Search for a doublet-triplet extension of the scalar sector through $H^{\pm\pm} \rightarrow W^{\pm}W^{\pm}$ decays at LHC

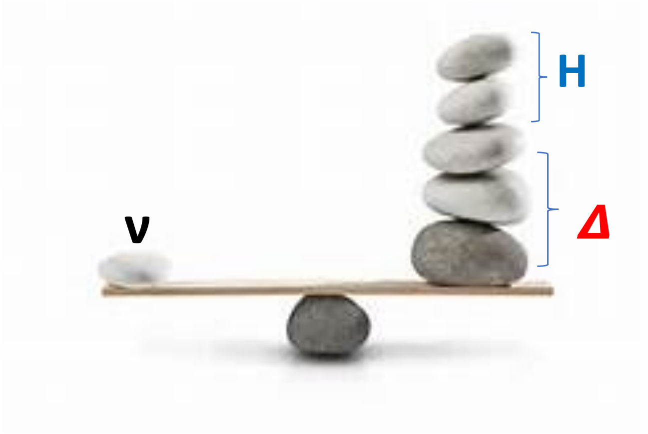
Lorenzo Basso*, *Cristinel Diaconu**, Venugopal Ellajosyula*/***, Yanwen Liu**, Emmanuel Monnier*, Gilbert Moultaka***, Ruiqi Zhang*/**

*** CPPM, IN2P3/Aix-Marseille Université**
**** USTC Hefei, China**
*****L2C/UM, Montpellier University**

王寬誠教育基金會
K. C. WONG EDUCATION FOUNDATION

Introduction

- Scalar sector as portal to new physics
- Neutrino oscillation → neutrinos have mass
  - May be explained by "see-saw" models $m_\nu \approx v/\Lambda$ (with Λ~GUT)
- Or extend the scalar sector doublet **H** by a scalar triplet ***Δ*** ("type II" see-saw model)
  - Triplet hypercharge, Y = 2 ($Q = I_3 + Y$)
  - Rich scalar structure ($H^{\pm\pm}$, $H^{\pm}$, A^0, H^0, h^0).
  - Naturally accommodate a Standard Model-like Higgs boson h^0



- In this talk: focus on $H^{\pm\pm}$ phenomenology.

Lagrangian

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,

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

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

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

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

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

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

Constrains from electroweak precision measurements

- SM custodial symmetry « protects » the ρ parameter:

$$\rho = \frac{M_W^2}{M_Z^2 \times \cos^2\theta_W} = 1$$

- HTM-enriched EWSB modifies ρ to

$$\rho \simeq 1 - 2\frac{v_t^2}{v_d^2} = 1 + \delta\rho \longrightarrow v_t \simeq v_d\sqrt{\delta\rho/2}$$

- Present precision PDG2014 $\rho_0 = 1.00040 \pm 0.00024$
  - The model possible only in the regime $v_t/v_d << 1$
  - The typical values still acceptable for **v_t < ~1.7 GeV**
  - Caveat: Radiative corrections?
    - positive for ΔY=0 models, not yet available for this model (ΔY=2)

$H^{\pm\pm}$ production and decay at colliders

Possible production mechanisms of doubly charged Higgs include

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

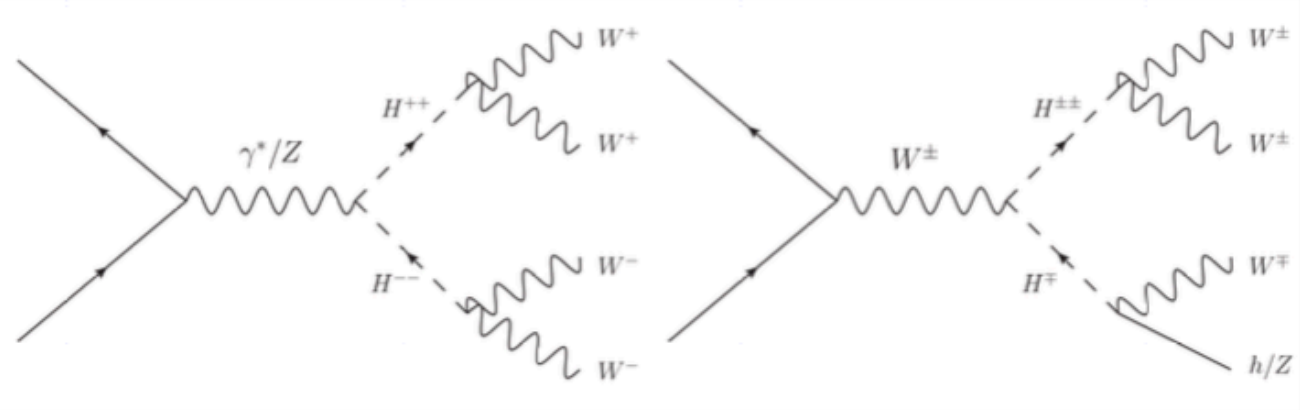


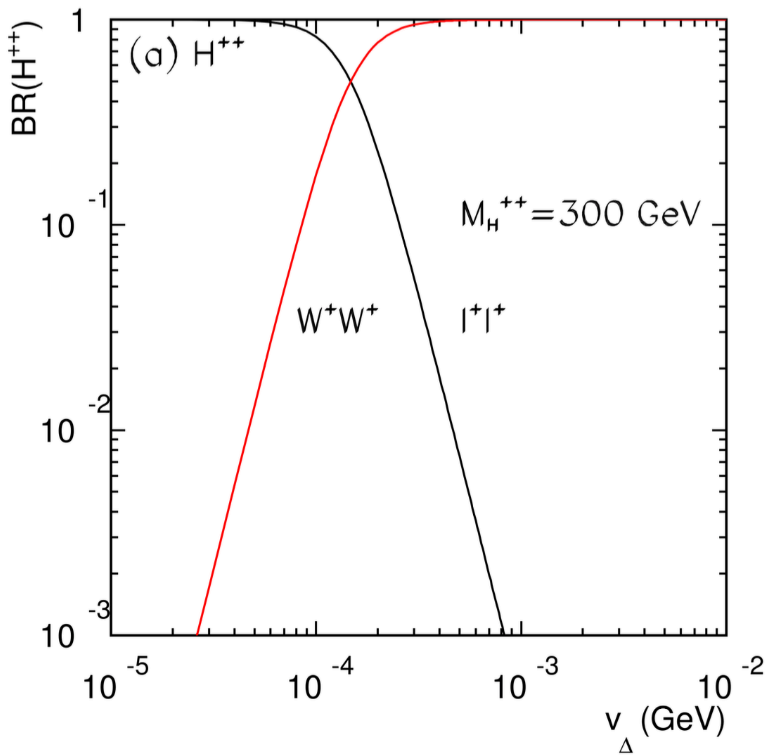
Figure 1: Pair-production and Associated-production

$H^{\pm\pm}$ decays

Two main modes of decay to choose from:

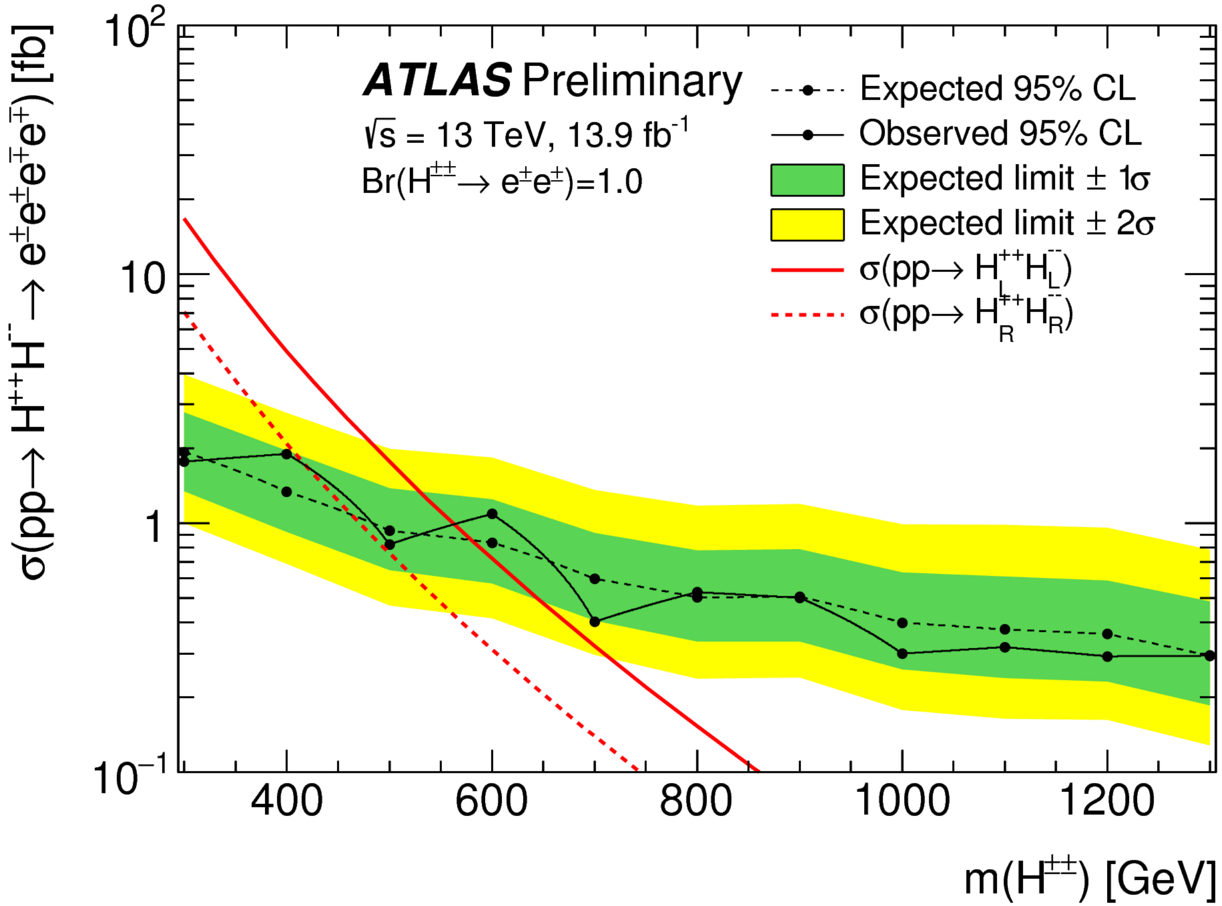
- $H^{\pm\pm} \to \ell^{\pm}\ell^{\pm}$. Searches for this mode have been performed at L3, OPAL, Delphi, CDF, ATLAS, CMS .. assuming 100% BR.
- $H^{\pm\pm} \to W^{\pm}W^{\pm} \to \ell^{\pm}\ell^{\pm}\nu\nu$.

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



Searches for $H^{\pm\pm}$ in di-lepton decay channel

- Masses of up to 700-800 GeV excluded
- Assuming 100% decays to leptons

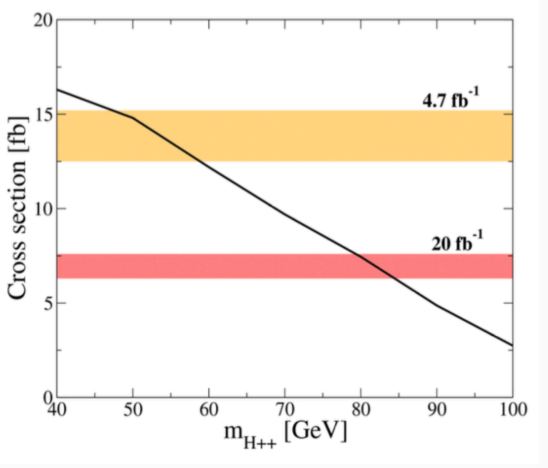


https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CONFNOTES/ATLAS-CONF-2016-051/

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

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

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

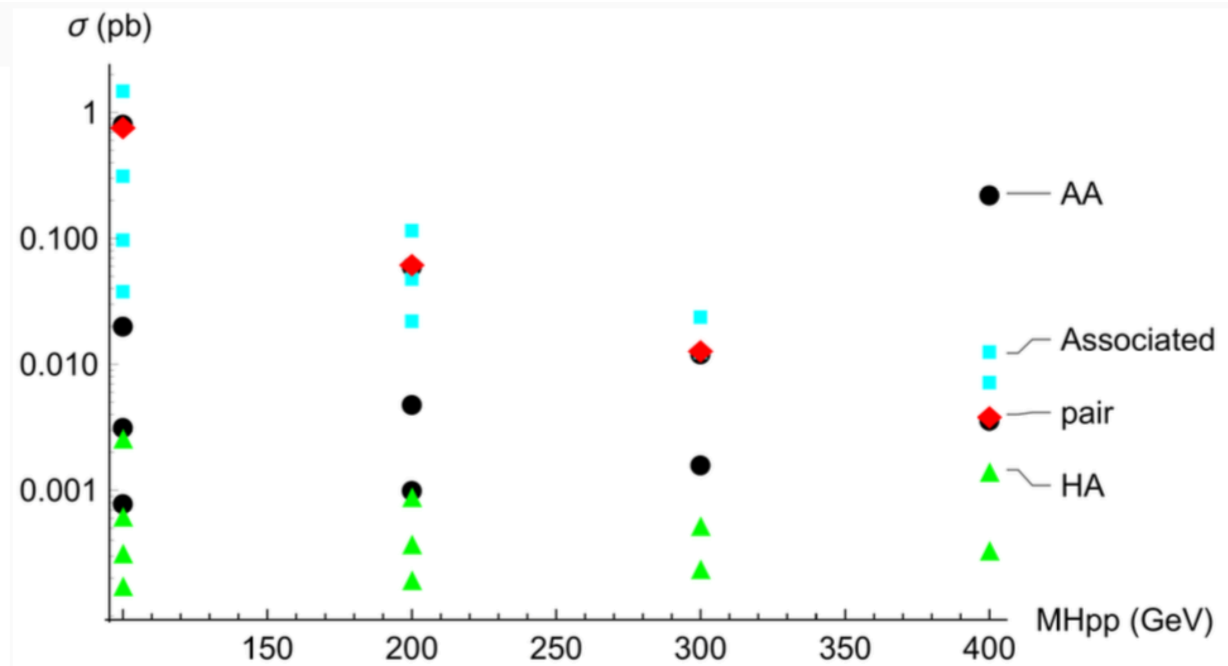


Lower limit reduced to 85 GeV from about 400 GeV(set by ATLAS (included in the backup) and CMS in leptonic decay modes). **Run1**

Goal: study the sensitivity at **Run 2**

Benchmark model for Run 2 @ LHC

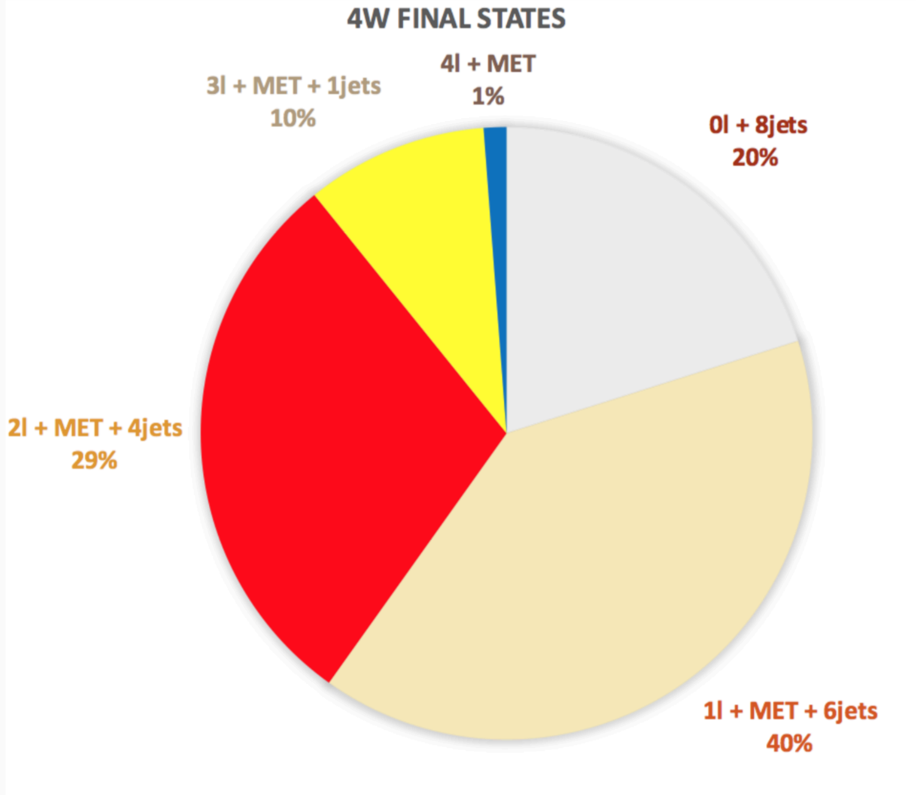
- CalcHEP used for the generation of the parton level events
  - v_t =0.1 GeV
  - $\sin(\alpha) = 10^{-4}$, where α is the mixing angle of the neutral *CP*-even Higgs.
  - The rest of the parameters are Higgs masses
  - Consider $M(h^0)$ = 125 GeV (SM)
- Consider pair production in the following, ie assume $M(H^{\pm}),M(A^0) >> M(H^{\pm\pm})$



Experimental signatures: final states with 4 W

$H^{\pm\pm}H^{\mp\mp} \to 4W$	BR (in %)
$\to 0\ell + 8$ jets	20.1
$\to 1\ell + \not{E}_T + 6$ jets	39.7
$\to 2\ell^{ss/os} + \not{E}_T + 4$ jets	29.3
$\to 3\ell + \not{E}_T + 2$ jets	9.6
$\to 4\ell + \not{E}_T +$ no jets	1.2

Table 1: Branching ratios for various final states



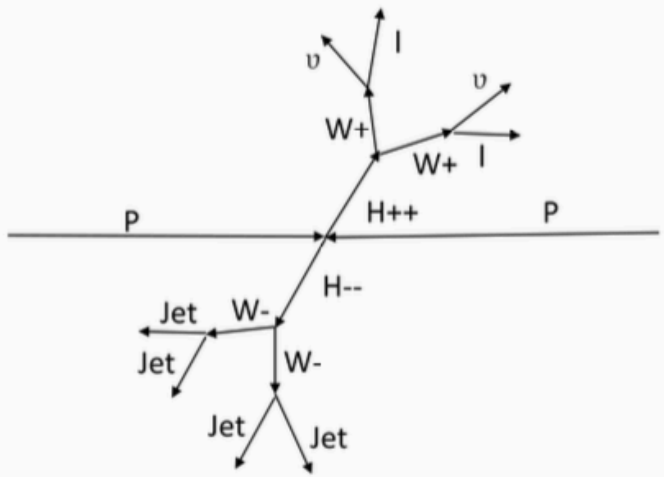
- 0ℓ and 1ℓ final states are affected by large multi-jet background.
- We consider $2\ell^{ss}, 3\ell, 4\ell$ final states.

Note: All results showed in the following are "Work in Progress"

Two same-sign leptons (2LSS) final state

Signal Region

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



Trigger requirement
Two tight leptons with same sign $p_T > 30$, 20 GeV respectively.
80 GeV $< \|M_{ll}\| <$ 100 GeV for ee channel
No B jet, MV2c10_70 working point
Njets ≥ 3

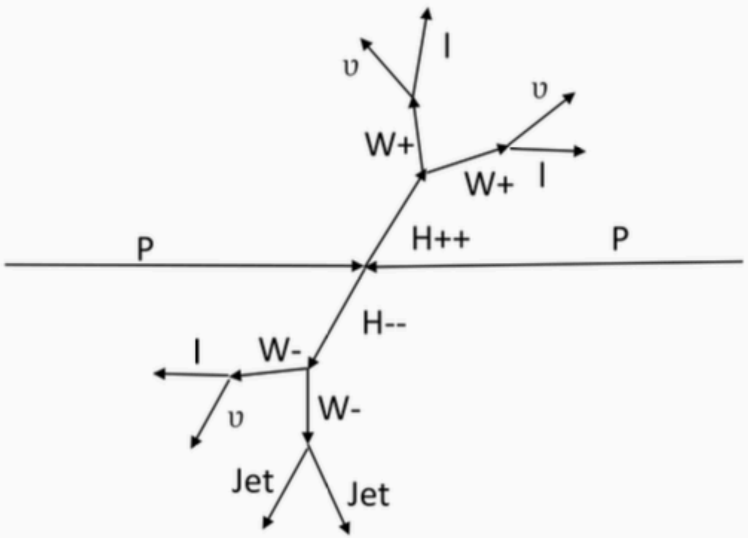
Dominant backgrounds

- **Prompt**: VV, VH, ttV, ttH. These are estimated **from MC**.
- **Fakes**: VJets, Vγ, Top. These are estimated using **data-driven fake-factor method**.
- **Charge MisID**: ZJets, Zγ, Top and WW are estimated using data-driven likelihood method.,
- Analysis is performed in 3 channels: ee, $\mu\mu$, $e\mu$

Three leptons final state (3L)

Signal Region

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



Dominant backgrounds

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

Cuts in preselection :

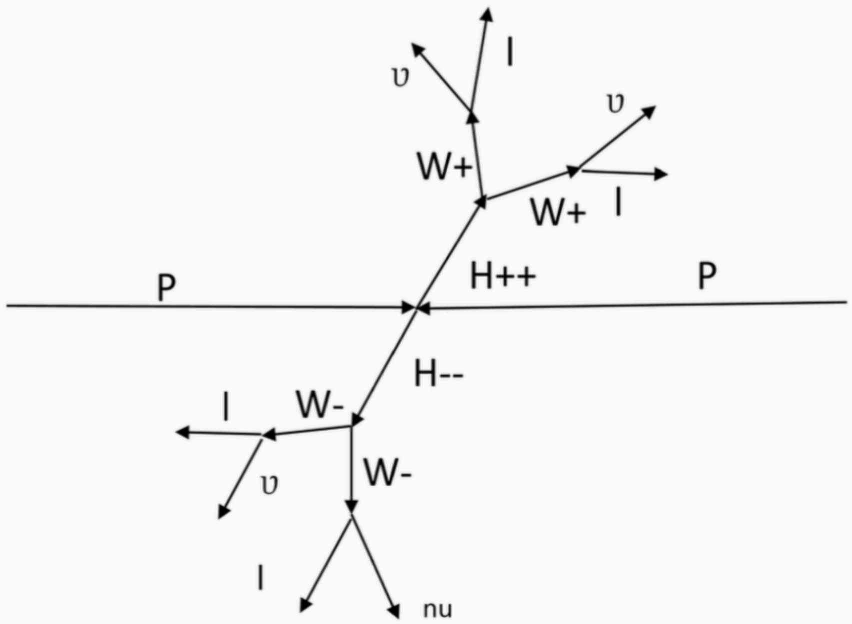
	Selection Criteria
A	Three leptons with $P_T^{0,1,2} > 10, 20, 20 GeV$
B	$\|M_{\ell\ell os,sf} - M_Z\| > 10$ GeV $M_{\ell\ell os} > 15$ GeV $MET > 30$ GeV $N_{\rm jet} >= 2$
C	$N_{\rm b-jet} = 0$

Four leptons (4L) signature

Signal: $H^{\pm\pm}H^{\mp\mp} \to W^{\pm}W^{\pm}W^{\mp}W^{\mp} \to 4\ell + E_T^{miss}$.

Step	Selection Criteria
T	4 Leptons
A	$Q = 0$, trigger, 2 tight
B	$\lvert M_{ell^+ell^-} - M_Z \rvert > 10$ GeV
C	$M_{ell^+ell^-} > 12$ GeV
D	$MET > 25$ GeV
E	$N_{b-jet} = 0$

Table 3: Cuts used in pre-selection region



Summary

- Successful “triangular” (Marseille-USTC-Montpellier) collaboration on a new physics topic in ATLAS

- The doublet-triplet scalar sector has attractive features:
  - ν masses, SM Higgs, spectacular phenomenology, no ultra-heavy bosons, no extra matter,..

- Finite triplet *vev* induces a dramatic change in phenomenology
  - H++ decays to WW (instead of leptons)
  - Not studied before at colliders
  - Rich and clean signature
  - Potential sensitivity with Run 2 data sample

- Further developments possible:
  - Explore more configurations: eg Democratic model, links to neutrino physics etc.
  - Open new production/decay channels

Scalar Portal

backup