Tools for investigating THDM models

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Using tools in HEP

Advantages of using tools: Using tools

- saves you time,
- avoids redoing stuff,
- avoids careless mistakes.

Typical drawbacks/caveats: Tools

- can be black boxes,
- often hard to get codes running (no professional development),
- lack documentation/support,
- contain code and "physics" bugs.

Personal advise

Try to use them as much as possible but always cross-check the results!

And do not get frustrated...

Phenomenolgy workflow

1. Define model,
2. calculate Feynman rules,
3. calculate observables,
4. test against theoretical and experimental constraints.

$\rightarrow$ Tools are available to support you at every step!

Disclaimer

All lists provided are probably incomplete!

Best overview available: `hepforge.org`

Tool categories

- "Lagrangian" tools:
  - Calculations related to Lagrangian.
- Loop calculators:
  - Generate and calculate Feynman diagrams.
- Collider tools:
  - Simulate collider events.
- Precision tools:
  - Get precise prediction for e.g. Higgs production XS, ...
- Tools implementing theoretical constraints:
  - Unitarity, vacuum stability, ...
- Tools implementing experimental constraints:
  - Collider constraints, flavour constraints, ...
- ...

"Lagrangian" tools

Mathematica packages:

- FeynRules (`feynrules.irmp.ucl.ac.be`),
- SARAH (`sarah.hepforge.org`).

Functionality:

- Check Lagrangian (symmetries?, all possible terms included?, anomalies?, ...),
- calculate Feynman rules,
- generate model files for other tools.

THDM RGEs:

- SARAH,
- PyR@TE (`pyrate.hepforge.org`),
- 2HDME (`github.com/jojelen/2HDME`).

Loop calculators

Generate Feynman diagrams:

- FeynArts (`feynarts.de`),
- QGRAF (`cfif.ist.utl.pt/~paulo/qgraf.html`).

Calculate Feynman diagrams:

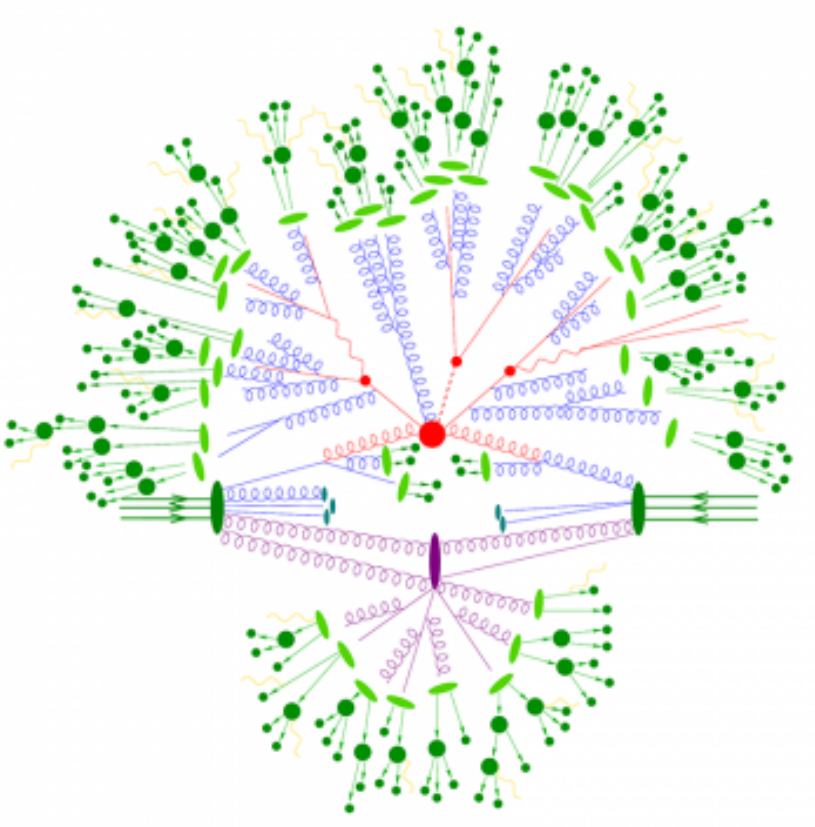
- Semi-automatic:
  - FeynCalc (`feyncalc.github.io`),
  - FormCalc (`feynarts.de/formcalc`).
- Automatic:
  - OpenLoops (`openloops.hepforge.org`),
  - Recola (`recola.hepforge.org`),
  - ...

Calculate loop integrals:

- LoopTools, Collier, Package-X, Tarcer, FIRE, SecDec, ...

Collider tools

- Simulate collider collisions:
  - PDFs, hard process, soft radiation, detector simulation, event analysis, ...
- Example tool chain:
  - `FeynRules` → `MadGraph` → `Pythia` → `Delphes` → `fastjet` → `root`
- Other tools: `Herwig`, `POWHEG`, `Sherpa`, `WHIZARD`, ...



Precision tools (for the THDM)

- 2HDECAY (`github.com/marcel-krause/2HDECAY`):
  - Higgs decays (including 1L corrections)
- 2HDMC (`2hdmc.hepforge.org`):
  - Electroweak precision observables (S, T, U),
  - anomalous magnetic moment of the muon,
  - Higgs decays (tree-level).
- 2HDME (`github.com/jojelen/2HDME`):
  - Electron electric dipole moment.
- HEPfit (`hepfit.roma1.infn.it`):
  - Higgs observables, flavour observables, electroweak precision observables, ...
- H-COUP (`www-het.phys.sci.osaka-u.ac.jp/~kanemu/HCOUP_HP1013/HCOUP_HP.html`):
  - Higgs decays (including 1L corrections)
- SPheno (`spheno.hepforge.org`):
  - Higgs decays/production cross-sections, flavour observables, electroweak precision observables, ...
- SusHi (`sushi.hepforge.org`):
  - Higgs production cross-sections.

Precision tools (cosmology)

- MicrOMEGAs (`lapth.cnrs.fr/micromegas`):
  - Dark matter relic abundance.
- DarkSUSY (`darksusy.hepforge.org`):
  - Dark matter observables.

Tools implementing theoretical constraints

- 2HDMC (`2hdmc.hepforge.org`):
  - Tree-level unitarity, vacuum stability.
- SPheno (`spheno.hepforge.org`):
  - Unitarity (including one-loop corrections).
- Vevacious (`vevacious.hepforge.org`):
  - Vacuum stability (including one-loop corrections).

Tools implementing experimental constraints

- HEPfit (`hepfit.roma1.infn.it`):
  - Higgs observables, flavour observables, electroweak precision observables, ...
- HiggsBounds (`gitlab.com/higgsbounds/higgsbounds`):
  - Searches for additional Higgs bosons.
- HiggsSignals (`gitlab.com/higgsbounds/higgssignals`):
  - Properties of 125 GeV Higgs.
- Lilith (`github.com/sabinekraml/Lilith-2`):
  - Properties of 125 GeV Higgs.

Conclusions

Concept of tools

Tools make algorithms/results accessible to community in a way not possible in a publication.

- A lot of calculations/algorithms is lost because they never got public.

$\rightarrow$ Always think about publishing your own results as a code!