MadGraph5
UFO/ALOHA

Olivier Mattelaer
FNRS

MG5: J. Alwall / M. herquet / F. Maltoni / T. Stelzer
ALOHA: P. Aquino / W. Link / F. Maltoni / T. Stelzer
UFO: C. Degrande / C. Duhr / B. Fuks / D. Grellsheid
T. Reiter
and a lot of external collaborators

lundi 26 mars 2012
MG5 Two Years AGO...
MG5 First Objectives

- Diagram Generation (tree level)  
- Diagram Drawing  
- Color Factor 95%
- Amplitude Computation  
- Helas Automatic Generation 75%
What’s Needed from FR

☐ Need A Python Module for the Model
☐ Discussion on this Workshop
☐ particles/vertices/parameters/couplings
☐ Lorentz information for creating Helas
☐ (See working Group)
What’s Needed from FR

- Need A Python Module for the Model ✔
- Discussion on this Workshop
- particles/vertices/parameters/couplings
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What’s Needed from FR

- Need A Python Module for the Model ✓
- Discussion on this Workshop
- particles/vertices/parameters/couplings
- Lorentz information for creating Helas ✓
- (See working Group)
Plan

- UFO
- ALOHA
- MadGraph5
Plan

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

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Avoid any possible limitations

- color
- lorentz structure
- number of particles in a vertex
- gauge
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 / GOSAM / Herwig++
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/GOSAM/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

- UFO
- ALOHA
- MadGraph5
Idea: Evaluate $m$ for fixed helicity of external particles.

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

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

→ Number for a given helicity

Diagrams made by MadGraph5
**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
- Evaluate interaction by interaction

Diagrams made by MadGraph5

\[\text{diagram 1} \quad \text{QED=2}\]

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 JI0XXX(W(1,1),W(1,2),GG,ZERO,ZERO,W(1,5))
**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
→ 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

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  - HEFT [Frederix] (2007)

- One routine by Lorentz structure

SLIH
Chiral Perturbation
Effective Field Theory
Chromo-magnetic operator
Full HEFT
NMSSM
BNV Model
Black Holes

Mattlelaer Olivier
MC4BSM: BSM in MadGraph 5
lundi 26 mars 2012
Automatic Creation of HELAS routine for ANY BSM theory

Output
- Fortran
- C++
- Python

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

Google translate

Type text or a website address or translate a document.

From: UFO  To: Helicity  Translate

Brussels October 2010

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ALOHA

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

Type text or a website address or translate a document.
Feynman Gauge
- UFO Model supports both Unitary gauge and Feynman gauge
- Quite trivial for ALOHA (just changing the propagator)
- Easy for MG5 (just have to add the goldstino)
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This is trivial to implement
Feynman Gauge

- UFO Model supports both Unitary gauge and Feynman gauge
- Quite trivial for ALOHA (just changing the propagator)
- Easy for MG5 (just have to add the goldstino)

This is trivial to implement

- Usefull to test the gauge invariance
- Might be more optimal for some processes/energy (need to be checked)
- Will be helpfull for NLO
The presence of width **BREAKS** gauge and lorentz invariance

Gauge results:

<table>
<thead>
<tr>
<th>Process</th>
<th>matrix</th>
<th>BRS</th>
<th>ratio</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>g g &gt; b b~ e+ e~ ve ve~</td>
<td>1.6829262916e-20 1.1523186709e-24 6.8471131304e-05</td>
<td>Failed</td>
<td></td>
<td></td>
</tr>
<tr>
<td>JAMP 0</td>
<td>7.3202114973e-19 4.3818201275e-23 5.9859201187e-05</td>
<td>Failed</td>
<td></td>
<td></td>
</tr>
<tr>
<td>JAMP 1</td>
<td>8.0802219962e-20 1.0339427857e-23 1.2795970039e-0</td>
<td>Failed</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Summary: 0/1 passed, 1/1 failed

Failed processes: g g > b b~ e+ e~ ve ve~

Lorentz invariance results:

<table>
<thead>
<tr>
<th>Process</th>
<th>Min element</th>
<th>Max element</th>
<th>Relative diff.</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>g g &gt; b b~ e+ e~ ve ve~</td>
<td>6.87874030489e-21 6.8885480993e-21 1.0385879728e-04</td>
<td>Failed</td>
<td></td>
<td></td>
</tr>
<tr>
<td>JAMP 0</td>
<td>2.8968137980e-20 2.9000153627e-20 1.1039819500e-03</td>
<td>Failed</td>
<td></td>
<td></td>
</tr>
<tr>
<td>JAMP 1</td>
<td>3.0460455373e-19 3.0461513397e-19 3.4733125877e-0</td>
<td>Failed</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Summary: 0/1 passed, 1/1 failed

Failed processes: g g > b b~ e+ e~ ve ve~
The presence of width **BREAKS** gauge and lorentz invariance

Complex mass scheme solves this problems

\[ M_c = \sqrt{M^2 - iM \ast W} \]

Needs to fix also yukawa in that way and compute couplings accordingly.
Complex Mass Scheme

- The presence of width **BREAKS** gauge and lorentz invariance
- Complex mass scheme solves this problems

\[ M_c = \sqrt{M^2 - iM \ast W} \]

Gauge results:
- Process: \( g g \rightarrow b \bar{b}^\ast e^+ e^- \) ve ve\^\
  - matrix: 1.3981771141e-20
  - BRS: 1.5230480926e-46
  - ratio: 1.0893098430e-26
  - Result: Passed
  - Summary: 1/1 passed, 0/1 failed

Gauge results (switching between Unitary/Feynman):
- Process: \( g g \rightarrow b \bar{b}^\ast e^+ e^- \) ve ve\^\
  - Unitary: 3.3591262659e-16
  - Feynman: 3.3591262659e-16
  - Relative diff.: 6.0178031715e-15
  - Result: Passed
  - Summary: 1/1 passed, 0/1 failed

Lorentz invariance results:
- Process: \( g g \rightarrow b \bar{b}^\ast e^+ e^- \) ve ve\^\
  - Min element: 4.0109884021e-21
  - Max element: 4.0109884021e-21
  - Relative diff.: 1.8756383941e-15
  - Result: Passed
  - Summary: 1/1 passed, 0/1 failed
Plan

- UFO
- ALOHA
- MadGraph5
Plan

- UFO
- ALOHA
- MadGraph5
MadGraph5 Goal

- Remove ALL limitations of MadGraph4
  - speed
  - number of particles
  - type of interactions
  - modularity / flexibility of the code
  - static HELAS library
To improve our web services we request that you register. Registration is quick and free. You may register for a password by clicking here. You can still use MadGraph 4 here.

Code can be generated either by:

1. Fill the form:
   - Model: SM
   - Input Process: p p > w+ j j QED=3, w+ > l+ vl
   - p and j definitions: p = d u s c d u s c q
   - sum over leptons: l+ = e+, mu+ ta+; l- = e-, mu- ta-; vl = ve, vm, vt; vl = ve-, vm-, vt-

3. MadGraph 5: Going Beyond.
   Johan Alwall (Fermilab), Michel Herquet (NIKHEF, Amsterdam), Fabio Maltoni, Olivier Mattelaer (Louvain U., CP3), Tim Stelzer (Illinois U., Urbana). FERMILAB-PUB-11-448-T.
   Published in JHEP 1106 (2011) 128
Speed

Matrix Element generation:

<table>
<thead>
<tr>
<th>Process</th>
<th>MadGraph 4</th>
<th>MadGraph 5</th>
<th>Subprocesses</th>
<th>Diagrams</th>
</tr>
</thead>
<tbody>
<tr>
<td>$pp \rightarrow jjj$</td>
<td>2 min</td>
<td>22 s</td>
<td>34</td>
<td>307</td>
</tr>
<tr>
<td>$pp \rightarrow jjl^+l^-$</td>
<td>23 min</td>
<td>26 s</td>
<td>108</td>
<td>1216</td>
</tr>
<tr>
<td>$pp \rightarrow jjjej^+e^-$</td>
<td>60 min</td>
<td>132 s</td>
<td>141</td>
<td>9012</td>
</tr>
<tr>
<td>$\bar{u}u \rightarrow e^+e^-e^-e^+e^-$</td>
<td>51 min</td>
<td>75 s</td>
<td>1</td>
<td>3474</td>
</tr>
<tr>
<td>$gg \rightarrow ggggg$</td>
<td>3 hours</td>
<td>5 min</td>
<td>1</td>
<td>7245</td>
</tr>
<tr>
<td>$pp \rightarrow jj(W^+ \rightarrow l^+\nu_l)$</td>
<td>10 min</td>
<td>19 s</td>
<td>82</td>
<td>304</td>
</tr>
<tr>
<td>$pp \rightarrow t\bar{t}$+full decays</td>
<td>6h</td>
<td>29 s</td>
<td>27</td>
<td>45</td>
</tr>
<tr>
<td>$pp \rightarrow \bar{q}/q \bar{q}/q$</td>
<td>14 min</td>
<td>63 s</td>
<td>313</td>
<td>475</td>
</tr>
<tr>
<td>$gg \rightarrow (\tilde{g} \rightarrow u\bar{u}\tilde{\chi}_0^0)(\tilde{g} \rightarrow u\bar{u}\tilde{\chi}_1^0)$</td>
<td>5 min</td>
<td>7 s</td>
<td>1</td>
<td>48</td>
</tr>
<tr>
<td>$pp \rightarrow (\tilde{g} \rightarrow jj\tilde{\chi}_1^0)(\tilde{g} \rightarrow jj\tilde{\chi}_1^0)$</td>
<td>—</td>
<td>30s</td>
<td>144</td>
<td>11008</td>
</tr>
</tbody>
</table>

Matrix Element evaluation (Fortran):

<table>
<thead>
<tr>
<th>Process</th>
<th>Function calls</th>
<th>Run time</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>MG 4</td>
<td>MG 5</td>
</tr>
<tr>
<td>$\bar{u}u \rightarrow e^+e^-$</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>$\bar{u}u \rightarrow e^+e^-e^-e^+$</td>
<td>110</td>
<td>80</td>
</tr>
<tr>
<td>$\bar{u}u \rightarrow e^+e^-e^-e^+e^-$</td>
<td>6668</td>
<td>3775</td>
</tr>
<tr>
<td>$\bar{u}u \rightarrow d\bar{d}$</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>$\bar{u}u \rightarrow d\bar{d}g$</td>
<td>16</td>
<td>16</td>
</tr>
<tr>
<td>$\bar{u}u \rightarrow d\bar{d}gg$</td>
<td>85</td>
<td>67</td>
</tr>
<tr>
<td>$\bar{u}u \rightarrow d\bar{d}ggg$</td>
<td>748</td>
<td>515</td>
</tr>
<tr>
<td>$\bar{u}u \rightarrow w\bar{u}gg$</td>
<td>160</td>
<td>116</td>
</tr>
<tr>
<td>$\bar{u}u \rightarrow w\bar{u}ggg$</td>
<td>1468</td>
<td>960</td>
</tr>
<tr>
<td>$\bar{u}u \rightarrow d\bar{d}d\bar{d}$</td>
<td>42</td>
<td>33</td>
</tr>
<tr>
<td>$\bar{u}u \rightarrow d\bar{d}d\bar{d}g$</td>
<td>310</td>
<td>197</td>
</tr>
<tr>
<td>$\bar{u}u \rightarrow d\bar{d}d\bar{d}gg$</td>
<td>3372</td>
<td>1876</td>
</tr>
<tr>
<td>$\bar{u}u \rightarrow d\bar{d}d\bar{d}d\bar{d}$</td>
<td>1370</td>
<td>753</td>
</tr>
</tbody>
</table>
number of particles

lundi 26 mars 2012
Type of Interactions

Effective Theory

multi fermion interactions
Effective Theory

multi fermion interactions

As well as new color structures
(triplet/sextet)
Mattlelaer Olivier

FR Mont St Odille 2012: MadGraph 5

Command Interface

Welcome to MadGraph 5

Version 1.3.16

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

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Nice Interactive session

MadGraph 5 (version 1.3.16)

Welcome to MadGraph 5

* * * * * * * * * * * *

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Nice Interactive session

Auto-completion

WELCOME to MADGRAPH 5

VERSION 1.3.16 2011-09-11

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Defined multiparticle vl = ve vm vt
Defined multiparticle vl~ = ve~ vm~ vt~
mg5> help
Nice Interactive session
Auto-completion
Tutorial
Interactive help

Welcome to MadGraph 5

Version 1.3.16
2011-09-11

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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

Auto-completion

Tutorial

interactive help

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

Welcome to MadGraph 5

WELCOME to MADGRAPH 5

VERSION 1.3.16

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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

Auto-completion

Tutorial

interactive help

Simple command set

import model sm

generate p p > e+ e-

output FORMAT MY_DIR

launch
Compact and optimise output for MadEvent

<table>
<thead>
<tr>
<th>Process</th>
<th>Subprocess directories</th>
<th>Channels for survey</th>
<th>Directory size</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ME 4</td>
<td>ME 5</td>
<td>ME 4</td>
</tr>
<tr>
<td>$pp \to W^+ j$</td>
<td>6</td>
<td>2</td>
<td>12</td>
</tr>
<tr>
<td>$pp \to W^+ jj$</td>
<td>41</td>
<td>4</td>
<td>138</td>
</tr>
<tr>
<td>$pp \to W^+ jjj$</td>
<td>73</td>
<td>5</td>
<td>1164</td>
</tr>
<tr>
<td>$pp \to W^+ jjjj$</td>
<td>296</td>
<td>7</td>
<td>15029</td>
</tr>
<tr>
<td>$pp \to l^+ l^- j$</td>
<td>12</td>
<td>2</td>
<td>48</td>
</tr>
<tr>
<td>$pp \to l^+ l^- jj$</td>
<td>54</td>
<td>4</td>
<td>586</td>
</tr>
<tr>
<td>$pp \to l^+ l^- jjj$</td>
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<td>5</td>
<td>5408</td>
</tr>
<tr>
<td>$pp \to l^+ l^- jjjj$</td>
<td>235</td>
<td>7</td>
<td>63114</td>
</tr>
<tr>
<td>$pp \to t\bar{t}$</td>
<td>3</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>$pp \to t\bar{t}j$</td>
<td>7</td>
<td>3</td>
<td>45</td>
</tr>
<tr>
<td>$pp \to t\bar{t}jj$</td>
<td>22</td>
<td>5</td>
<td>417</td>
</tr>
<tr>
<td>$pp \to t\bar{t}jjj$</td>
<td>34</td>
<td>6</td>
<td>3816</td>
</tr>
</tbody>
</table>
Remove ALL limitations of MadGraph4
- speed
- number of particles
- type of interactions
- modularity / flexibility of the code
MadGraph5 Goal

- Remove ALL limitations of MadGraph4
  - speed
  - number of particles
  - type of interactions
  - modularity / flexibility of the code

So we succeed the initial goal
After the initial Goal?
After the initial Goal?
After the initial Goal?

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After the initial Goal?

Current 1.4.3

Not possible to detail everything

1.4.0
What’s new

- Improve Phase-space integration
What’s new

- Improve Phase-space integration
- automatic order restriction for any model

```bash
mg5>display coupling_order
  QCD : weight = 1
  QED : weight = 2
```
What’s new

- Improve Phase-space integration
- automatic order restriction for any model

mg5>display coupling_order
  QCD : weight = 1
  QED : weight = 2
mg5>generate p p > w- > b b~ e+ ve jj
INFO: Checking for minimal orders which gives processes.
INFO: Please specify coupling orders to bypass this step.
INFO: Trying coupling order WEIGHTED=8
INFO: Trying coupling order WEIGHTED=9
INFO: Trying coupling order WEIGHTED=10
INFO: Trying process: g g > w- > b b~ e+ ve d u~ WEIGHTED=10
INFO: Process has 63 diagrams

If no coupling order specify: take minimal weight
What’s new

- Improve Phase-space integration
- automatic order restriction for any model

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  QCD : weight = 1
  QED : weight = 2
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INFO: Process has 63 diagrams

QED=4, QCD=2

If no coupling order specify: take minimal weight
What’s new

☐ Check that the param_card is compatible with the model
What’s new

- Check that the param_card is compatible with the model
- MSSM will support SLAH1 card
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  - configuration files
  - New interface for madevent
- Easy to install pythia-pgs/Delphes/...
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- Possibility to compute partial width (and BR)
- Improving the gridpack
- add a cut forbidding on-shell particles but allowing off-shell contribution (?).
$ \text{Explanation}$

\[ p p > e^+ e^- ZZ \]
$ \text{explanation}$

$$pp \rightarrow e^+ e^- Z$$

BW cutt = 5
(small for the example)
$ \text{Explanation}$

$p p \rightarrow e^+ e^- Z$

$Z$-onshell veto

$BW \text{cut} = 5$
(small for the example)
$ \text{Explanation}$

$p p \rightarrow e^+ e^- Z$

$Z$-onshell veto

BW cutt = 5 (small for the example)

$\text{Offshell } Z \text{ interference is BG}$
And After...

- Inclusion of new output
  - MadDarkMatter
  - MadWeight
  - ...

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And After...

- Inclusion of new output
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And After...

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And After...

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And After...

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And After...

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- ...
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- usermod for UFO model
- MadAnalysis5
- color ordered amplitude
- recursion relations
- computing the widths

**Diagram 19**

```
1 \ u \ 2 \ u\sim \ g \ 3 \ u \ 4 \ u\sim

5
```

**QCD=5**
Computing the widths

- mg5> compute_widths Z
- First evaluate $2>2$ and $2>3$ contribution
- Compute ONLY the relevant contribution
- Write the new param_card.dat
We are VERY happy
What we need from FR

- 4 fermion operator
- Unitary Operator
- spin 3/2
- Automatic width for 2>2?

We are VERY happy
What we need from FR

- 4 fermion operator
- Unitary Operator
- spin 3/2
- Automatic width for 2>2?

We are VERY happy

And of course NLO

Details in Valentin/Rik’s talk

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MadGraph 5 is working
We have included a lot of features
A lot of improvements are ongoing

https://launchpad.net/madgraph5