out

- **⇒** LET approximates full cross section within a few percent
Single Higgs Production in MCHM5 w/ Top Partners

Gillioz, Gröber, Grojean, MMM, Salvioni

\[ \frac{\sigma}{\sigma_{\text{SM}}} = \frac{(1-2\xi)^2}{1-\xi} \]

- LET very accurate cross section for any heavy fermion spectrum:
- Green points: allowed by EWPD and collider constraints
- Grey points: excluded by current collider constraints
- Orange: Projected exclusion by LHC8
What about Composite Double Higgs Production?

- Double Higgs production through gluon fusion:
  * sensitive to trilinear Higgs self-coupling
  * access to anomalous $HHf\bar{f}$ coupling

▷ Can be enhanced compared to the SM process
▷ Mediated by top and bottom loops and heavy quark loops; here heavy top partners
▷ Different fermions can contribute within one loop
▷ Sensitivity to details of heavy composite sector?
Double Higgs Production in MCHM5 w/ Top Partners

\[ \xi = 0.25, \sin \phi_L > 0.5 \]

<table>
<thead>
<tr>
<th>$\sigma/\sigma_{SM}$</th>
<th>$N_{\text{events}}/300 \text{ fb}^{-1}$</th>
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</table>

- grey: excluded @ 7 TeV
- orange: tested @ 8 TeV
- green: allowed

pure Higgs nonlinearities

3σ evidence, 300 fb$^{-1}$

only top; partners

\[ \leftarrow \text{integrated out} \]

top and partners

\[ \leftarrow \text{integrated out} \]
How to resolve the Top Loops?

• Inclusive gluon fusion Higgs production cannot disentangle
  * long distance physics (modified top coupling)
  * short distance physics (new particles running in the loop)

• Determination of top Yukawa coupling in $t\bar{t}H$ production: difficult
  14%-4% LHC$^{14}_{300}$-LHC$^{14}_{3000}$ vs 10%-4% ILC$^{500}$-ILC$^{1000}$

• Alternative: Boosted Higgs production in association with a high $p_T$ jet
  Banfi, Martin, Sanz; Azatov, Paul; Grojean, Salvioni, Schlaffer, Weiler; Englert, McCullough, Spannowsky
How to resolve the Top Loops?

- **High** $p_T \sim$ sensitivity to detail of loop particles  
  Baur, Glover; Langenegger et al.

- **Remarks**  
  ◊ $p_T$ distribution only known at LO  
  ◊ in NLO in the heavy $m_t$ approximation  
  Schmidt; deFlorian et al; Ravindran et al; Glosser, Schmidt; Anastasiou et al; Boughezal et al; Harlander et al  
  ◊ $b$-quark in resummed $p_T$  
  Grazzini, Sargsyan; Alwall et al; Bagnaschi et al; Mantler, Wiesemann; Banfi et al  

![Graph showing $\kappa_t$ vs. $\kappa_R$ with contours for different $R^0$ values]
Effective Lagrangian Approach
**General Framework for BSM Studies**

**Aim:** Study large class of BSM models through Higgs physics

- Higgs couplings to SM particles, $g_{hf}$, $g_{HV}$, Spin and CP quantum numbers, $J^{CP}$
- Higgs self-interactions, $g_{hhh}, g_{hhhh}$

**Indirect impact of BSM on Higgs Physics**

- general coupling modifications: absolute value and tensor structure $\Rightarrow$
- determination of couplings and CP properties cannot be treated separately in general
- coupling modifications from new particles in loop induced couplings (e.g. $g_{hgg}$, $g_{h\gamma\gamma}$), mixing with other scalar states (e.g. extended Higgs sector, portal Higgs)

**Direct impact of BSM Physics**

- Higgs decays into new lighter particles, e.g. Higgs-to-Higgs decays, invisible Higgs decays;
- SM-like Higgs from cascade decays; detection of new particles; ...

**How access BSM physics in a general, model-independent way?**

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**Effective Lagrangian Approach**

- **Natural Mechanisms for EWSB**
  - New physics at some scale \( \lambda \sim \mathcal{O}(\text{TeV}) \)
  - New physics generates deviations in SM Higgs physics

- **Convenient framework for model-independent analysis:** Effective Lagrangian Approach
  - * assume few basic principles (e.g. field content, SM gauge symmetries)
  - * parametrize SM deviations by higher-dimensional operators built of SM fields
  - * Operators = low-energy remnants of heavy NP integrated out at \( \Lambda \) ⇒
  - * Operators suppressed by scale \( \Lambda \)

- **Example:** \( SU(3) \times SU(2) \times U(1) \) invariance \( \sim \) leading NP effects described by \( D = 6 \) operators

\[
\mathcal{L}_{\text{eff}} = \sum_{n} \frac{f_{n}}{\Lambda^{2}} \mathcal{O}_{n}
\]
Choice of Basis

• **Number of Independent Dim-6 Operators**: 59 assuming 1 generation of fermions

• **Different operator bases used in the literature**

• **What defines a good basis?**
  
  ◊ captures in few operators impact of different NP scenarios
  
  ◊ exploit correlations to eliminate redundant operators (EOM/field redefinitions)
  
  ◊ separate operators with different sizes in their coefficients
  
  ◊ determine most relevant operators when investigating BSM scenarios

• **Operators relevant for Higgs physics:**
  
  e.g. Elias-Miró, Espinosa, Masso, Pomarol;
  Elias-Miró, Grojean, Gupta, Marzocca, Pomarol, Riva;
  Gupta, Pomarol, Riva

  * Operators only affecting Higgs physics (CP-conserving): 8
  
  * Operators related to EWPT (LEP1, LEP2, Tevatron): 7
  
  * Operators related to TGC measurements (LEP2, LHC): 3
**Higgs Primaries**

- **Higgs Primaries**
  - set of physical quantities best suited to constrain NP
  - *Higgs/8: $h\gamma\gamma$, $hZ\gamma$, $hgg$, $hff$, $hVV$ and $h^3$ couplings*
  - *EWPT/7, TGC/3*

- **Where to expect BSM effects?**
  - $h \rightarrow Vff$ already constrained from e.g. TGC
  - $BR(h \rightarrow Z\gamma)$ can still hide large deviations
**Higgs Primaries**

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$h \rightarrow Z\gamma$ versus TGC
Higgs Primaries

• Higgs Primaries
  set of physical quantities best suited to constrain NP
  * Higgs/8: \( h\gamma\gamma, hZ\gamma, hgg, hff, hVV \) and \( h^3 \) couplings
  * EWPT/7, TGC/3

• Where to expect BSM effects?
  ◇ \( h \rightarrow Vff \) already constrained from e.g. TGC
  ◇ \( BR(h \rightarrow Z\gamma) \) can still hide large deviations

\( h \rightarrow Z\gamma \) versus TGC
Effective Theory Approach Versus Specific Models

- **Effective Field Theory Approach**
  * assume few basic principles (e.g. field content, SM gauge symmetries)
  * parametrize SM deviations by higher-dimensional operators

  **Advantage:** study large class of models
  **Disadvantage:** cannot account for effects from light particles in the loops,
  Higgs decays into non-SM particles
  **Solution:** study specific BSM models capturing these features

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Going Beyond the SM

UnHiggs
Gaugephobic Higgs
Composite Higgs
Gauge Higgs
Simplest Higgs
Private Higgs
Intermediate Higgs
Littlest Higgs
Fat Higgs
Higgsless
Twin Higgs
Lone Higgs
Phantom Higgs
Little Higgs
Slim Higgs
Portal Higgs
What Can We Learn From Coupling Measurements?

- **The Standard Model Higgs Boson**
  - Test relation \( g_{hXX} \sim m_X \) predicted by Higgs mechanism

- **Deviations from SM couplings ← New Physics**
  - modified Higgs properties through mixing effects with other scalars or mixture between elementary and composite state in case of a composite particle (partial compositeness)
  - modified Higgs properties through loop effects or effective low-energy operators (strong interaction)

**What is the Scale of New Physics that can be Probed?**

- **Expansion in higher dimensional operators** to describe coupling deviation \( \sim \)
  \[
  g_{hXX} = g_{hXX}^{SM} [1 + \Delta] \quad \Delta = \mathcal{O}(v^2/\Lambda^2_*)
  \]
Effective New Physics Scales

Rauch et al.

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- Effective New Physics scales $\Lambda_*$ extracted from coupling measurements

<table>
<thead>
<tr>
<th>$\Lambda_*$ [TeV]</th>
<th>LHC</th>
<th>HL-LHC</th>
<th>LC</th>
<th>HL-LC</th>
<th>HL-LHC + HL-LC</th>
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<tr>
<td>$hWW$</td>
<td>0.82</td>
<td>0.87</td>
<td>2.35</td>
<td>3.18</td>
<td>3.48</td>
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<td>$hZZ$</td>
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<td>$htt$</td>
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<td>0.50</td>
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<td>$hbb$</td>
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<td>0.44</td>
<td>1.15</td>
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<tr>
<td>$h\tau\tau$</td>
<td>0.52</td>
<td>0.58</td>
<td>0.96</td>
<td>1.34</td>
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<td>$hgg$</td>
<td>0.55</td>
<td>1.07</td>
<td>1.30</td>
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<tr>
<td>$h\gamma\gamma$</td>
<td>0.15</td>
<td>0.18</td>
<td>0.24</td>
<td>0.36</td>
<td>0.44</td>
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Loop-induced couplings to gluons and photons contain only the contribution of the contact terms.
Strongly Interacting Light Higgs (SILH)

• **SILH Lagrangian:** first term of an expansion in $\xi = v^2/f^2$ [$f$: typical scale of strong sector]

Giudice, Grojean, Pomarol, Rattazzi

Englert, Freitas, MMM, Plehn, Rauch, Spira, Walz

<table>
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<tr>
<th>$\xi$</th>
<th>LHC</th>
<th>HL-LHC</th>
<th>LC</th>
<th>HL-LC</th>
<th>HL-LHC+HL-LC</th>
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<td>universal</td>
<td>0.076</td>
<td>0.051</td>
<td>0.008</td>
<td>0.0052</td>
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<tr>
<td>non-universal</td>
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<td>0.0023</td>
<td>0.0019</td>
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<table>
<thead>
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<th>$f$ [TeV]</th>
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<tr>
<td>universal</td>
<td>0.89</td>
<td>1.09</td>
<td>2.82</td>
<td>3.41</td>
<td>3.41</td>
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<tr>
<td>non-universal</td>
<td>0.94</td>
<td>1.98</td>
<td>5.13</td>
<td>5.65</td>
<td>5.65</td>
</tr>
</tbody>
</table>

universal: fermions in spinorial representation

Agashe, Contino, Pomarol

non-universal: fermions in fundamental representation

Contino, Da Rold, Pomarol

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Mixing Effects – 2HDM

- $\rho$-parameter exp close to 1 $\sim$ extensions of Higgs sector by $SU(2)$ singlet or doublet

- 2HDM potential assuming CP-conservation and global $\mathbb{Z}_2$ discrete symmetry $[\phi_1 \rightarrow -\phi_1]$
  
  Flores, Sher; Gunion et al; Lee; Branco et al; Gunion, Haber

  $$V = m_{11} |\phi_1|^2 + m_{22} |\phi_2|^2 - m_{12}^2 (\phi_1^\dagger \phi_2 + \text{h.c}) + \lambda_1 |\phi_1|^4 + \lambda_2 |\phi_2|^4$$

  $$+ \lambda_3 |\phi_1|^2 |\phi_2|^2 + \lambda_4 |\phi_1^\dagger \phi_2|^2 + \frac{1}{2} \lambda_5 [(\phi_1^\dagger \phi_2)^2 + \text{h.c}].$$

- Couplings to fermions
  
  - type I: all fermions couple only to $\phi_2$;
  - type II: up-/down-type fermions couple to $\phi_2/\phi_1$, respectively; $\rightarrow$ MSSM
  - lepton-specific: quarks couple to $\phi_2$ and charged leptons couple to $\phi_1$;
  - flipped: up-type quarks and leptons couple to $\phi_2$ and down-type quarks couple to $\phi_1$.

- Higgs sector after EWSB CP-even neutral: $h^0, H^0$, CP-odd neutral; $A^0$, charged $H^\pm$
Fit to Couplings of Aligned 2HDM

\[ g_X = g_X^{SM} (1 + \Delta_X) \]

Rauch et al.

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Summary

- **Higgs Discovery**
  - Higgs Signal compatible with SM-like Higgs Boson
  - Interpretation within numerous BSM physics models possible

- **Composite Higgs Models**
  - Example for strong EWSB dynamics
  - Compatible with LHC Data

- **Effective Lagrangian Approach**
  - Covers a large class of models
  - Identify operators relevant for Higgs physics
  - Complement by investigations in specific models

- **Coupling Measurements**
  - 2HDM compatible with data
  - LHC accuracy allows to probe scales of $\mathcal{O}(1 \text{ TeV})$
Summary

Exciting times and discoveries are ahead of us. With the LHC and HL-LHC we will have the excellent machine at hand to investigate Higgs and New Physics and gain insights in the true nature of the underlying theory.

Work has only started!
Thank You For Your Attention!