THDM - scalar sector and signal production status

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Towards a pheno paper

We have a model proposed, TII, with interesting signatures not quantitatively looked at. Interesting and rich pheno in scalar sector.

Describe the phenomenology of the scalar sector, in particular the doubly-charged Higgs.

For this we need:

- free parameters $\rightarrow$ constraints: scan of allowed parameter space
- for them, evaluate cross sections for choosing best benchmarks
- pheno study of signal/bkg $\rightarrow$ hints for exclusion/discovery power

Need to choose benchmarks, create signal AND background events

Neutral scalar sector

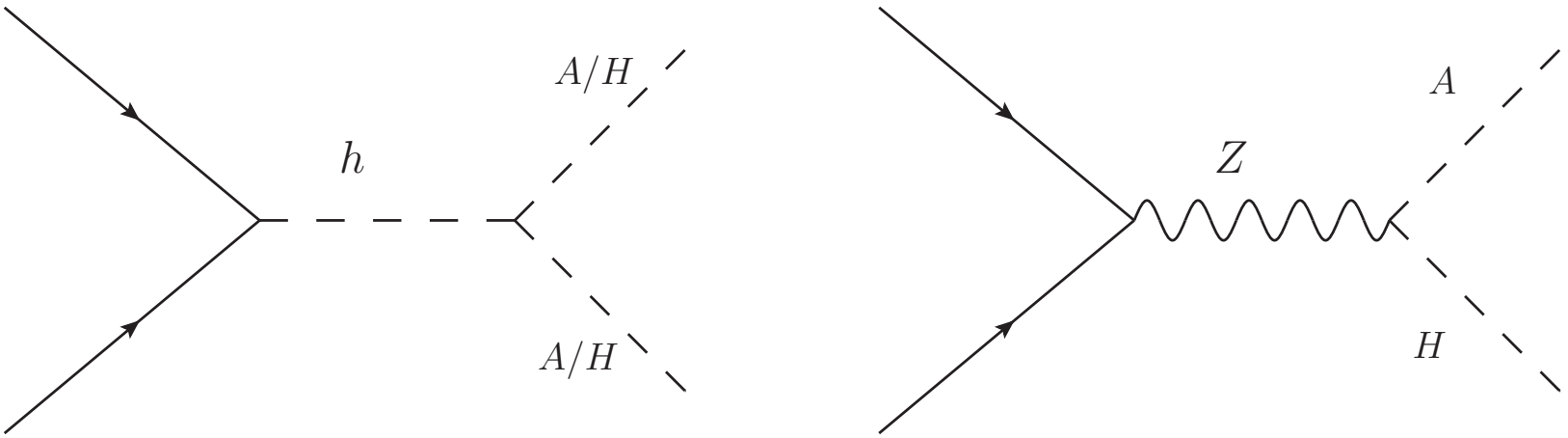


Figure : Neutral Higgs boson production mechanisms: (left) pair production, (right) CP-even / CP-odd associated production.

Charged scalar sector - I

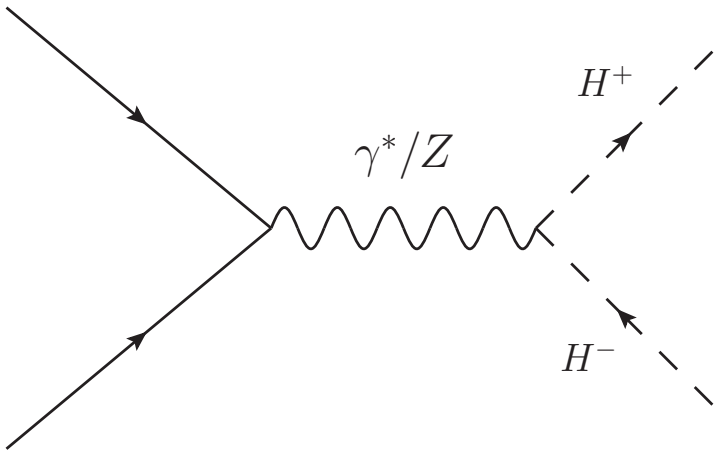
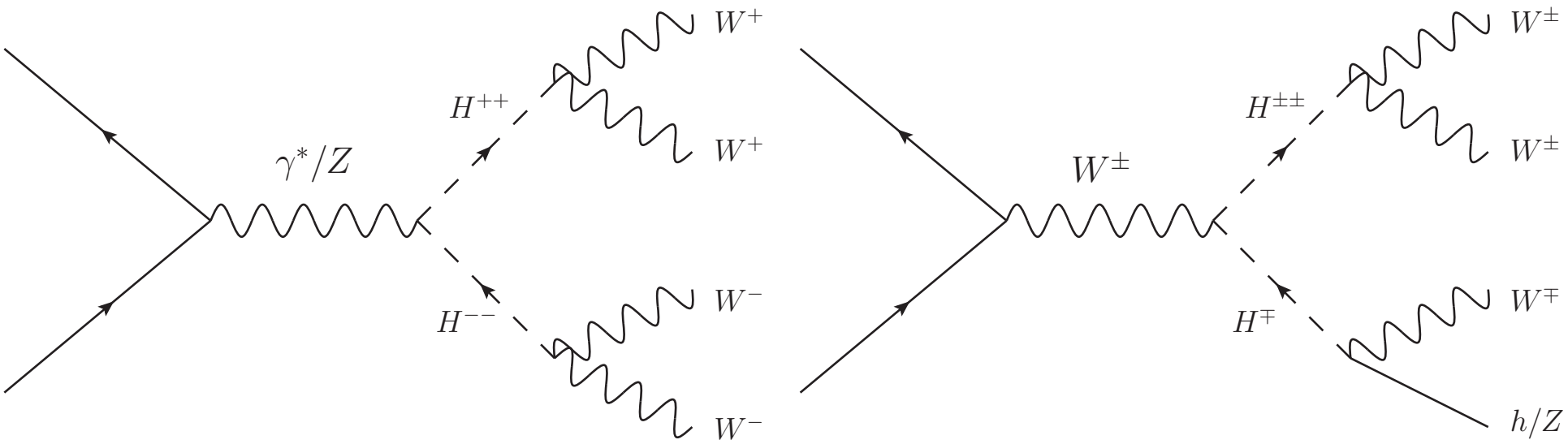


Figure : Singly-charged Higgs boson pair-production mechanism.

Charged scalar sector - II



Doubly-charged Higgs boson production mechanisms: (left) pair production, (right) single production in association with a singly-charged Higgs boson.

Input parameters - I

Inputs from Gilbert, these are all valid points fulfilling all (simplified) theoretical constraints

$\sin\alpha$	$m_{H^{\pm\pm}}$	$m_{H^{\pm}}$	m_{H^0}	m_{A^0}
0.	100.	100.	100.00031399061868	100.
0.	100.	200.	264.5752488305759	264.5751311064591
0.	100.	300.	412.3106354531287	412.3105625617606
0.	100.	400.	556.776484976137	556.7764362830021
0.	200.	200.	200.0001557343423	200.
0.	200.	300.	374.16581899976217	374.16573867739413
0.	200.	400.	529.1503134482512	529.1502622129182
0.	300.	300.	300.0001001795879	300.
0.	300.	400.	479.58320886201017	479.5831523312719
0.	400.	300.	141.42156875018287	141.4213562373095
0.	400.	400.	400.0000677779723	400.

Input parameters - II

Inputs as from Gilbert, in `CalcHEP` are read with lower precision

mHpp	mHp	mH	mha
100.	100.	100.	100.
100.	200.	264.575	264.575
100.	300.	412.311	412.311
100.	400.	556.776	556.776
200.	200.	200.	200.
200.	300.	374.166	374.166
200.	400.	529.15	529.15
300.	300.	300.	300.
300.	400.	479.583	479.583
400.	300.	141.422	141.421
400.	400.	400.	400.

$\rightarrow$ problem of fine-tuning of scalar lambda couplings?

Cross sections

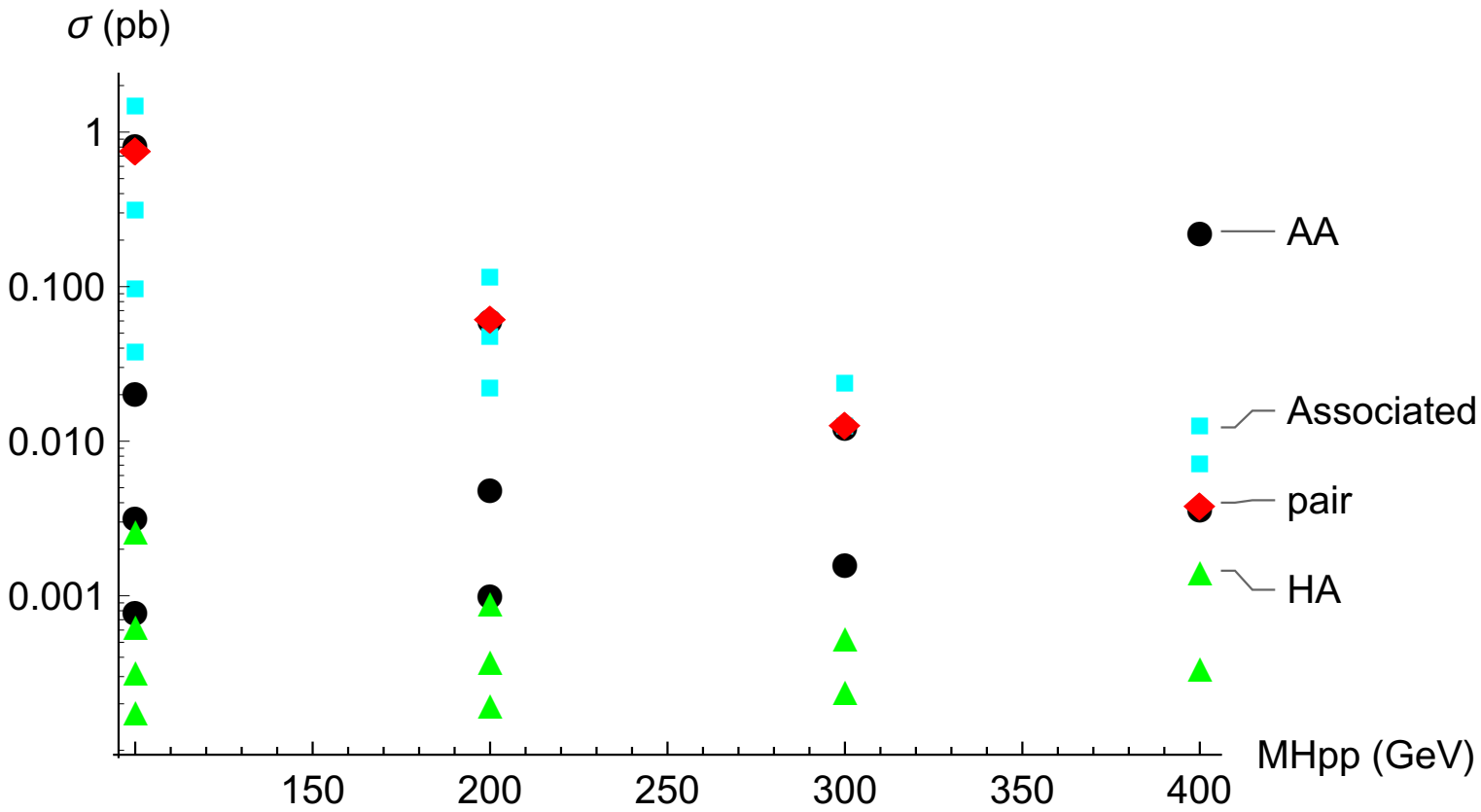


Figure : Cross sections for the various scalar production processes.

Partial widths also calculated, they only need to be displayed (2-body vs 3-body comparison/matching)

Proliferation of final state

When production and decay are combined together, we end up in one of the following cases:

$$pp \to H^{++}H^{--} \to W^+W^+W^-W^- \quad \to \quad \begin{cases} 2\ell^+ + 2\ell^- + \not{E}_T \\ 3\ell + 2j + \not{E}_T \\ 2\ell^\pm + 4j + \not{E}_T \end{cases}$$

$$pp \to H^{\pm\pm}H^{\mp} + h.c. \to W^\pm W^\pm \quad + \quad \begin{cases} \overbrace{if(m_{H^\mp} \lesssim 150\ \text{GeV})}^{H^\mp \to \bar{c}s} & \to \quad 2\ell^\pm + 2j + \not{E}_T \\ \underbrace{if(m_{H^\mp} \gtrsim 150\ \text{GeV})}_{H^\mp \to W^\mp h/Z} & \to \quad \begin{cases} 3\ell + 2b + \not{E}_T \\ 2\ell^\pm + 2b + 2j + \not{E}_T \\ 3\ell + 2j + \not{E}_T \\ 2\ell^\pm + 4j + \not{E}_T \end{cases} \end{cases}$$

Problem

Samples for

$pp \to H^{++} H^{--} \to \ell^+\ell^+\nu\nu\ \ell^-\nu W^-,\ (W^- \to jj)$ and

$pp \to H^{++} H^{--} \to \ell^+\ell^+\nu\nu\ jjW^-,\ (W^- \to \ell^-\nu)$

have different cross sections for $M_{H^{\pm\pm}} = 200,\ 300,\ 400$ GeV.

For $M_{H^{\pm\pm}} = 100$ GeV it is fine.

I suspect that forcing the 3-body decays when both W's are on-shell somehow biases the cross sections.

I checked that all total production xs and partial widths are ok. Somehow combination wrong.

New inclusive samples for all on-shell W's already created

(but need lots of events + skimming to distill the various lepton multeplicities $\to$ should be done at detector level to account for some fake electrons?)

Cross sections

Processes	sigma (fb)	unc (%)
u,u~->H++,H--	2.2205e+01	4.08e-02
u~,u->H++,H--	2.2212e+01	4.43e-02
d,d~->H++,H--	8.3421e+00	4.66e-02
d~,d->H++,H--	8.3472e+00	4.87e-02
s,s~->H++,H--	1.0904e+00	5.50e-02
s~,s->H++,H--	1.0906e+00	5.61e-02
c,c~->H++,H--	7.0718e-01	6.15e-02
c~,c->H++,H--	7.0764e-01	5.79e-02
Total	6.4702e+01	

Figure : Cross sections evaluated by `CalcHEP`.

Also, $\Gamma(H^{\pm\pm})|_{200\text{ GeV}} = 6.96\,10^{-7}$ GeV, BR($H^{\pm\pm} \to W^{\pm}W^{\pm}$) $\simeq 1$

Comparison of partial widths

Decays	width (GeV)
H++->n1,e+,W+	1.0052e-07
H++->n2,e+,W+	4.3461e-08
H++->n3,e+,W+	3.6083e-09
H++->n1,m+,W+	3.4108e-08
H++->n2,m+,W+	4.1432e-08
H++->n3,m+,W+	7.1973e-08
H++->n1,tt+,W+	1.2932e-08
H++->n2,tt+,W+	6.2605e-08
H++->n3,tt+,W+	7.1881e-08
W+->n1,e+	1.5155e-01
W+->n2,e+	6.5557e-02
W+->n3,e+	5.4462e-03
W+->n1,m+	5.1485e-02
W+->n2,m+	6.2513e-02
W+->n3,m+	1.0855e-01
W+->n1,tt+	1.9503e-02
W+->n2,tt+	9.4410e-02
W+->n3,tt+	1.0847e-01
H--->n1,e-,W-	1.0041e-07
H--->n2,e-,W-	4.3467e-08
H--->n3,e-,W-	3.6110e-09
H--->n1,m-,W-	3.4113e-08
H--->n2,m-,W-	4.1401e-08
H--->n3,m-,W-	7.1996e-08
H--->n1,tt-,W-	1.2918e-08
H--->n2,tt-,W-	6.2557e-08
H--->n3,tt-,W-	7.1891e-08
W-->u~,d	6.3503e-01
W-->u~,s	3.2608e-02
W-->c~,d	3.2584e-02
W-->c~,s	6.3374e-01
Widths	
Widths	
Total	5.8010e+00

Decays	width (GeV)
H++->n1,e+,W+	1.0045e-07
H++->n2,e+,W+	4.3444e-08
H++->n3,e+,W+	3.6093e-09
H++->n1,m+,W+	3.4114e-08
H++->n2,m+,W+	4.1495e-08
H++->n3,m+,W+	7.1895e-08
H++->n1,tt+,W+	1.2925e-08
H++->n2,tt+,W+	6.2572e-08
H++->n3,tt+,W+	7.1942e-08
W+->n1,e+	1.5155e-01
W+->n2,e+	6.5557e-02
W+->n3,e+	5.4462e-03
W+->n1,m+	5.1485e-02
W+->n2,m+	6.2513e-02
W+->n3,m+	1.0855e-01
W+->n1,tt+	1.9503e-02
W+->n2,tt+	9.4410e-02
W+->n3,tt+	1.0847e-01
H--->u~,d,W-	4.2091e-07
H--->u~,s,W-	2.1627e-08
H--->c~,d,W-	2.1602e-08
H--->c~,s,W-	4.2001e-07
W-->n1,e-	1.5155e-01
W-->n2,e-	6.5557e-02
W-->n3,e-	5.4462e-03
W-->n1,m-	5.1485e-02
W-->n2,m-	6.2513e-02
W-->n3,m-	1.0855e-01
W-->n1,tt-	1.9503e-02
W-->n2,tt-	9.4410e-02
W-->n3,tt-	1.0847e-01
Widths	
Widths	
Total	4.5680e+00

Summary

- chain for systematic study of scalar sector in place
- automatised xs and decay width evaluation and plotting
- this will allow us to choose benchmark points
- signal is being generated: LHE, and automatised PY8+Delhpes3 chain
- pheno backgrounds: some are coming. Need PY8 configuration card
- Signal + bkg $\rightarrow$ pheno exclusion/discovery study