Extended scalar sector in DTHM

$H^{\pm\pm} \rightarrow W^{\pm}W^{\pm}$

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June 27, 2016

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Contents of the talk

Motivation and model description

Motivation

- Massless neutrinos in Standard Model. But neutrino oscillation discovered $\rightarrow$ neutrinos have mass.
- On of the ways to obtain neutrino masses is via the type II seesaw by introducing a scalar triplet.
- Since triplet hypercharge, Y $= 2$ ($Q = I_3 + \frac{Y}{2}$), doubly charged Higgs is a unique feature with clean decay channels.
- Rich scalar structure ($H^{\pm\pm}, H^{\pm}, A^0, H^0, h^0$).
- Naturally obtain a Standard Model-like Higgs.
- The main reference is The Higgs potential in Type II Seesaw models.

Focus of this talk is on charged Higgses, in particular $H^{\pm\pm}$.

The potential

A scalar triplet, Δ, with a hypercharge, $Y_\Delta = 2$, is included along with the SM doublet. $H \sim (1, 2, 1)\,, \Delta \sim (1, 3, 2)$ under the SM gauge group, $SU(3) \times SU(2) \times U(1)$. The most general Lagrangian in the scalar sector can then be written as,

$$\mathcal{L} = (D_\mu H)^\dagger (D^\mu H) + Tr(D_\mu \Delta)^\dagger (D^\mu \Delta) - V(H, \Delta) + \mathcal{L}_{Yukawa} \tag{1}$$

where $V(H, \Delta)$ is given by,

$$\begin{aligned} V(H, \Delta) = &- m_H^2 H^\dagger H + \frac{\lambda}{4}(H^\dagger H)^2 + m_\Delta^2 Tr(\Delta^\dagger \Delta) + [\mu(H^\dagger i\sigma^2 \Delta^\dagger H) + h.c.] \\ &+ \lambda_1 (H^\dagger H) Tr(\Delta^\dagger \Delta) + \lambda_2 (Tr \Delta^\dagger \Delta)^2 + \lambda_3 Tr\left(\Delta^\dagger \Delta\right)^2 \\ &+ \lambda_4 H^\dagger \Delta \Delta^\dagger H. \end{aligned}$$

Besides the yukawa terms in SM, an additional term for the neutrinos is added. if Y_ν denotes the neutrino yukawa, this term is:

$$\mathcal{L}_{Yukawa} \supset -Y_\nu L^T C \otimes i\sigma^2 \Delta L \tag{2}$$

where L: $SU(2)_L$ lepton doublets.

Production Modes

Possible production mechanisms of doubly charged Higgs include

- Pair production: $\gamma^*, Z^* \to H^{\pm\pm} H^{\mp\mp}$
- Associated production: $W^{\pm *} \to H^{\pm\pm} H^{\mp}$
- Single production: $W^{*+} W^{*+} \to H^{\pm\pm} \Rightarrow$ much smaller contribution.

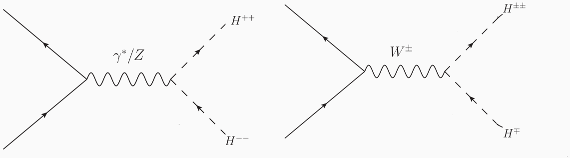


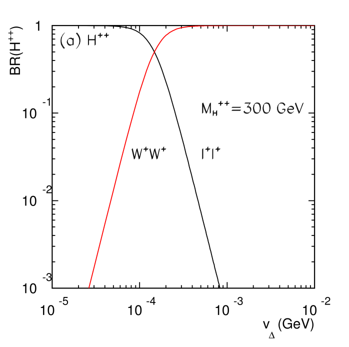
Figure 1: Pair-production and Associated-production

Decay Modes

Two main modes of decay to choose from:

- $H^{\pm\pm} \to \ell^{\pm}\ell^{\pm}$. Searches for this mode have been performed at L3, OPAL, Delphi, CDF, ATLAS, CMS .. assuming 100% BR.
- $H^{\pm\pm} \to W^{\pm}W^{\pm} \to \ell^{\pm}\ell^{\pm}\nu\nu$.

Dependence of branching ratio into leptons and W's on the vev of the triplet (v_t) shown below. Source: Testing type II seesaw



Arbitrarily high values of v_t are not allowed.

- Custodial symmetry in the SM forces $\rho \sim 1$.
- In DTHM, modified ρ at tree level is given by,

$$\rho = \frac{v_d^2 + 2v_t^2}{v_d^2 + 4v_t^2} (< 1),$$

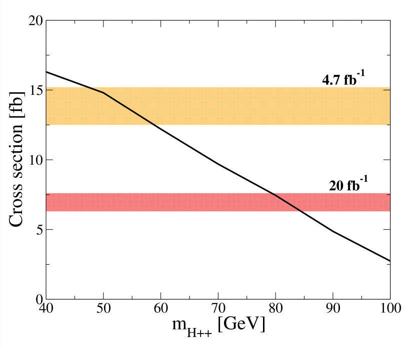
- At 2σ level, experimentally measured $\rho_0 = 1.0004 \pm 0.00048$
- Upper bound on v_t of about 1.6 GeV.

Phenomenology

Type 2 Seesaw with dominant WW decay mode

Kanemura et al studied a region in parameter space where $H^{++} \to W^{\pm *} W^{\pm *}$ is dominant i.e. $v_t > 0.1$ MeV.

- Production: $pp \to \gamma^*/Z^* \to H^{\pm\pm} H^{\mp\mp}$ and $pp \to W^{\pm *} \to H^{\pm\pm} H^{\mp}$.
- Decay: $H^{++} H^{--} \to W^+ W^+ W^- W^- \to \ell^\pm \ell^\pm \not{E}_T + X$
  $H^{\pm\pm} H^{\mp} \to W^\pm W^\pm + X \to \ell^\pm \ell^\pm \not{E}_T + X$
- Assumption: $H^{\pm\pm}$ and $H^\pm$ have the same mass.



- Triplet Higgses have fermiophobic couplings (couplings proportional to neutrino masses).
- The existing limits on $H^\pm$ or the other Higgses don't apply because of the triplet coupling.
- **Lower limit reduced to 85 GeV from about 400 GeV**(set by ATLAS (included in the backup) and CMS in leptonic decay modes).

Parameter and Cross-sections

Different processes can have the same final states in this model. For example:

$$pp \to \gamma^*, Z^* \to H^{\pm\pm} H^{\mp\mp} \to 4W \to 3\ell + 2j + E_T^{miss} \text{ and}$$
$$pp \to W^{*\pm} \to H^{\pm\pm} H^{\mp} \to 3W + Z \to 3\ell + 2j + E_T^{miss}$$

Cross-sections of other processes giving the same final states need to be evaluated to estimate the contributions.

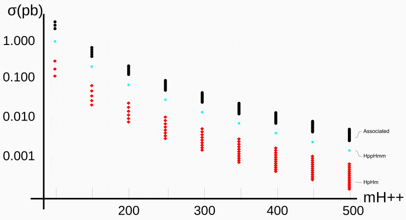


Figure 2: Cross-sections as a function of the mass of $H^{\pm\pm}$

The model was implemented in CalcHEP. Parameters for simulation:

- $\sin\alpha = 10^{-4} \Rightarrow$ mixing between netural $\mathcal{CP}_{even}$ Higgses is negligible.
- $m_{h^0} = 126$ GeV
- $m_{H^{\pm\pm}} = 200$ GeV, $m_{H^\pm} = 193$ GeV
- $m_{H^0} = m_{A^0} = 163$ GeV

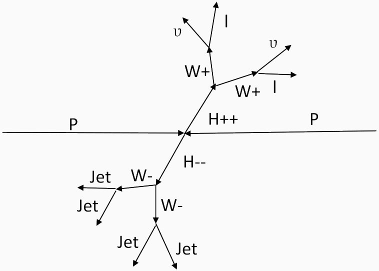
These are parameters allowed by all the theoretical constraints put together.

Experimental analysis

Signal region definitions: $mH^{\pm\pm} = 200$ GeV

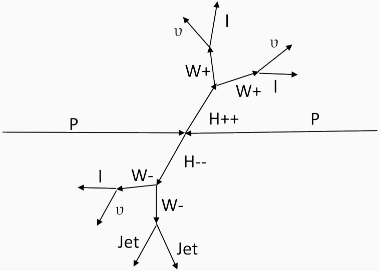
Signal Region I

$H^{\pm\pm}H^{\mp\mp} \to 4W \to 2\ell^{ss} + E_T^{miss} + 4j$



Signal Region II

$H^{\pm\pm}H^{\mp\mp} \to 4W \to 3\ell + E_T^{miss} + 2j$



The dominant backgrounds are:

- Prompt: WZ, ZZ. These are estimated from MC.
- Non-prompt: $t\bar{t}$, Z+jets. These are estimated using data-driven methods.

Both regions employ some event level cuts such as triggers, p_T cuts, E_T^{miss}, $M_{\ell\ell}$.
The analysis further exploits some discriminating variables such as angular correlations between the leptons etc.

Examples of discriminating variables

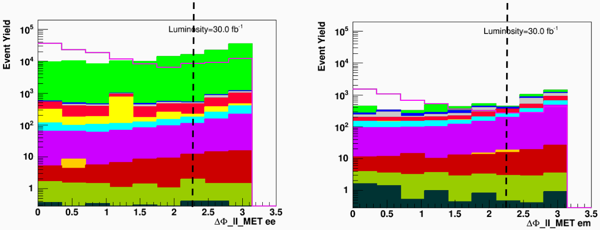


Figure 3: $\Delta\phi$ between leptons and E_T^{miss} in $2\ell^{ss}$ channel

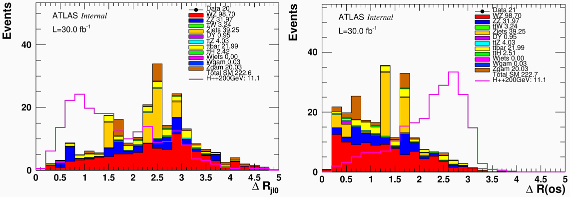


Figure 4: ΔR between same-sign (left) and opposite-sign leptons in 3ℓ channel

Sensitivity

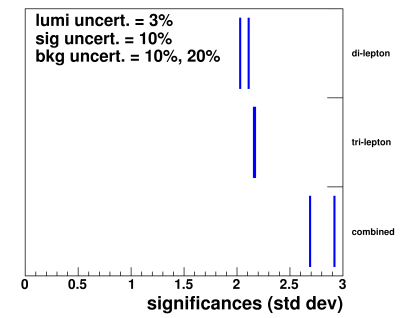


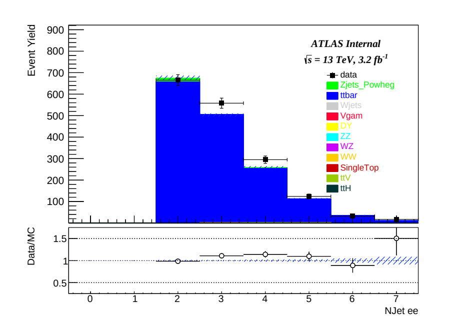
Figure 5: Expected sensitivity at 30 fb^{-1}

Using the above mentioned cuts, the expected sensitivity in the combined two-lepton and three-lepton channels was about 2.9σ.

Background: Control plots

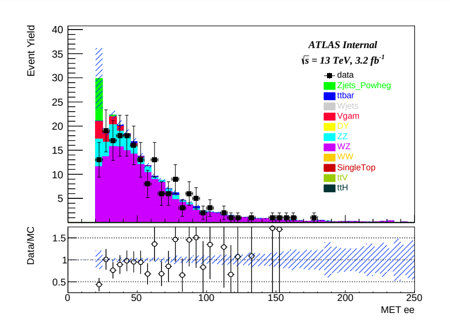
ttbar

- Two tight leptons with opposite sign leptons, pT at least 20 GeV.
- $|InvMll - ZMass| > 20$ GeV
- At least two b-jets(MV2c20_77).



WZ

- Three tight leptons, pT at least 20 GeV.
- $|InvMll - ZMass| < 45$ GeV.
- B-Veto(MV2c20_77) and MET at least 20 GeV.



Conclusion

- The model was implemented in CalcHEP.
- Lots of possible variations.
  - Associated production
  - Generalized parameters etc.
  - Targeting a phenomenology paper with these studies.
- Analysis is in place.
- Targeting Moriond 2017 with 2015 and 2016 data for a CONF-NOTE.
- Experimental paper by September 2017.

Backup