Photon interactions in MadGraph/MadEvent v4

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An indisputable reason to study photons interactions?


GENESIS 1:3-4
Outline

- MadGraph/MadEvent v4
- Photons interactions
- Going beyond the Standard Model
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Why tree-level?

- Most of the current collider pheno is done at tree-level both at the theoretical and (even more) at experimental level.

- Experiments may need **fully exclusive descriptions**.

- MC at **NLO** are very recent (and impressive) achievements, but **currently limited** to a small set of key SM processes.
Why tree-level?

Always the fastest way,

very often the most accurate way,

sometimes the only way to bring ideas to life and test them in the experiments!
Why Matrix Elements?

- “Natural” approach for phase space regions where perturbative expansion is effective (hard, high angle, ...)
- Take into account all possible interferences
- Simulate correctly spin correlations
- Can be used for new analysis techniques
**MadGraph**

- Basic building blocks: **Feynman diagrams**
- Generates "empty" topologies for $m>n$ diagrams and "fill" them using valid interaction vertices
- Knowing particles properties, produces Feynman diagrams and suitable calls to the HELAS library
MadEvent

- Integrates the MEs from MadGraph to generate events. Uses adaptive methods like VEGAS to adjust a “grid” to numerically flatten peaks

- But: time expensive, peaks must lie on integration variables

- Solutions exist: Multi-Channel Integration (Amegic, Nextcalibur, Whizard), Single Diagram Enhanced MCI (MadEvent):
  \[
  |\sum_i A_i|^2 = \sum_i \left(\frac{|A_i|^2}{\sum_j |A_j|^2} \sum_k |A_k|^2\right)
  \]
  - One peaked function per diagram
  - Parallel in nature
New web generation

The new web generation:

- User inputs model/parameters/cuts.
- Code runs in parallel on one of our farms (UCL, UIUC, Roma).
- Returns cross section, plots, parton-level events.
- Returns also Pythia and PGS events if needed.

Advantages:

- Reduces overhead to getting results.
- Events can easily be shared/temporarily stored.
MG/ME v4 features

- Helicity amplitudes, based on HELAS
- Parallel phase space integration (up to 10 external particles)
- Les Houches Accord standards for model parameters (LHA) and for the parton-level event files (LHEF)
- CKKW and kt-MLM matching methods
- Interfaces for Pythia, Sherpa (and Herwig)
- Analysis platforms: ExRootAnalysis and MadAnalysis
- “Decay chains” syntax for diagram generation
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Basic principle...

If MG/ME can do the job for ee, ep and pp collisions ...

... it can do it as well for collisions involving photon(s)
Matrix elements for photon physics

* MadGraph can generate diagrams for any hard scattering process with $\gamma\gamma$, $\gamma e$ and $\gamma p$ as initial states

* At this stage, no assumption is made on photon exact origin

* E.g. Associated WH production at the LHC
Events production for photon physics

* Both electron and proton (no breaking) beams have been implemented as photon sources in MadEvent (status 2 and 3 for the photon beam) by members of the UCL-CP3 photon group (Thanks!).

* Electron: Weizsaecker-Williams EPA formula (very basic)

\[
f_\gamma(z) = \frac{\alpha}{2\pi} \log \frac{s}{m_e^2} \left[ \frac{1 + (1 - z)^2}{z} \right]
\]

* Proton: more model dependent since the proton is not an elementary particle (V.M.Budnev et al., Phys.Rep. 15C (1975) 181)

* No polarized \( \gamma \) beams yet, but trivial to implement (already there for electrons)
Real-life applications

S. OVYN, SEE SEVERINE'S PRESENTATION

Obtained using MadGraph/MadEvent

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New models

MG/ME deals with different physical models as directories containing:

- **particles.dat**: particle list with name, PDG codes, properties, ...

- **interactions.dat**: list of all possible 3- and 4-vertices

- **couplings.f**: analytic expressions for Feynman rule couplings

MG/ME comes with several predefined models: MSSM, 2HDM, HEFT, BSM top, ...
New models (2)

- **Calculators**: generic name for tools generating param_card.dat files (text files with all model parameters compliant with the Les Houches Accord format). Exist for MSSM, 2HDM, ...

- **USRMOD**: script allowing users to implement their own models by modifying the SM default

- **Limitation**: computing Feynman rules by hand is a hard task...
FeynRules

✿ New package to compute Feynman rules from Lagrangian

✿ Theorist friendly Mathematica package

✿ Completely generic, zeroth level output is TeX!

✿ Interfaces for MG/ME, but also for FeynArts, Sherpa and CalcHEP

✿ Standard Model and simple models implemented and tested, MSSM on its way
FeynRules (example)

SM SCALAR AND EXTRA SINGLET(S)

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\[ L = -\frac{1}{2}(D_{\mu} \Phi)^\dagger(D_{\mu} \Phi) - \frac{\lambda_0}{8}(\Phi^\dagger \Phi - f_0^2)^2 \]

\[ - \frac{1}{2}(\partial_{\mu} H)^2 - \frac{\lambda_1}{8}(2f_1 H - \Phi^\dagger \Phi)^2 \]

FROM CLAIRE DUHR’S PRESENTATION AT MC4BSM08
\[ \Phi = \{0, h + f0\} \]

\[ \text{LHill} = -\frac{1}{2} \text{del}[H, \mu]^2 - \frac{1}{11} \frac{1}{8} (2 f1 H - H C[\Phi] \cdot \Phi)^2 \]

\[ \frac{1}{2} \partial_{\mu}(H)^2 - \frac{1}{8} \frac{1}{11} (2 f1 H - \Phi^\dagger \cdot \Phi)^2 \]

\[ L = -\frac{1}{2} (D_{\mu} \Phi)^\dagger (D_{\mu} \Phi) \]

\[ -\frac{\lambda_0}{8} (\Phi^\dagger \Phi - f_0^2)^2 \]

\[ -\frac{1}{2} (\partial_{\mu} H)^2 \]

\[ -\frac{\lambda_1}{8} (2 f_1 H - \Phi^\dagger \Phi)^2 \]
FeynRules (example)
FeynRules (example)
BSM with photons

Example: effect of an anomalous $\gamma tu, c$ coupling for single top production in $\gamma p$ interactions at the LHC

$$i e e t \frac{\sigma_{\mu \nu} q^\nu}{\Lambda} k_{t u} \gamma u A^\mu$$

J. DEFAVEREAU, SEE JEROME’S TALK
Conclusion

- MadGraph/MadEvent v4 is a multi-purpose, user-friendly event generation package based on exact matrix element calculations. It has been designed for both signal and complex background studies.

- It can deal with initial state photons, either as real beams or coming from e and p, using EPA

- Various BSM models are now available, and new ones have never been so easy to implement
Thanks for your attention!