MadLoop5 Status

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Presentation
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Outline

- What was **ML4** capable of ?
- More than One between **ML4** and **ML5**...
- Results
- Closing words

Cut-Loop diagrams

With a specific example

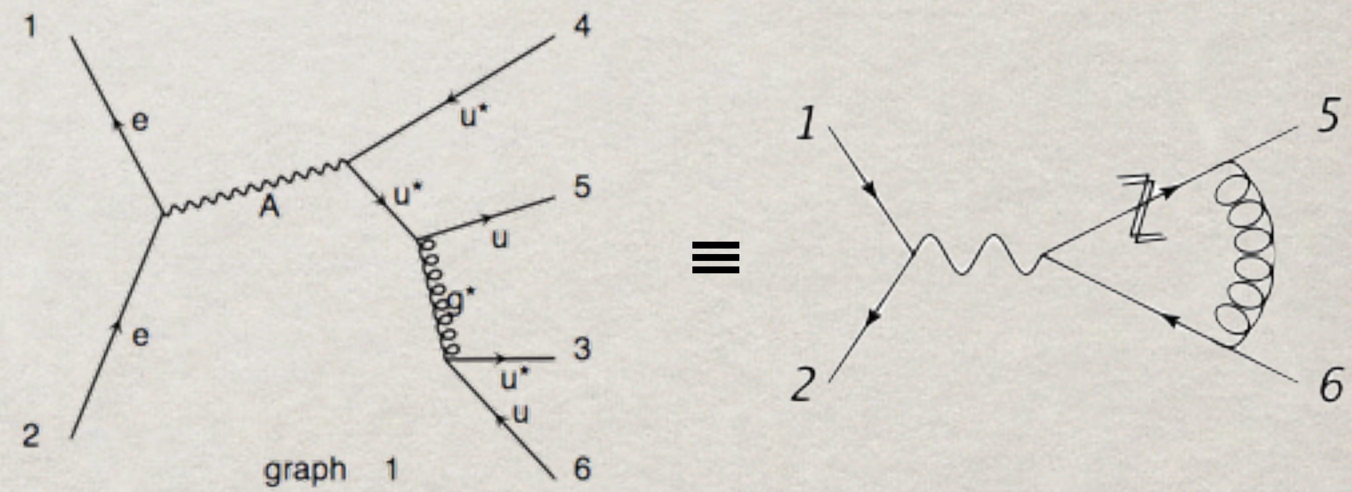
Consider $e^+e^- \rightarrow \gamma \rightarrow u\bar{u}$:

- Loop particles are denoted with a star. When MG is asked for $e^+e^- \rightarrow u^*\bar{u}^*u\bar{u}$ it gives back eight diagrams. Two of them are:

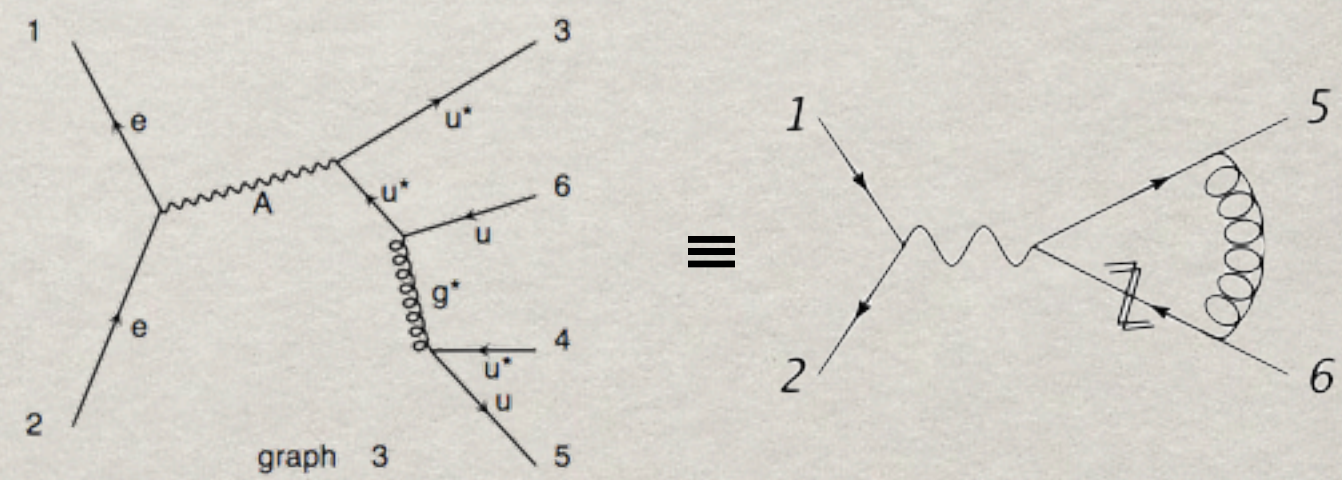
- Selection is performed to keep only one cut-diagram per loop contributing in the process

- Tags are associated to each cut-diagram. Those whose tags are **mirror and/or cyclic permutations** of tags of diagram already in the loop-basis are taken out.

- Additional custom filter to eliminate tadpoles and bubbles attached to external legs.



Diag $_1 = [u^*(6)g^*(5)u^*(A)]$

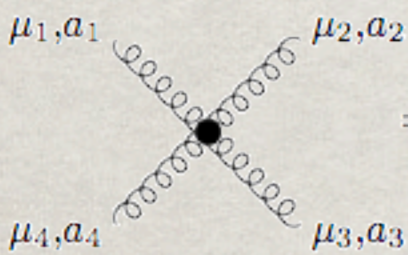


Diag $_3 = [u^*(A)u^*(6)g^*(5)]$

MadLoop in MG4

What it could **NOT** do

✓ No four-gluon vertex at born level :



$$= -\frac{ig^4 N_{col}}{96\pi^2} \sum_{P(234)} \Big\{ \Big[\frac{\delta_{a_1a_2}\delta_{a_3a_4}+\delta_{a_1a_3}\delta_{a_4a_2}+\delta_{a_1a_4}\delta_{a_2a_3}}{N_{col}} + 4\,Tr(t^{a_1}t^{a_3}t^{a_2}t^{a_4}+t^{a_1}t^{a_4}t^{a_2}t^{a_3})\,(3+\lambda_{HV}) - Tr(\{t^{a_1}t^{a_2}\}\{t^{a_3}t^{a_4}\})\,(5+2\lambda_{HV})\Big]\, g_{\mu_1\mu_2}g_{\mu_3\mu_4} + 12\frac{N_f}{N_{col}}Tr(t^{a_1}t^{a_2}t^{a_3}t^{a_4})\left(\frac{5}{3}g_{\mu_1\mu_3}g_{\mu_2\mu_4} - g_{\mu_1\mu_2}g_{\mu_3\mu_4} - g_{\mu_2\mu_3}g_{\mu_1\mu_4}\right)\Big\}$$

✓ All born contribution must factorize the same power of all coupling orders.

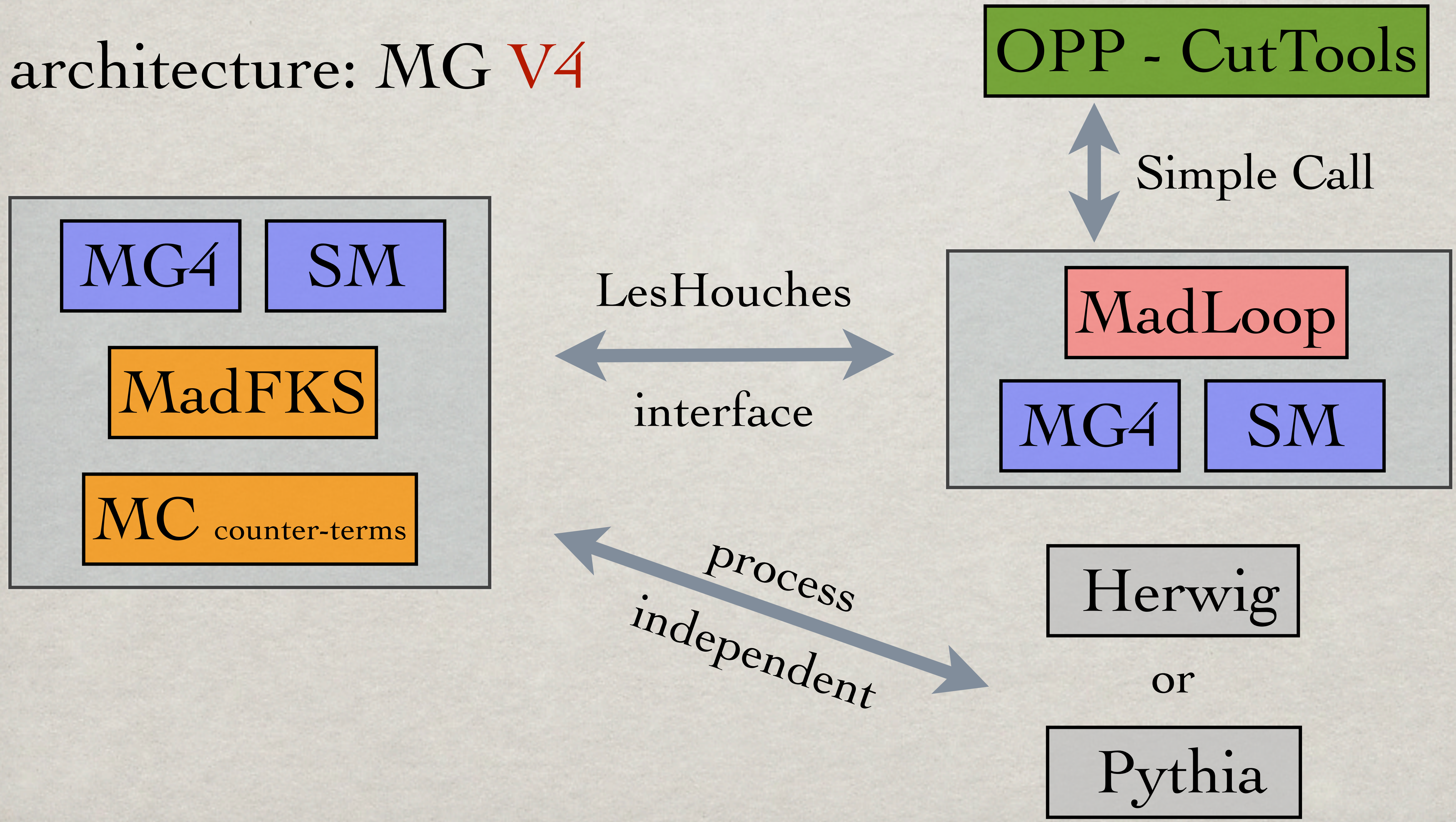
✕ No finite-width effects of unstable massive particles also appearing in the loop.

✕ Handle BSM models

aMC@NLO

Towards full automation

architecture: MG V4



What ML4 could do

- Running time: Two weeks on a 150+ node cluster
- Proof of efficient EPS handling with $Zt\bar{t}$
- Successful cross-check against known results
- Large K-factors sometimes
- No cuts on b, robust numerics with small P_T

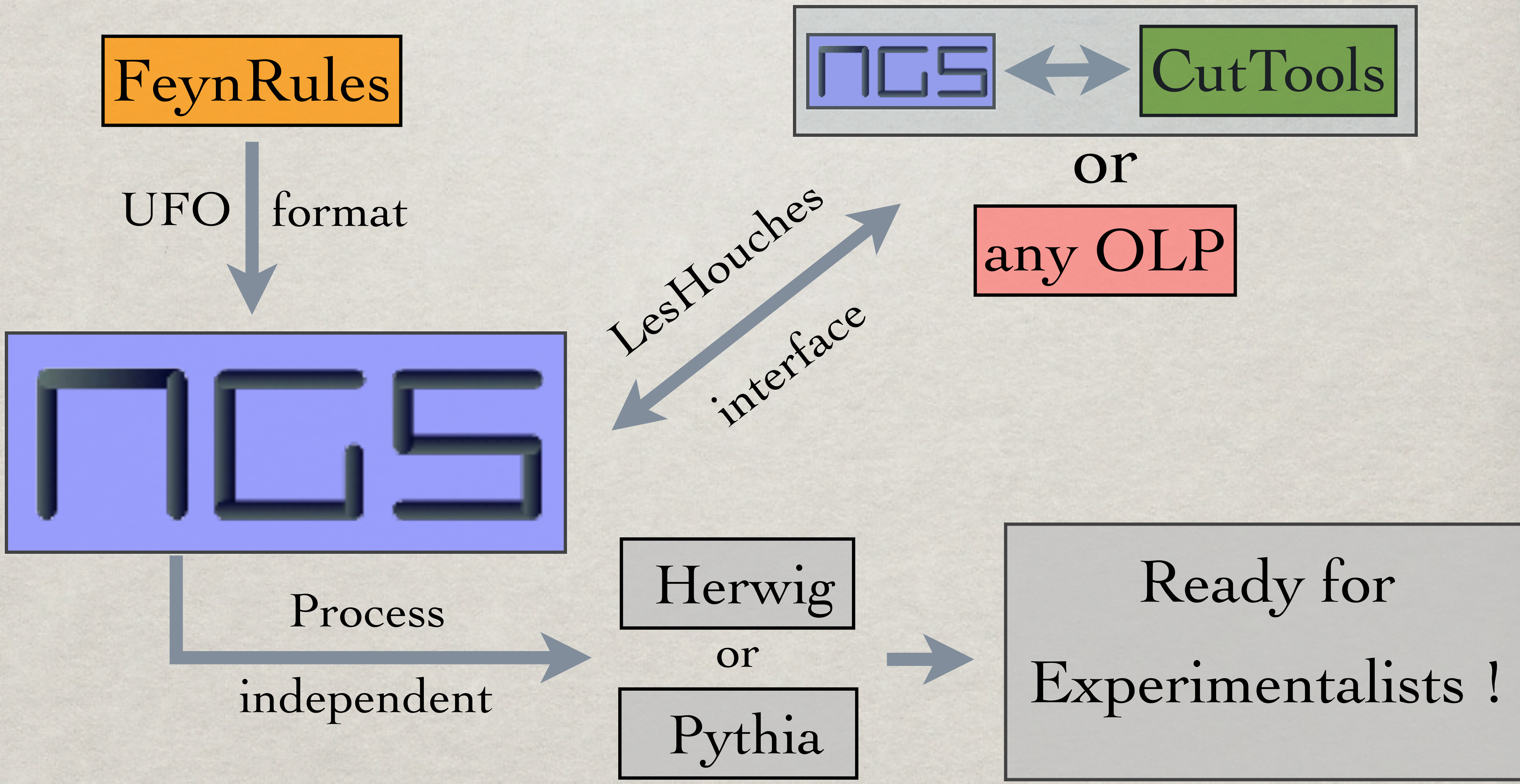
	Process	μ	n_{lf}	Cross section (pb) LO	Cross section (pb) NLO
a.1	$pp \to t\bar{t}$	m_{top}	5	123.76 ± 0.05	162.08 ± 0.12
a.2	$pp \to tj$	m_{top}	5	34.78 ± 0.03	41.03 ± 0.07
a.3	$pp \to tjj$	m_{top}	5	11.851 ± 0.006	13.71 ± 0.02
a.4	$pp \to t\bar{b}j$	$m_{top}/4$	4	25.62 ± 0.01	30.96 ± 0.06
a.5	$pp \to t\bar{b}jj$	$m_{top}/4$	4	8.195 ± 0.002	8.91 ± 0.01
b.1	$pp \to (W^+ \to)e^+\nu_e$	m_W	5	5072.5 ± 2.9	6146.2 ± 9.8
b.2	$pp \to (W^+ \to)e^+\nu_e j$	m_W	5	828.4 ± 0.8	1065.3 ± 1.8
b.3	$pp \to (W^+ \to)e^+\nu_e jj$	m_W	5	298.8 ± 0.4	300.3 ± 0.6
b.4	$pp \to (\gamma^*/Z \to)e^+e^-$	m_Z	5	1007.0 ± 0.1	1170.0 ± 2.4
b.5	$pp \to (\gamma^*/Z \to)e^+e^- j$	m_Z	5	156.11 ± 0.03	203.0 ± 0.2
b.6	$pp \to (\gamma^*/Z \to)e^+e^- jj$	m_Z	5	54.24 ± 0.02	56.69 ± 0.07
c.1	$pp \to (W^+ \to)e^+\nu_e b\bar{b}$	$m_W + 2m_b$	4	11.557 ± 0.005	22.95 ± 0.07
c.2	$pp \to (W^+ \to)e^+\nu_e t\bar{t}$	$m_W + 2m_{top}$	5	0.009415 ± 0.000003	0.01159 ± 0.00001
c.3	$pp \to (\gamma^*/Z \to)e^+e^- b\bar{b}$	$m_Z + 2m_b$	4	9.459 ± 0.004	15.31 ± 0.03
c.4	$pp \to (\gamma^*/Z \to)e^+e^- t\bar{t}$	$m_Z + 2m_{top}$	5	0.0035131 ± 0.0000004	0.004876 ± 0.000002
c.5	$pp \to \gamma t\bar{t}$	$2m_{top}$	5	0.2906 ± 0.0001	0.4169 ± 0.0003
d.1	$pp \to W^+W^-$	$2m_W$	4	29.976 ± 0.004	43.92 ± 0.03
d.2	$pp \to W^+W^- j$	$2m_W$	4	11.613 ± 0.002	15.174 ± 0.008
d.3	$pp \to W^+W^+ jj$	$2m_W$	4	0.07048 ± 0.00004	0.1377 ± 0.0005
e.1	$pp \to HW^+$	$m_W + m_H$	5	0.3428 ± 0.0003	0.4455 ± 0.0003
e.2	$pp \to HW^+ j$	$m_W + m_H$	5	0.1223 ± 0.0001	0.1501 ± 0.0002
e.3	$pp \to HZ$	$m_Z + m_H$	5	0.2781 ± 0.0001	0.3659 ± 0.0002
e.4	$pp \to HZj$	$m_Z + m_H$	5	0.0988 ± 0.0001	0.1237 ± 0.0001
e.5	$pp \to Ht\bar{t}$	$m_{top} + m_H$	5	0.08896 ± 0.00001	0.09869 ± 0.00003
e.6	$pp \to Hb\bar{b}$	$m_b + m_H$	4	0.16510 ± 0.00009	0.2099 ± 0.0006
e.7	$pp \to Hjj$	m_H	5	1.104 ± 0.002	1.036 ± 0.002

ML5 TWO YEARS AGO...

aMC@NLO

FULL AUTOMATION

architecture: MG V5



Tuesday, March 27, 2012

MadLoop V4 to V5

Great improvements

✓ = non-optimal | ✓ = done optimally | ✕ = not done | ✕ = not done YET

Task	MadLoop V4	MadLoop V5
Generation of L-Cut diagrams, loop-basis selection	✓-	✓++
Color Factor computation	✓-	✓
Counter-term (UV/R2) diagrams generation	✓-	✓
Mixed order perturbation (generation level)	✕	✓
File output	✓--	✓
Drawing of Loop diagrams	✕	✓
Full SM implementation for QCD perturbations	✓	✓
4-gluon R2 computation	✕	✓
Automated parallel tests	✕	✓
Automatic sanity checks (Ward, ε^{-2})	✓	✓
EPS handling	✓ (no mp)	✕
Virtual squared	✓-	✕
Decay Chains	✕	✕
Automatic loop-model creation	✕	✕
Complex mass scheme and massive bosons in the loop	✕	✕/✓

MadLoop5

Synthax

- Process generation
  - `generate <process> <born_orders> [<option>=<pert_orders>] <born_orders>`
  - Ex: `generate p p > W+ W- d d~ QED=2 [virt=QCD] QCD=6 QED=4 WEIGHTED=14`

```
aMC@NLO>generate g g > t t~ [virt=QCD]
Switching from interface aMC@NLO to ML5
INFO: Generating process: g g > t t~ [ QCD ]
INFO: Generated 3 born diagrams
INFO: Generated 45 loop diagrams with 21 R2 and 76 UV counterterms
Process generated in 1.427 s
ML5>output standalone
INFO: initialize a new standalone directory: PROC_SA_loop_sm_0
INFO: Generating Helas calls for process: g g > t t~ [ QCD ] WEIGHTED=6
INFO: Processing color information for loop process: g g > t t~ [ QCD ] WEIGHTED=6
INFO: Processing color information for born process: g g > t t~ [ QCD ] WEIGHTED=6
INFO: Creating color matrix  loop process: g g > t t~ [ QCD ] WEIGHTED=6
INFO: Creating files in directory /Users/Spooner/Documents/PhD/MG5/FKS5/PROC_SA_loop_sm_0/SubProcesses/P0_gg_ttx
INFO: Generating loop Feynman diagrams for Process: g g > t t~ [ QCD ] WEIGHTED=6
INFO: Generating born Feynman diagrams for Process: g g > t t~ [ QCD ] WEIGHTED=6
Generated helas calls for 1 subprocesses (90 diagrams) in 0.846 s
Wrote files for 10 OPP calls in 0.225 s
Export UFO model to MG4 format
ALOHA: aloha creates VVV1 routines
ALOHA: aloha creates VVVV4 routines
ALOHA: aloha creates GHGHG routines
ALOHA: aloha creates FFV1 routines
ALOHA: aloha creates R2_GG_3 routines
ALOHA: aloha creates R2_GG_2 routines
ALOHA: aloha creates R2_GG_1 routines
ALOHA: aloha creates VVVV3 routines
ALOHA: aloha creates R2_QQ_2 routines
ALOHA: aloha creates R2_QQ_1 routines
ALOHA: aloha creates VVVV1 routines
INFO: For loop processes, the compiler must be fortran90compatible, like gfortran.
INFO: Use Fortran compiler gfortran
INFO: Running make for Helas
INFO: Running make for Model
Output to directory /Users/Spooner/Documents/PhD/MG5/FKS5/PROC_SA_loop_sm_0 done.
ML5>launch
WARNING: If you edit this file don't forget to modify
         consistently the different parameters, especially
         the width of all particles.
Do you want to edit file: param_card.dat? [n, y, path of the new param_card.dat]
n
```

```
---------------------------------------------------------------------------------------
n        E             px             py              pz               m
1   0.5000000E+03  0.0000000E+00  0.0000000E+00  0.5000000E+03  0.0000000E+00
2   0.5000000E+03  0.0000000E+00  0.0000000E+00 -0.5000000E+03  0.0000000E+00
3   0.5000000E+03  0.1039662E+03  0.4169273E+03 -0.1870353E+03  0.1743000E+03
4   0.5000000E+03 -0.1039662E+03 -0.4169273E+03  0.1870353E+03  0.1743000E+03
---------------------------------------------------------------------------------------
---------------------------------------------------------------------------------------
Matrix element born   =   0.59326404245927544      GeV^       0
Matrix element finite =  -0.51012237966656715      GeV^       0
Matrix element 1eps   =   0.24083172730803246      GeV^       0
Matrix element 2eps   =  -6.6850000680580154E-002  GeV^       0
---------------------------------------------------------------------------------------
finite / (born*ao2pi) =   -45.785104664756432
1eps   / (born*ao2pi) =    21.615412851715373
2eps   / (born*ao2pi) =   -5.9999999999999956
---------------------------------------------------------------------------------------
```

Results snapshot

- How faster are they generated?

Process	Generation time[1]		Output size[2]		Compilation time[3]		Running time[4]	
d d~ > u u~	**8.750 s**	**5.378 s**	200 Kb	268 Kb	0.931 s	2.996 s	0.0088 s	0.0094 s
d d~ > d d~ g	**17.04 s**	**104.8 s**	124 Kb	1.7 Mb	4.799 s	19.181 s	0.64 s	0.74 s
d d~ > d d~ u u~	**22.50 s**	**2094 s**	232 Kb	3.3 Mb	37.75 s	45.02 s	1.93 s	2.34 s
g g > g g g g	**38 min**	×	25 Mb	×	211 min	×	72 min	×
u d~ > w+ g g g	**123 s**	×	1Mb	×	43 s	×	121 s	×
u d~ > w+ g g g g	**64 min**	×	17 Mb	×	9 min	×	137 min	×

[1] : Process generated retaining all contribution with massive top and bottom quarks.
[2] : Of the equivalent `matrix.f` file. [4] : Per PS points, Color/Helicity summed.

MadLoop5 = ♦ (green)
MadLoop4 = ♦ (purple)

- Why ?
  - The MG5 `from_group` algorithm is already much faster for tree-level diagrams.
  - It is modified so that bubbles and tadpoles are not generated.
  - When generating diagrams for a given L-Cut particle, all previously considered L-Cut particles are vetoed from being loop-lines.

NEXT ON PIPE-LINE

- Complex mass scheme for finite-width effects
- Handle unstable PS points finite with quadrupole precision
- Polish event-generation along with MadFKS5
- Implement output for loop-induced processes
- Automatic Loop UFO Model generation with FeynRules
- Decay chains specifications
- Case-study SUSY ? (If not already irrelevant by then:)
- Speed upgrade? (probably relevant by then:)

Final Word

True Automation is at the door

- aMC@NLO shows that an experimental analysis fully at NLO done without theory support is not science fiction any more !

- First presentation of complete SM loop model in MG5.

- Some ad: http://amcatnlo.cern.ch/, where you will find :
  - NLO event samples to be showered by the user
  - On-line running of MadLoop4 for a single phase-space point check.

Thanks