MadLoop5 Status

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Presentation
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MCWorkshop

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Outline

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

Existing tools

- Flexible tools for NLO predictions do not exist:
  - MCFM *[Campbell & Ellis & ...]* has it available almost all relevant process for background studies at the Tevatron and LHC, but gives only fixed-order, parton-level results
  - MC@NLO *[Frixione & Webber & ...]* has matching to specific parton shower to describe fully exclusive final states, but the list of available processes is relatively short
  - POWHEG BOX *[Nason et al.]* provides a framework to match any existing parton level NLO computation to a parton shower. However, the NLO computation is not automated and some work by the user is needed to implement a new process
- Idea: write an automatic tool that is flexible and allows for any process to be computed at NLO accuracy, including matching to the parton shower to deliver events ready for experimentalists ➔ **a**MC@NLO

aMC@NLO in a nutshell

- MadFKS, build on MadGraph, computes all contributions to a NLO computation, except for the finite part of the virtual amplitude
- MadLoop computes the virtual corrections to any process in the SM using the OPP method as implemented in CutTools
- Combine MadFKS and MadLoop to get any distribution/cross section at (parton-level) NLO accuracy
- Add terms to remove double counting when matching to the parton shower: aMC@NLO
- Shower the generated events using Herwig or Pythia to get fully exclusive predictions at NLO accuracy (for IR-safe observables).

Why automation?

- Save time
  Trade time spent on computing a process with time on studying the physics behind it.

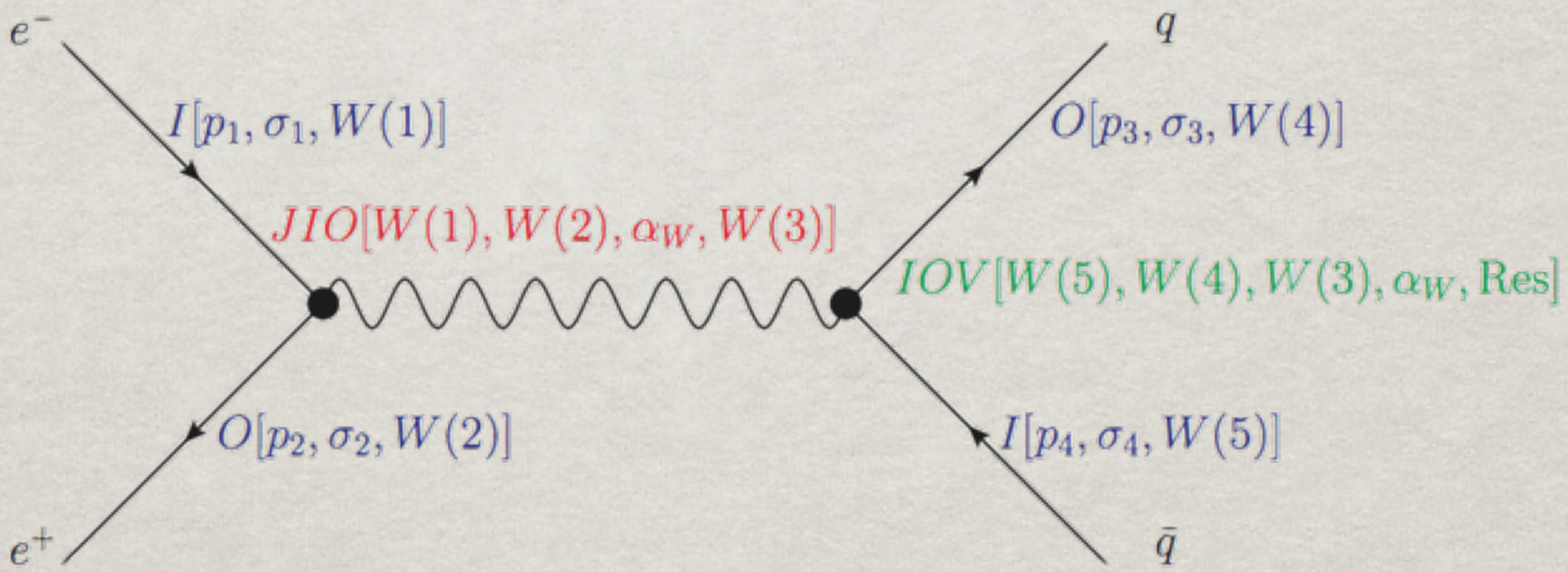
- Avoid bugs
  Having a trusted program extensively checked once and for all, eliminates obvious bugs when running different processes.

- Use of the same framework for all processes
  It only requires to know how to efficiently use one single program to do all NLO phenomenology.

MadGraph

The evolutive way of computing tree-diagrams

- First generates all tree-level Feynman Diagrams
- Compute the amplitude of each diagram using a chain of calls to HELAS subroutines



- Finally square all the related amplitude with their right color factors to construct the full LO amplitude

Cut-Loop diagrams

With a specific example

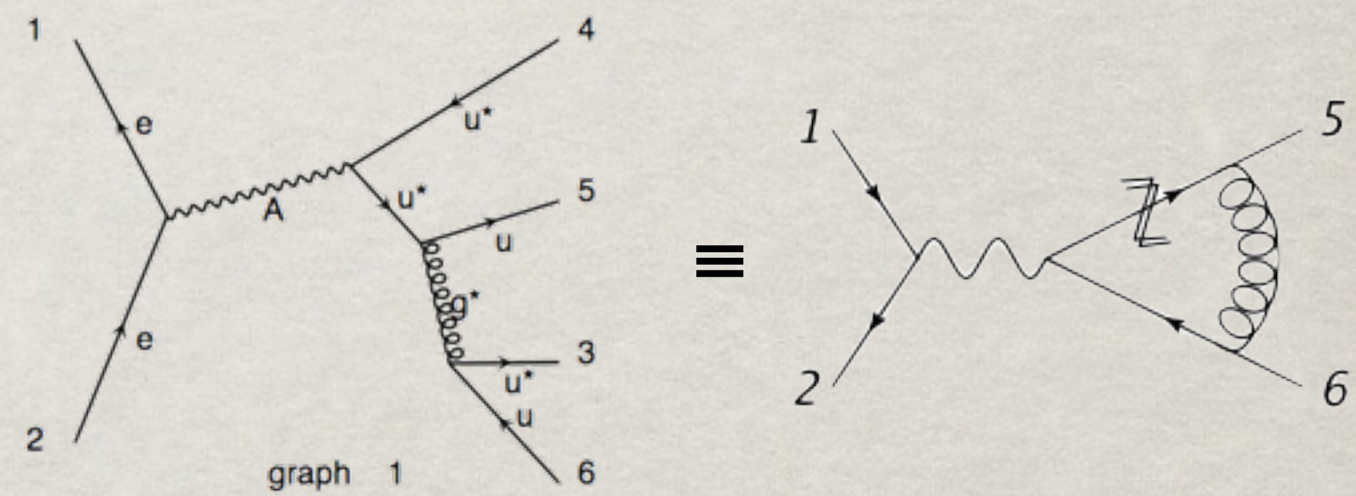
Consider $e^+e^- \to \gamma \to u\bar{u}$:

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

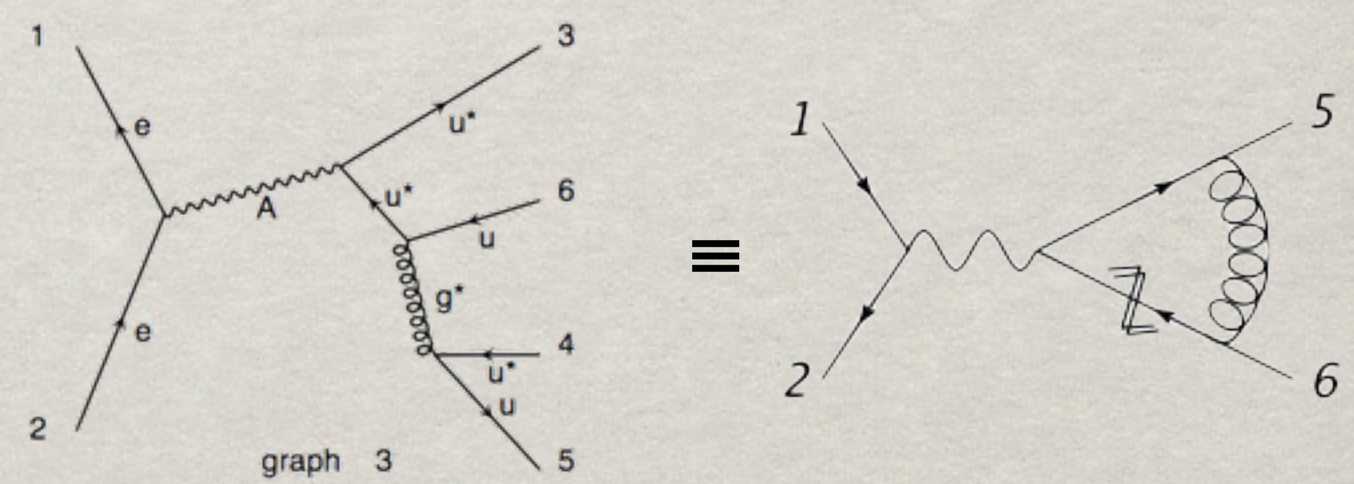
- Selection is performed to keep only one cut-diagram per loop contributing in the process

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

What ML4 could do

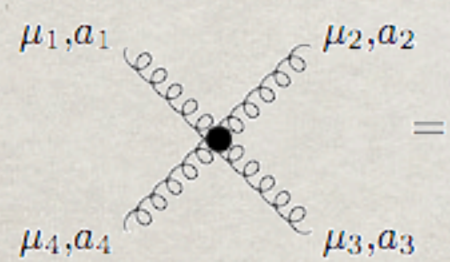
- Running time: Two weeks on a 150+ node cluster
- Proof of efficient EPS handling with $Zt\bar{t}$
- Successful cross-check against known results
- Large K-factors sometimes
- No cuts on b, robust numerics with small P_T

	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	$pp \to HZ j$	$m_Z + m_H$	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

MadLoop in MG4

What it could NOT do

✓ No four-gluon vertex at born level :



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

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

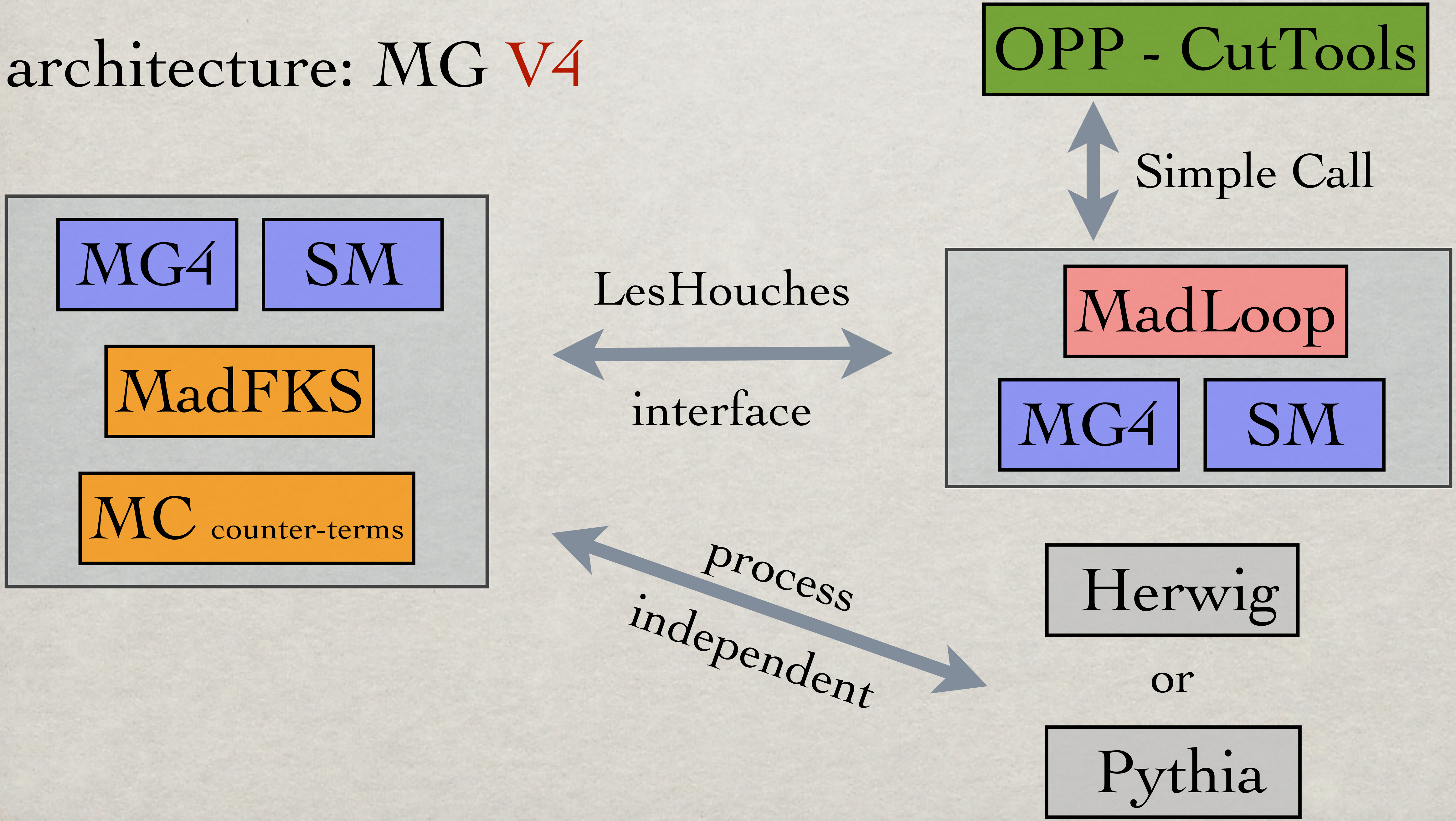
✗ No finite-width effects of unstable massive particles also appearing in the loop.

✗ Handle BSM models

aMC@NLO

Towards full automation

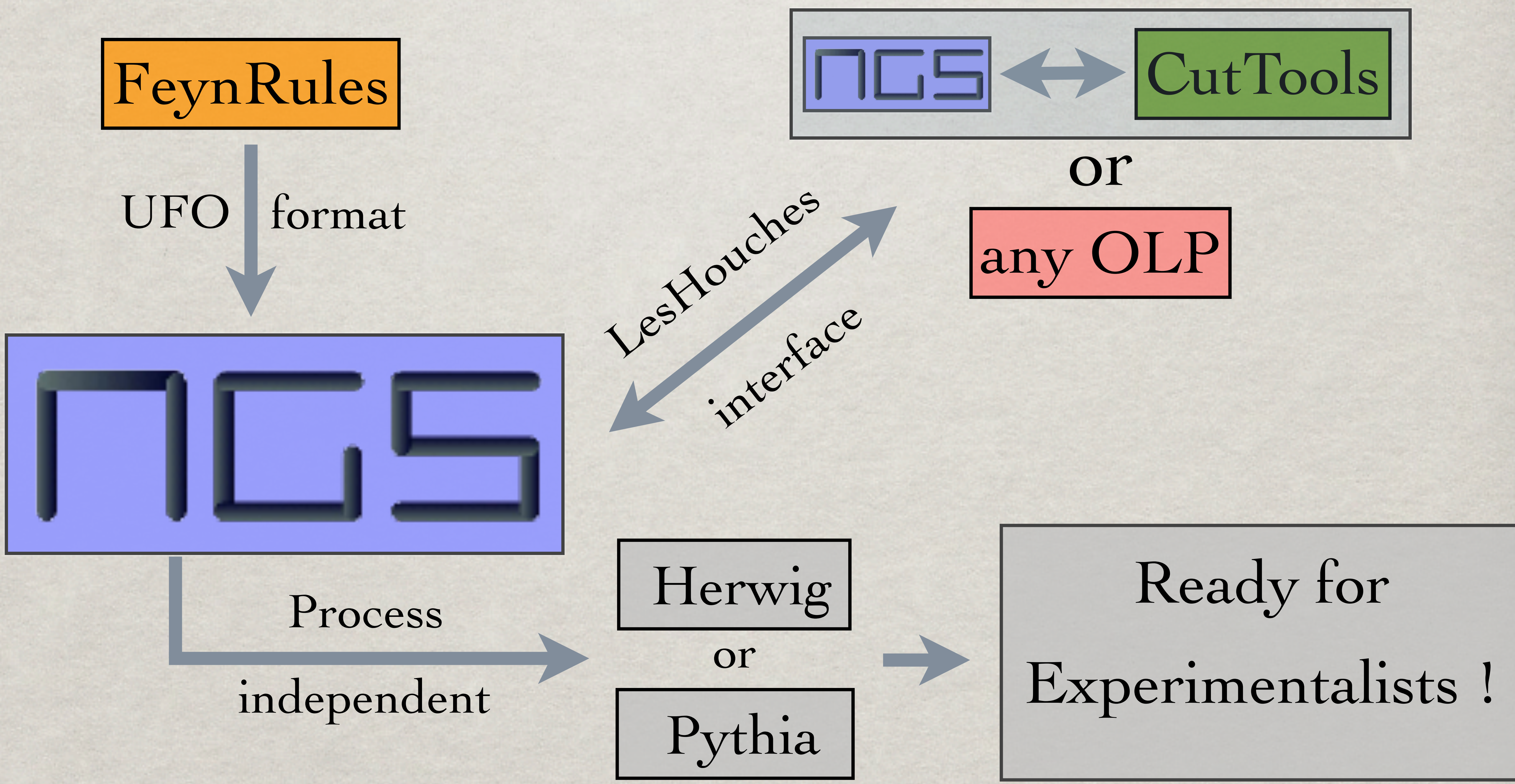
architecture: MG V4



aMC@NLO

FULL AUTOMATION

architecture: MG V5



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	✓	✓ *almost*
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	✕	✕

NEXT ON PIPE-LINE

- Finish the full SM implementation for QCD corrections
- Complex mass scheme for finite-width effects
- Handle unstable PS points finite with quadrupole precision
- Implement output for loop-induced processes
- Polish event-generation along with MadFKS5
- Automatic Loop UFO Model generation with FeynRules
- Decay chains specifications
- Case-study SUSY ? (If not already irrelevant by then)

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	✕	soon	✕	soon	✕

[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 = ♦
MadLoop4 = ♦

- 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.

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 *almost* 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 validated aMC@NLO code for specific proc. (soon)
  - On-line running of MadLoop4 for a single phase-space point check.

Thanks