

## Carleton node activities

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First RISE Collaboration Meeting: NonMinimal Higgs  
University of Warsaw, December 6–8, 2015

## People at Carleton

### Active theory faculty:

- Steve Godfrey
- Thomas Gregoire
- Heather Logan
- Daniel Stolarski (joins Jan 2016)

### PhD students:

- Hugues Beauchesne
- Kevin Earl
- Terry Pilkington
- Alexandre Poulin

### Postdocs:

- Alejandro de la Puente
- Andrea Peterson
- Katy Hartling\*
- Ken Moats\*

### MSc students:

- Gage Bonner
- Robyn Campbell
- Hassan Easa
- Ben Keeshan
- Rouzbeh Modarresi Yazdi
- Will Scott

\*leaving for industry in near future

## From the RISE NonMinimal Higgs proposal:

*... a group of people with complementary expertises that range from model builders to high-energy tool developers who will finally make the connection to the LHC's experimental collaborations. ... will result in a database together with high-energy tools where a number of models will be readily available for testing by the experimental groups at the LHC and future colliders.*

## Recent activities on NonMinimal Higgs: Georgi-Machacek model

Georgi & Machacek 1985; Chanowitz & Golden 1985

\* overlap with Toyama and Southampton nodes \*

SM Higgs bidoublet + two isospin-triplets in a **bitriplet**:

$$\Phi = \begin{pmatrix} \phi^{0*} & \phi^+ \\ -\phi^{+*} & \phi^0 \end{pmatrix} \quad X = \begin{pmatrix} \chi^{0*} & \xi^+ & \chi^{++} \\ -\chi^{+*} & \xi^0 & \chi^+ \\ \chi^{++*} & -\xi^{+*} & \chi^0 \end{pmatrix}$$

Constructed to preserve  $SU(2)_L \times SU(2)_R$  in scalar potential

### Physical spectrum:

- Two custodial singlets  $\rightarrow h^0, H^0$   $m_h, m_H$   $\leftarrow$  similar
- Custodial triplet  $\rightarrow (H_3^+, H_3^0, H_3^-)$   $m_3$   $\leftarrow$  to 2HDM

- Custodial fiveplet  $(H_5^{++}, H_5^+, H_5^0, H_5^-, H_5^{--})$   $m_5$   $\leftarrow$  new!

Fermiophobic but vector-philic: interesting to search in VBF  $\rightarrow H_5$

Couplings to  $VV$  proportional to  $s_H \equiv 2\sqrt{2}v_\chi/v_{SM}$

$s_H^2 =$  fraction of  $M_W^2$  and  $M_Z^2$  coming from the triplet vev

## Recent activities on NonMinimal Higgs: Georgi-Machacek model

Scalar potential, theory constraints, spectrum, decoupling limit

K. Hartling, K. Kumar, H.E. Logan, “The decoupling limit in the Georgi-Machacek model,”  
arXiv:1404.2640

Constraints from  $b \rightarrow s\gamma$ , etc (ported from Type-I 2HDM)

K. Hartling, K. Kumar, H.E. Logan, “Indirect constraints on the Georgi-Machacek model and implications for Higgs couplings,” arXiv:1410.5538

→ GMCALC code: theory checks, spectrum calc, decay BRs

K. Hartling, K. Kumar, H.E. Logan, “GMCALC: a calculator for the Georgi-Machacek model,”  
arXiv:1412.7387 <http://people.physics.carleton.ca/~logan/gmcalc/> (inspired by 2HDMC :)

Decays now include doubly-offshell  $V^*V^*$ , but QCD corrections are still in bad shape.

Other offshell processes like  $H_5 \rightarrow H_3^*V^*$ ,  $H \rightarrow tt^*$  below threshold also need improvement.

## Recent activities on NonMinimal Higgs: Georgi-Machacek model

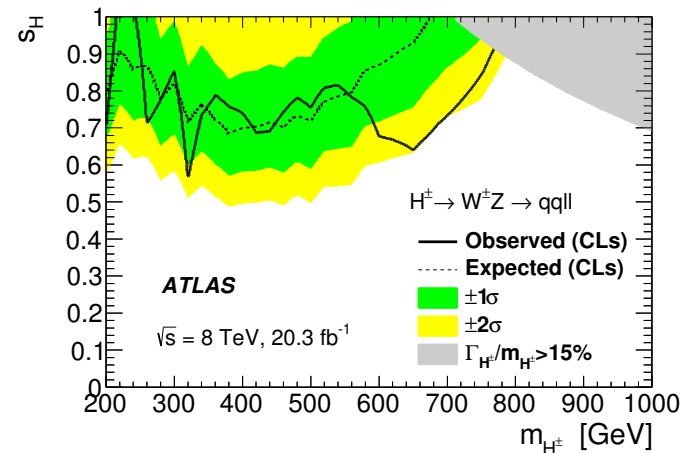
VBF  $\rightarrow H_5$  cross sections (VBF@NNLO), widths (GMCALC)

H.E. Logan, M. Zaro, "Recommendations for the interpretation of LHC searches for  $H_5^0$ ,  $H_5^\pm$ , and  $H_5^{\pm\pm}$  in vector boson fusion with decays to vector boson pairs," LHCHSWG-2015-001

- Tables being updated for HXSWG YR4

- Benchmark parameter plane "H5plane" in  $m_5-s_H$  defined,  $m_5 \in [200, 3000]$  GeV

(Not as strong as Chiang, Kanemura, Yagyu  $\rightarrow$  arXiv:1407.5053)



ATLAS 1503.04233

Model files for MadGraph5\_aMC@NLO, both LO and NLO

C. Degrande, K. Hartling, H.E. Logan, A.D. Peterson, M. Zaro, "Automatic predictions in the Georgi-Machacek model at next-to-leading order accuracy," arXiv:1512.xxxxx

<http://feynrules.irmp.ucl.ac.be/wiki/GeorgiMachacekModel> (paper to appear in  $\sim 18$  hrs)

(LO UFO file K. Kunal, NLO UFO file A.D. Peterson; param\_card generated by GMCALC)

## Recent activities on NonMinimal Higgs: Georgi-Machacek model

Nearly completed: 1-loop calculation of  $H_5^\pm \rightarrow W^\pm \gamma$  and similar

K. Hartling, H.E. Logan, + C. Degrande(?) (inspired by V. Ilisie's talk, Lisbon, Sep 2014 :)

Important for  $m_5 < M_W + M_Z$ . Will be implemented in future GMCALC release.

In progress: Study of Georgi-Machacek model + singlet scalar dark matter

R. Campbell, S. Godfrey, H.E. Logan, A. Poulin

Very constrained by dark matter requirements. Extend to non-dark-matter scalar? Idea was originally to allow non-SM decays of  $h(125)$ , but dark matter constraints limit this severely.

In progress: Study of custodial symmetry violation by RGE running at 1-loop in Georgi-Machacek model

B. Keeshan, H.E. Logan, T. Pilkington

How nearby must the custodial-symmetric UV completion be? How big a custodial violation in mass splittings and mixings is allowed by rho parameter constraints? How does that affect the phenomenology? e.g. otherwise-fermiophobic  $H_5 \rightarrow f\bar{f}$  induced by mixing?

## Recent activities on NonMinimal Higgs: Georgi-Machacek model

Some obvious future directions:

- Interface GMCALC to HiggsBounds/HiggsSignals
- Benchmark characterization study for “H5plane” benchmark
- Various collider-pheno studies using UFO model file,  
e.g.  $VBF \rightarrow H_5^0/H^0 \rightarrow VV$  lineshapes can overlap & interfere  
(I am bad at MadGraph; need expert collaborators :)
- How to help/convince LHC expts to improve lower bound on  $m_5$   
from  $pp \rightarrow H_5^{\pm\pm} H_5 \rightarrow$  likesign dibosons a la Kanemura, Kikuchi,  
Yagyu, Yokoya arXiv:1412.7603?
- Reinterpreting 2HDM searches to constrain  $H^0$ ,  $H_3^\pm$ ,  $H_3^0$



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Two things for the tools database:

**GMCALC** spectrum calculator + theory checks + decays

<http://people.physics.carleton.ca/~logan/gmcalc/>

**LO & NLO UFO model files** for use with MadGraph5\_aMC@NLO

<http://feynrules.irmp.ucl.ac.be/wiki/GeorgiMachacekModel>

