Physics Beyond the Standard Model

Extended Higgs sector: Introduction

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The Standard Model Higgs doublet

The SM contains a complex $SU(2)_L$ doublet:

Higgs doublet Φ $(1, \mathbf{2}, \frac{1}{2})$

$$\mathcal{L}_\Phi = \mathcal{L}_{\Phi\,\text{kin.}} - V(\Phi, \Phi^\dagger) \tag{1}$$

$$\mathcal{L}_{\Phi\,\text{kin.}} = |D^\mu \Phi|^2, D^\mu = \partial^\mu + i g_W T^a W^{a,\mu} + i g_Y Y B^\mu \tag{2}$$

$$V(\Phi, \Phi^\dagger) = -\mu^2 |\Phi|^2 + \lambda |\Phi|^4, \mu^2 > 0 \tag{3}$$

In the unitary gauge, $\Phi = \frac{1}{\sqrt{2}} \begin{pmatrix} 0 \\ v + h(x) \end{pmatrix}$

Electroweak symmetry breaking $\rightarrow$ W and Z boson masses:

$$M_W = \frac{g_W v}{2},\ M_Z = \frac{M_W}{C_W} = \frac{v}{2}\sqrt{g_Y^2 + g_W^2},\ \tan\theta_W = \frac{g_Y}{g_W}$$

Models

1. Higgs Doublet $\rightarrow$ Higgs Triplet
2. SM + Higgs Triplet
3. SM + Higgs Singlet (scalar gauge singlet)
4. SM + another Higgs doublet (with same hypercharge): 2HDM

Higgs Triplet models

- $SO(3)$- adjoint representation of $SU(2)$, Jacobi identity
- Case1. $SU(2)_L$-Doublet $\Phi \rightarrow SO(3)$-Triplet
  $\Delta = (\Delta_1, \Delta_2, \Delta_3)^T$,
  EW symmetry breaking for specific hypercharge values.
- Case2. SM + Higgs Triplet
- Higgs potential $V(\Phi, \Phi^\dagger, \Delta, \Delta^\dagger)$, new Higgs bosons, mass eigenstates, interaction with gauge bosons
- ρ-parameter at the tree level:
  $\rho = \frac{M_W^2}{c_W^2 M_Z^2} \neq 1$ (Custodial symmetry broken)

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Higgs Singlet models

- SM + Higgs Singlet, S (real scalar singlet)
- Higgs potential $V(\Phi, \Phi^\dagger, S)$, no contribution to EW breaking
- Neutral Higgs bosons: mixing of the two real scalar fields, mass eigenstates

Singlet and Triplet models: investigate Higgs and gauge sectors only

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Two-Higgs-doublet models (2HDM)

- SM + another Higgs doublet: two Higgs doublets with same hypercharge
- Higgs potential $V(\Phi_1, \Phi_1^\dagger, \Phi_2, \Phi_2^\dagger)$
- New Higgs bosons, mass eigenstates, interaction with gauge bosons
- Various Yukawa interaction types: Flavor changing neutral current (FCNC) mediated by Higgs bosons

Interesting observables will be discussed in Chapter 8(the last chapter).