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

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interactions.dat

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couplings.f

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

param_card.dat

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|DECAY| 25 | 4.77286447e-03 | # H1 decays
|   | 1.7765195e-04 | 2 | 13 | -13 | # BR(H1 -> mu mu~)
|   | 4.986710e-02 | 15 | -15 | # BR(H1 -> ta ta~)
|   | 6.82757014e-02 | 2 | 4 | -4 | # BR(H1 -> c c~)

NEEDS CALCULATOR!
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

- 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

\[ V = \mu_1 H_1 \dagger H_1 + \mu_2 H_2 \dagger H_2 - \left( \mu_3 H_1 \dagger H_2 + \text{h.c.} \right) \]
\[ + \lambda_1 \left( H_1 \dagger H_1 \right)^2 + \lambda_2 \left( H_2 \dagger H_2 \right)^2 \]
\[ + \lambda_3 \left( H_1 \dagger H_1 \right) \left( H_2 \dagger H_2 \right) + \lambda_4 \left( H_1 \dagger H_2 \right) \left( H_2 \dagger H_1 \right) \]
\[ + \left[ \left( \lambda_5 H_1 \dagger H_2 + \lambda_6 H_1 \dagger H_1 + \lambda_7 H_2 \dagger H_2 \right) \left( H_1 \dagger H_2 \right) + \text{h.c.} \right] \]
TwoHiggsCalc: Yukawa sector

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

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

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<th>0</th>
<th>Y1S/G1S</th>
<th>0</th>
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<th>Y1B/G1B</th>
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<tr>
<td>Y3D/G3D</td>
<td>0</td>
<td>0</td>
<td>Y3S/G3S</td>
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<td>0</td>
<td>Y3B/G3B</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

- Only assumptions:
  - 1\textsuperscript{st} 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, $m_{H^\pm}^2 = m_{A^0}^2 + m_W^2$ so OK in the decoupling limit.
- With a twisted custodial symmetry, one can have a natural small $\Delta T$ 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: \( H^+ \rightarrow W^+ A^0 \rightarrow W^+ b\bar{b} \)

  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