BSM in MadGraph5

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UCL

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UFO: C. Degrande, C. Duhr, B. Fuks,
D. Grellscheid, T. Reiter
ALOHA: P. Aquino, W. Link, F. Maltoni, T. Stelzer

jeudi 22 mars 2012
Plan

- Introduction / MadGraph5
- UFO
- ALOHA
- Color
- Model
Why simulating BSM?
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- Dedicated research
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- Dedicated research
- If we observe something unexpected
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- If we don’t observe anything
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- Dedicated research
- If we observe something unexpected
- If we don’t observe anything
- We want a model independent way to constraint the possible new physics
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- Dedicated research
- If we observe something unexpected
- If we don’t observe anything
  - We want a model independent way to constraint the possible new physics
- Dimension 6 Operator formalism
Lagrangian

Detector events
From Theory to Detector

- Lagrangian
- Feynman Rules
- Detector events
From Theory to Detector

Lagrangian → FeynmanRules → matrix-element → parton events → Detector events
From Theory to Detector

- Lagrangian
- Feynman Rules
- Matrix-element
- Parton events
- Hadronize events
- Detector events
From Theory to Detector

Lagrangian
FeynRules
FeynmanRules
MODEL: UFO

matrix-element
parton events
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Detector events
From Theory to Detector

- Lagrangian
- Feynman Rules
- MODEL: UFO
- Helicity Amplitude
- HELAS / ALOHA
- MadGraph
- matrix-element
- parton events
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- Detector events
From Theory to Detector

Lagrangian

FeynmanRules

FeynRules

MODEL: UFO

Helicity Amplitude

HELAS / ALOHA

matrix-element

MadGraph

parton events

MadGraph / MadEvent

hadronize events

Detector events
From Theory to Detector

- Lagrangian
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  - HELAS / ALOHA
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- MODEL: UFO
- MadGraph
- MadGraph / MadEvent
- Matrix-element
- Parton events
- Pythia
- Hadronize events
- Detector events
From Theory to Detector

- **Lagrangian**
- **FeynRules**
- **FeynmanRules**
- **MODEL: UFO**
- **Helicity Amplitude**
- **HELAS / ALOHA**
- **matrix-element**
- **MadGraph**
- **MadGraph / MadEvent**
- **parton events**
- **Pythia**
- **hadronize events**
- **Delphes**
- **Detector events**

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From Theory to Detector

Lagrangian

FeynRules

FeynmanRules

MODEL: UFO

Matrix-element

Helicity Amplitude HELAS / ALOHA

MadGraph

MadGraph / MadEvent

Parton events

Pythia

Hadronize events

Delphes

Detector events

Fully Automated

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From Theory to Detector

- Lagrangian
- FeynRules
- FeynmanRules
- MadGraph
- matrix-element
- parton events
- hadronize events
- Detector events
- one single command!

- MODEL: UFO
- HELICITY AMPLITUDE
- HELAS / ALOHA
- MadGraph / MadEvent
- Pythia
- Delphes
MadGraph5 Goal

☐ Remove ALL limitations of MadGraph4
  ☐ speed
  ☐ type of interactions
  ☐ number of particles
  ☐ nicer interface
number of particles

![Diagram with labeled particles and numbers]

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Command Interface

WELCOME to MADGRAPH 5

VERSION 1.3.16 2011-09-11

The MadGraph Development Team - Please visit us at
https://server06.fynu.ucl.ac.be/projects/madgraph

Type 'help' for in-line help.
Type 'tutorial' to learn how MG5 works

load MG5 configuration from /Users/omatt/.mg5_config
Loading default model: sm
models.import_ufo: Restrict model sm with file models/sm/rest.models.import_ufo: Run "set stdout_level DEBUG" before import INFO: Change particles name to pass to MG5 convention
Defined multiparticle p = g u c d s u~ c~ d~ s~
Defined multiparticle j = g u c d s u~ c~ d~ s~
Defined multiparticle l+ = e+ mu+
Defined multiparticle l- = e- mu-
Defined multiparticle vl = ve vm vt
Defined multiparticle vl~ = ve~ vm~ vt~
mg5>help
Nice Interactive session

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Auto-completion

**************
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*MadGraph 5*  
WELCOME to MADGRAPH 5

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mg5> help
Nice Interactive session
Auto-completion
Tutorial
interactive help
If You test it, you are going to like it!

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Nice Interactive session
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interactive help
Simple command set

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mg5>help
Command Interface

- Nice Interactive session
- Auto-completion
- Tutorial
- Interactive help

- Simple command set
- Import model sm
- Generate p p > e+ e-
- Output FORMAT MY_DIR
- Launch

---

Mattlelaer Olivier

20/09/11 at Rome: MadGraph 5

jeudi 22 mars 2012
Plan

- Introduction / MadGraph5
- UFO
- ALOHA
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- Model
UFO: Motivations
Avoid multiple output model written by FR.
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Avoid multiple output model written by FR.
- Avoid multiple output model written by FR.
- Have the generator to adapt to the model and not the opposite.
Avoid multiple output model written by FR.

Have the generator to adapt to the model and not the opposite.

Avoid any possible limitations
  - color
  - lorentz structure
  - number of particles in a vertex
  - gauge
UFO: Motivations

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- Joint model for MG5 / GOLEM / Herwig++
UFO: Motivations

- Avoid multiple output model written by FR.
- Have the generator to adapt to the model and not the opposite.
- Avoid any possible limitations
  - color
  - lorentz structure
  - number of particles in a vertex
  - gauge
- Joint model for MG5 / GOLEM / Herwig++
- Python Object Oriented Model
Universal FeynRules Output (UFO)

**particles.py:**

```python
G = Particle(pdg_code = 21,
    name = 'G',
    antiname = 'G',
    spin = 3,
    color = 8,
    mass = 'ZERO',
    width = 'ZERO',
    texname = 'G',
    antitexname = 'G',
    line = 'curly',
    charge = 0,
    LeptonNumber = 0,
    GhostNumber = 0)
```

**lorentz.py:**

```python
VVV1 = Lorentz(name = 'VVV1',
    spins = [ 3, 3, 3 ],
    Structure =
    'P(3,1)*Metric(1,2) -
P(3,2)*Metric(1,2) -
P(2,1)*Metric(1,3) +
P(2,3)*Metric(1,3) +
P(1,2)*Metric(2,3) -
P(1,3)*Metric(2,3)')
```

**couplings.py:**

```python
GC_4 = Coupling(name = 'GC_4',
    value = '-G',
    order = {'QCD':1})
```

**vertices.py:**

```python
V_2 = Vertex(name = 'V_2',
    particles = [ P.G, P.G, P.G ],
    color = [ 'f(1,2,3)' ],
    lorentz = [ L.VVV1 ],
    couplings = {(0,0):C.GC_4})
```
Plan

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Idea: Evaluate $m$ for fixed helicity of external particles.

$$M = \bar{u} \gamma^\mu \nu \, P_{\mu \nu} \, \bar{u} \gamma^\nu \nu$$
Idea: Evaluate $m$ for fixed helicity of external particles.

$$M = \bar{u} \gamma^\mu v P_{\mu\nu} \bar{u} \gamma^\nu v$$

Number for a given helicity
Idea: Evaluate $m$ for fixed helicity of external particles.

\[
M = \overline{u} \gamma^\mu v P_{\mu\nu} \overline{u} \gamma^\nu v
\]

Number for a given helicity
Idea: Evaluate $m$ for fixed helicity of external particles.

$$M = \overline{u} \gamma^\mu \gamma^\nu \gamma^\nu \gamma^\nu P_{\mu\nu} \nu$$

- Number for a given helicity
- Evaluate interaction by interaction

Diagrams made by MadGraph 5

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**Idea:** Evaluate $m$ for fixed helicity of external particles.

\[ M = (\bar{w} \gamma^\mu v) P_{\mu \nu} (\bar{w} \gamma^\nu v) \]

- Number for a given helicity
- Evaluate Interaction by interaction

\begin{itemize}
  \item \textbf{CALL} IXXXXX(P(0,1),ZERO,NHEL(1),+1*IC(1),W(1,1))
  \item \textbf{CALL} OXXXXX(P(0,2),ZERO,NHEL(2),-1*IC(2),W(1,2))
  \item \textbf{CALL} OXXXXX(P(0,3),MT,NHEL(3),+1*IC(3),W(1,3))
  \item \textbf{CALL} IXXXXX(P(0,4),MT,NHEL(4),-1*IC(4),W(1,4))
  \item \textbf{CALL} JI0XXX(W(1,1),W(1,2),GG,ZERO,ZERO,W(1,5))
\end{itemize}
**Idea:** Evaluate $m$ for fixed helicity of external particles.

\[ M = \overline{u} \gamma^\mu v P_{\mu \nu} \overline{u} \gamma^\nu v \]
**Idea:** Evaluate $m$ for fixed helicity of external particles.

\[ M = \overline{w} \gamma^\mu v P_{\mu\nu} \overline{w} \gamma^\nu v \]

- Number for a given helicity
- Evaluate interaction by interaction

CALL IXXXX(P(0,1),ZERO,NHEL(1),+1*IC(1),W(1,1))
CALL OXXXX(P(0,2),ZERO,NHEL(2),-1*IC(2),W(1,2))
CALL OXXXX(P(0,3),MT,NHEL(3),+1*IC(3),W(1,3))
CALL IXXXX(P(0,4),MT,NHEL(4),-1*IC(4),W(1,4))
CALL JIOXXX(W(1,1),W(1,2),GG,ZERO,ZERO,W(1,5))
CALL IOVXXX(W(1,4),W(1,3),W(1,5),GG,AMP(1))
Speed:

- The complexity grows linearly with the number of diagram
- Recycling between diagram (so reduces the factorial growth)
Limitations
Spins of the particles
Limitations

- Spins of the particles
- One routine by Lorentz structure
Limitations

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  - HEFT [Frederix] (2007)
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Limitations

- Spins of the particles
- One routine by Lorentz structure
  - HEFT [Frederix] (2007)
- This requires an automation!!
- Automatic Creation of HELAS routine for ANY BSM theory

- Output
  - Fortran
  - C++
  - Python

The Helas routine for BSM without the pain to write it.
ALOHAN

From: UFO  To: Helicity

Type text or a website address or translate a document.
ALOHA

Options:
- Standard
- Unitary gauge
- Complex-mass scheme
- Loop (HELAS)

Type text or a website address or translate a document.
ALOHA

Options:
- Standard
- Unitary gauge
- Complex-mass scheme
- Loop

(HELAS)

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ALOHA IS PURE PYTHON and standalone
ALOHA FEATURE

- ALOHA IS PURE PYTHON and standalone
- ALOHA IS FAST
- ALOHA IS PURE PYTHON and standalone
- ALOHA IS FAST
- SM in 3s
ALOHA FEATURE

- ALOHA IS PURE PYTHON and standalone
- ALOHA IS FAST
  - SM in 3s
  - MSSM in 5s
ALLOHA FEATURE

- ALOHA IS PURE PYTHON and standalone
- ALOHA IS FAST
  - SM in 3s
  - MSSM in 5s
- Possible to ask a subset of routine (Done in MG5)
ALOHA FEATURE

- ALOHA IS PURE PYTHON and standalone
- ALOHA IS FAST
  - SM in 3s
  - MSSM in 5s
- Possible to ask a subset of routine (Done in MG5)
- spin implemented
ALOHA FEATURE

- ALOHA IS PURE PYTHON and standalone
- ALOHA IS FAST
  - SM in 3s
  - MSSM in 5s
- Possible to ask a subset of routine (Done in MG5)
- spin implemented
  - Scalar
ALOHA FEATURE

- ALOHA IS PURE PYTHON and standalone
- ALOHA IS FAST
  - SM in 3s
  - MSSM in 5s
- Possible to ask a subset of routine (Done in MG5)
- spin implemented
  - Scalar
  - Fermion
*ALOHA FEATURE*

- ALOHA IS PURE PYTHON and standalone
- ALOHA IS FAST
  - SM in 3s
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- Possible to ask a subset of routine (Done in MG5)
- spin implemented
  - Scalar
  - Fermion
  - Vector
ALOHA FEATURE

- ALOHA IS PURE PYTHON and standalone
- ALOHA IS FAST
  - SM in 3s
  - MSSM in 5s
- Possible to ask a subset of routine (Done in MG5)
- Spin implemented
  - Scalar
  - Fermion
  - Vector
  - Spin2
Type of Interactions

Effective Theory

multi fermion interactions
Comparisons between explicit propagators and 4-fermion vertex

t-channel $u \ u > t \ t$

s-channel $u \ u > t \ t$
Plan

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Color sextet and $\varepsilon^{ijk}$ implementations

Diquark cross sections with coupling 0.01

Jet $p_T$:s, fully matched $pp \rightarrow D + 0,1,2$ jets

7 TeV LHC
Plan

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FAQ about the Model

- You can still use v4 model (but not C++ output possible) -- import model_v4 --
- This model is too large? MG5 can simplify it.
  - set masses/couplings to zero
- You can check that your model is valid by
  - checking the gauge invariance
  - checking the lorentz invariance
  - checking consistency of ALOHA output
    -- check PROCESS --
- The usermod (v4) is still working. A new one for the UFO model is on its way.
Any BSM should be possible in a fully automatic and efficient way!

If you need anything else, please let us know.
MadGraph 5 is ready for production both for SM and for BSM
https://launchpad.net/madgraph5