The two-Higgs-doublet model implementation in MadGraph v4

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Plan

- Motivations for a generic 2HDM
- MG/ME implementation
- TwoHiggsCalc: the 2HDM calculator
  - Scalar potential
  - Yukawa sector
- Validation
- Collider phenomenology: a light A^0

Motivations for a generic 2HDM

- Simple extension of SM scalar sector, yet with rich phenomenology:
  - New sources of CP violation
  - Flavour Changing Neutral Currents
  - Higgs bosons lighter than the LEP bound
  - Dark Matter candidates (e.g. IDM, Aaron Pierce's talk)
  - Improved naturalness (Barbieri and Hall)
  - ...
- Useful toy model to study scalar sector of larger BSM models (SUSY, Little Higgs, UED, ...)
- Almost any electroweak scalar phenomenology can be simulated in practice (process by process or by adding new particles)

Maximal freedom is required !

MG/ME v4 implementation

particles.dat

```
h1      h1      S       D       MH1     WH1     S       h1      25
h2      h2      S       D       MH2     WH2     S       h2      35
h3      h3      S       D       MH3     WH3     S       h3      36
h-      h+      S       D       MHC     WHC     S       hc      37
```

interactions.dat

```
w+ h- h1 GWHCH1 QED
w- h1 h+ GWH1HC QED
w+ h- h2 GWHCH2 QED
w- h2 h+ GWH2HC QED
w+ h- h3 GWHCH3 QED
w- h3 h+ GWH3HC QED
```

couplings.f

```
gwhch1=-ee/(2*sw)*dcmplx(0,1)*dcmplx(+TA1*1,TN1*1)
gwh1hc=ee/(2*sw)*dcmplx(0,1)*dcmplx(+TA1*1,-TN1*1)
gwhch2=-ee/(2*sw)*dcmplx(0,1)*dcmplx(+TA2*1,+TN2*1)
gwh2hc=ee/(2*sw)*dcmplx(0,1)*dcmplx(+TA2*1,-TN2*1)
gwhch3=-ee/(2*sw)*dcmplx(0,1)*dcmplx(+TA3*1,+TN3*1)
gwh3hc=ee/(2*sw)*dcmplx(0,1)*dcmplx(+TA3*1,-TN3*1)
```

param_card.dat

```
Block MASS # Mass spectrum
     25      1.15409520e-02   # Higgs 1
     35      3.00000000e+02   # Higgs 2
```

NEEDS CALCULATOR !

```
DECAY  25      4.77286447e-03      # H1 decays
     1.77695195e-04     2     13     -13 # BR(H1 -> mu mu~)
     4.98676310e-02     2     15     -15 # BR(H1 -> ta ta~)
     6.82757014e-02     2      4      -4 # BR(H1 -> c c~)
```

BRIDGE can do it !

TwoHiggsCalc

- Model “Calculator” (in the MG/MEv4 terminology) for the 2HDM written in C
- Input and Output in a format similar to the SUSY LHA one (MG/ME standard)
- Full control on 2HDM potential parameter space and Yukawa couplings
- Output spectrum, mixing, total widths and BRs
- Available online with a web interface on all MadGraph clusters

TwoHiggsCalc: the potential

lambda1	1
lambda2	1
lambda3	1
lambda4	0
lambda5	0
Norm of lambda6	0
Norm of lambda7	0
Phase of lambda6	0
Phase of lambda7	0
Mass of Charged Higgs (GeV)	300

- Only assumptions:
  - charge conservation
- Check for
  - minimization
  - true minimum
- Parameters can be entered in any basis
  - THC works in the Higgs basis
  - Gen2HB takes care of the basis change

$$
\begin{aligned}
V = {} & \mu_1 H_1^\dagger H_1 + \mu_2 H_2^\dagger H_2 - \left(\mu_3 H_1^\dagger H_2 + \text{h.c.}\right) \\
& \lambda_1 \left(H_1^\dagger H_1\right)^2 + \lambda_2 \left(H_2^\dagger H_2\right)^2 \\
& + \lambda_3 \left(H_1^\dagger H_1\right)\left(H_2^\dagger H_2\right) + \lambda_4 \left(H_1^\dagger H_2\right)\left(H_2^\dagger H_1\right) \\
& + \left[\left(\lambda_5 H_1^\dagger H_2 + \lambda_6 H_1^\dagger H_1 + \lambda_7 H_2^\dagger H_2\right)\left(H_1^\dagger H_2\right) + \text{h.c.}\right]
\end{aligned}
$$

TwoHiggsCalc: Yukawa sector

$$\mathcal{L}_Y = \frac{\overline{Q_L}\sqrt{2}}{v}\left[(M_d H_1 + Y_d H_2) d_R + (M_u \tilde{H}_1 + Y_u \tilde{H}_2) u_R\right] + \frac{\overline{E_L}\sqrt{2}}{v}\left[(M_e H_1 + Y_e H_2) e_R\right]$$

Yukawa couplings to the second Higgs doublet of the down type quarks (norm and phase)

Y1D/G1D	0	0	Y1S/G1S	0	0	Y1B/G1B	0	0
Y2D/G2D	0	0	Y2S/G2S	0	0	Y2B/G2B	0	0
Y3D/G3D	0	0	Y3S/G3S	0	0	Y3B/G3B	0	0

- Only assumptions:
  - 1st generation massless
  - CKM reduced to Cabibbo angle
- Running of quark masses not (yet) implemented but “Yukawa” masses distinguished from “kinematic” masses to give maximal flexibility

Validation

- Validation of the simplified version of the model (with diagonal Yukawa matrices) almost done:
  - Couplings values manually checked
  - Comparison in SM and MSSM (MadGraphv4) limits of the model for all couplings and tens of cross sections (thanks to S. Ovyn)
  - Comparison with CompHep/CalcHep cross sections for standard 2HDM processes
- Validation of the full implementation is in progress

Collider phenomenology: a light pseudoscalar

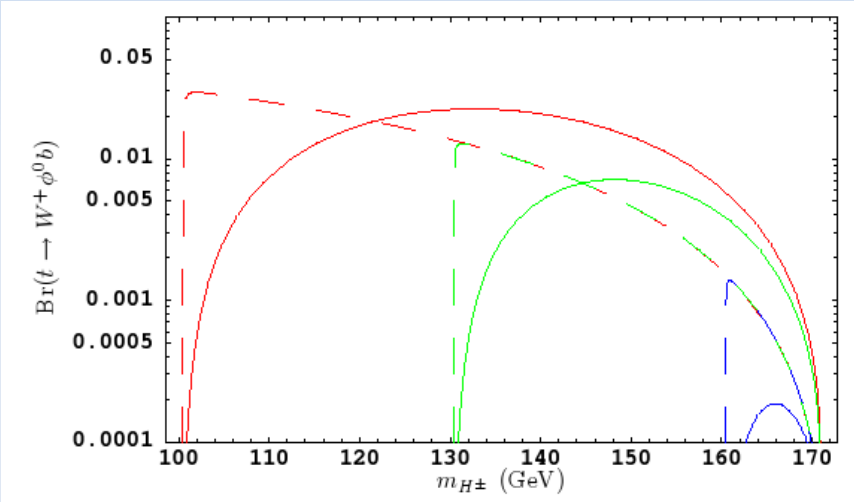
- In general one has to assume $m_{A^0} \simeq m_{H^\pm}$ to avoid large contributions to T (usual custodial symmetry)
- In MSSM, $m^2_{H^\pm} = m^2_{A^0} + m^2_{W^\pm}$ so OK in the decoupling limit
- With a *twisted* custodial symmetry, one can have a natural small ΔT if $m_{H^0} = m_{H^\pm}$ (see hep-ph/0703051, J.-M. Gérard and MH) allowing a light pseudoscalar and its unusual associated phenomenology

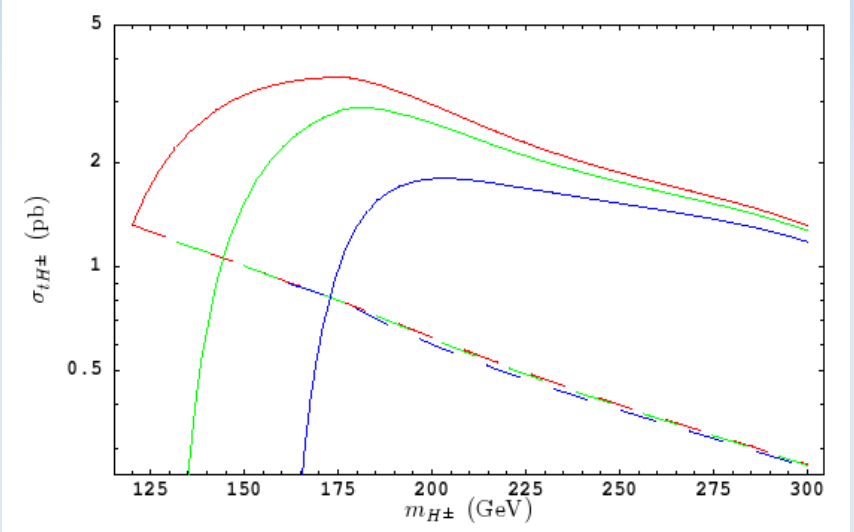
Collider phenomenology: a light pseudoscalar

- Unusual dominant decay: $H^+ \to W^+ A^0 \to W^+ b\bar{b}$

  The ONLY chance to see the charged Higgs

- Top decays and single top associated production (2W4b and 2W3b final states)





- Preliminary results (MG/ME 4.1 parton level)
  - Acceptance of signal varying between 3 and 30%
  - 2W4b channel could be interesting both at Tevatron and LHC
  - 2W3b inclusive analysis possible due to low ttb background

Conclusion

- The generic 2HDM is available (among others) in MG/ME v4
- The associated calculator, TwoHiggsCalc, is also available via a user friendly web interface. Any basis convention can be used. Computes widths and BRs (now can use BRIDGE)
- Can be used for various scalar sector studies
- Extensively validated at various levels and in its SM and MSSM limits
- Full phenomenological study of a theoretically motivated light pseudoscalar scenario on the way