MadGraph & aMC@NLO

Olivier Mattelaer
UCL

MG5: J. Alwall, M. Herquet, F. Maltoni, OM, T. Stelzer
UFO: C. Degrande, C.Duhr, B. Fuks, OM,
D. Grellscheid, T.Reiter
ALOHA: P. Aquino,W. Link, F.Maltoni, OM, T.Stelzer
MadSpin: P. Artoisenet, R. Frederix, OM, R. Rietkerk
aMC@NLO: http://amcatnlo.web.cern.ch/amcatnlo/people.htm

From Theory to Detector

Lagrangian

Detector events

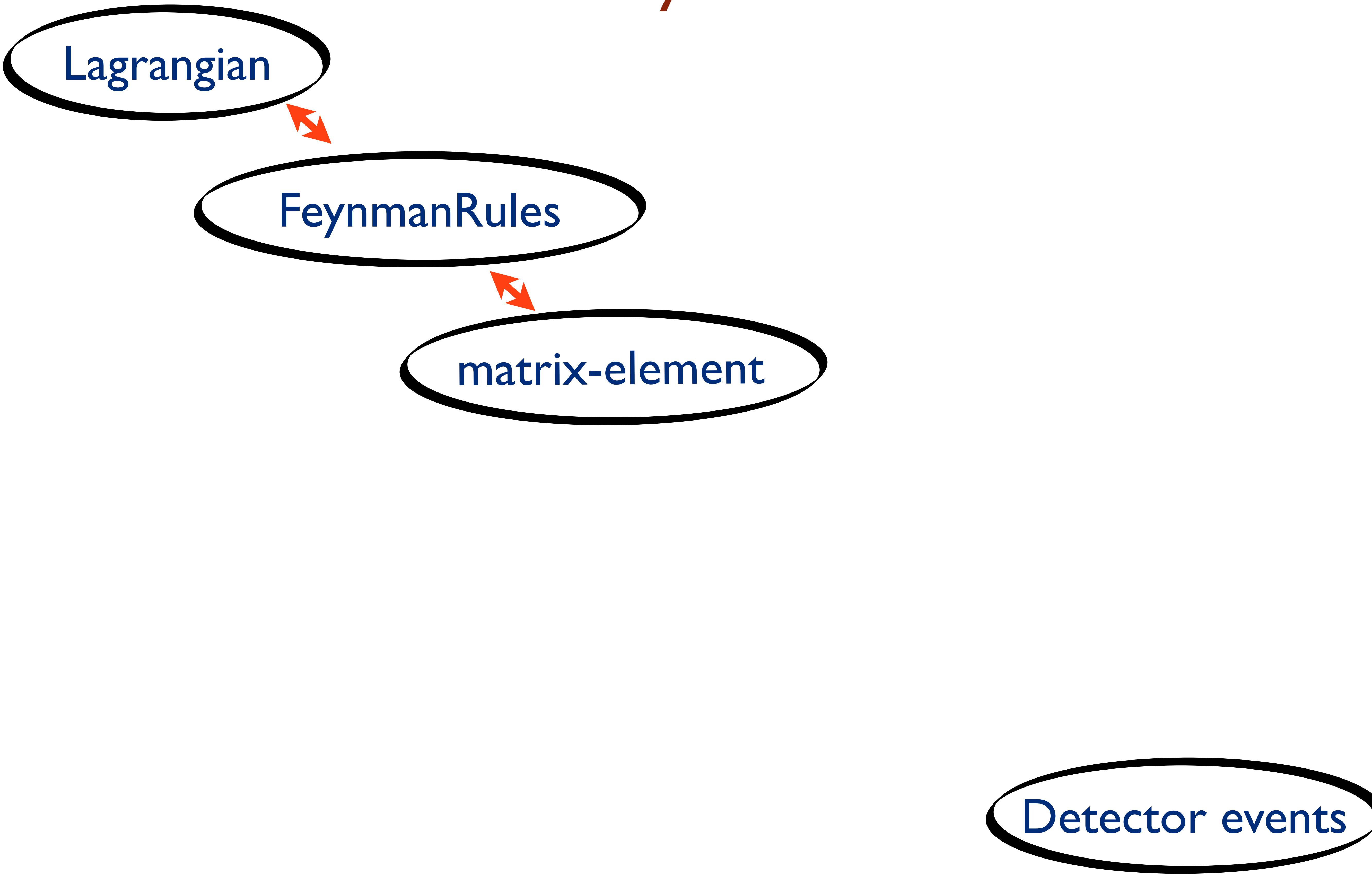
From Theory to Detector

Lagrangian

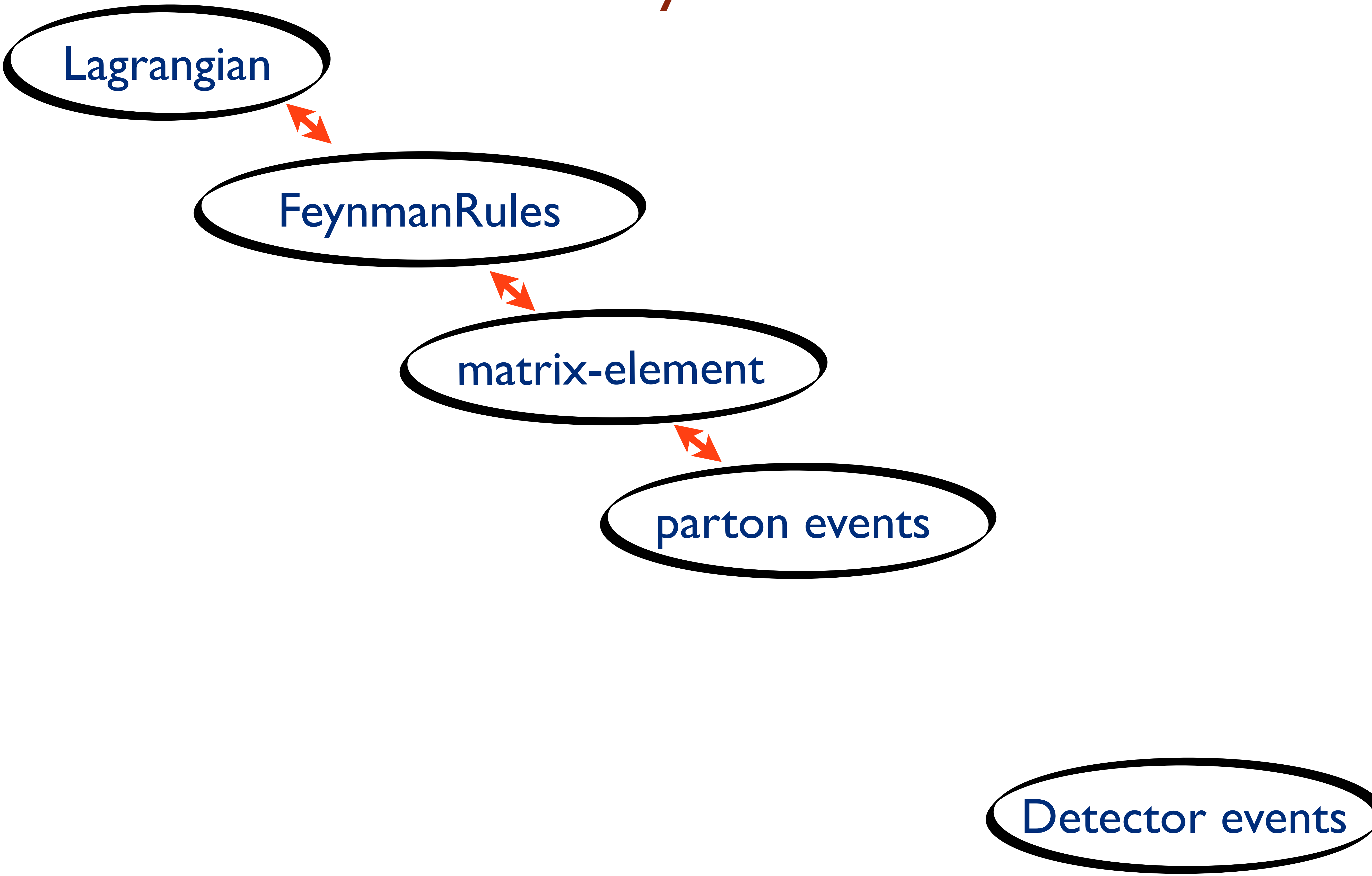
FeynmanRules

Detector events

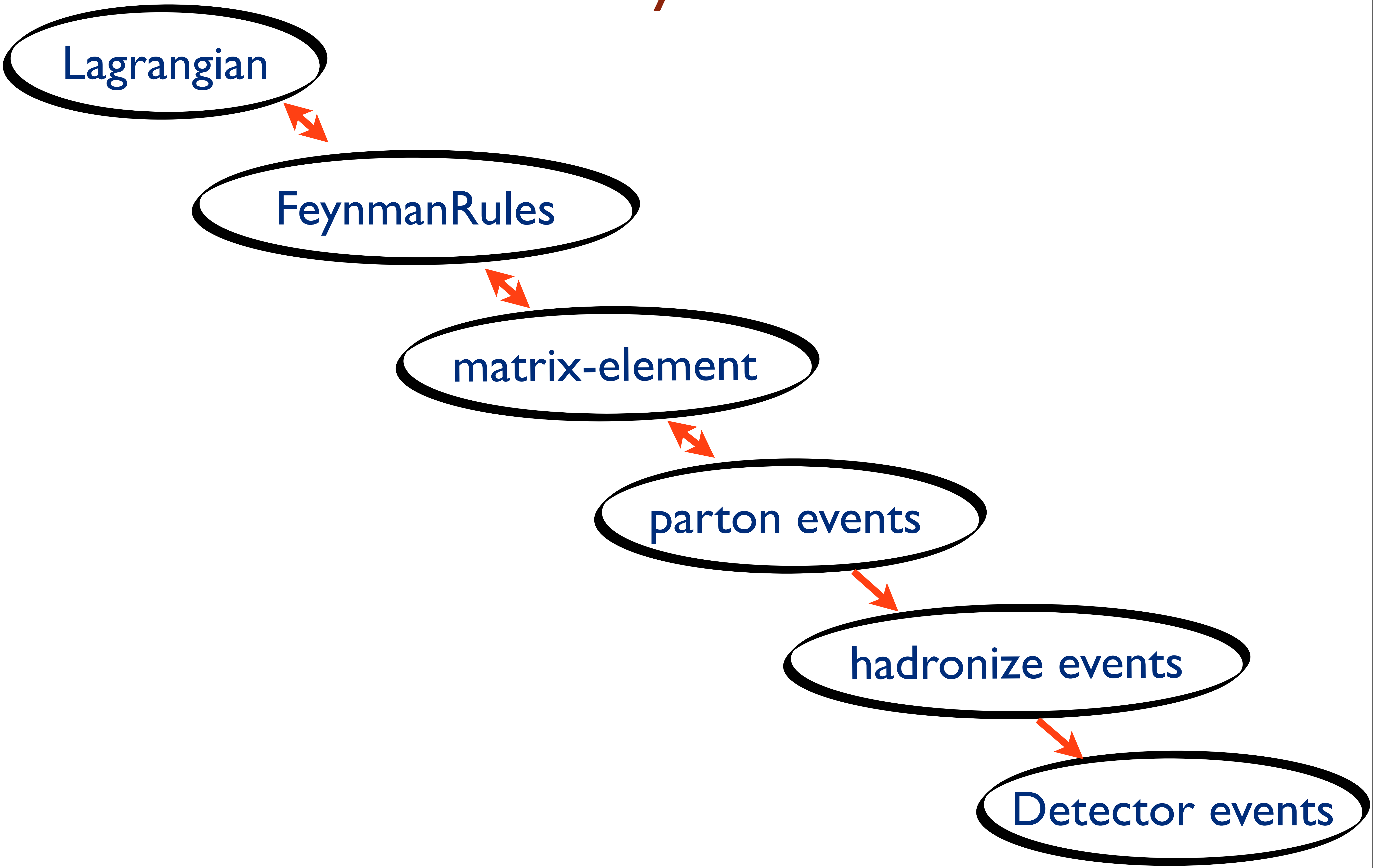
From Theory to Detector



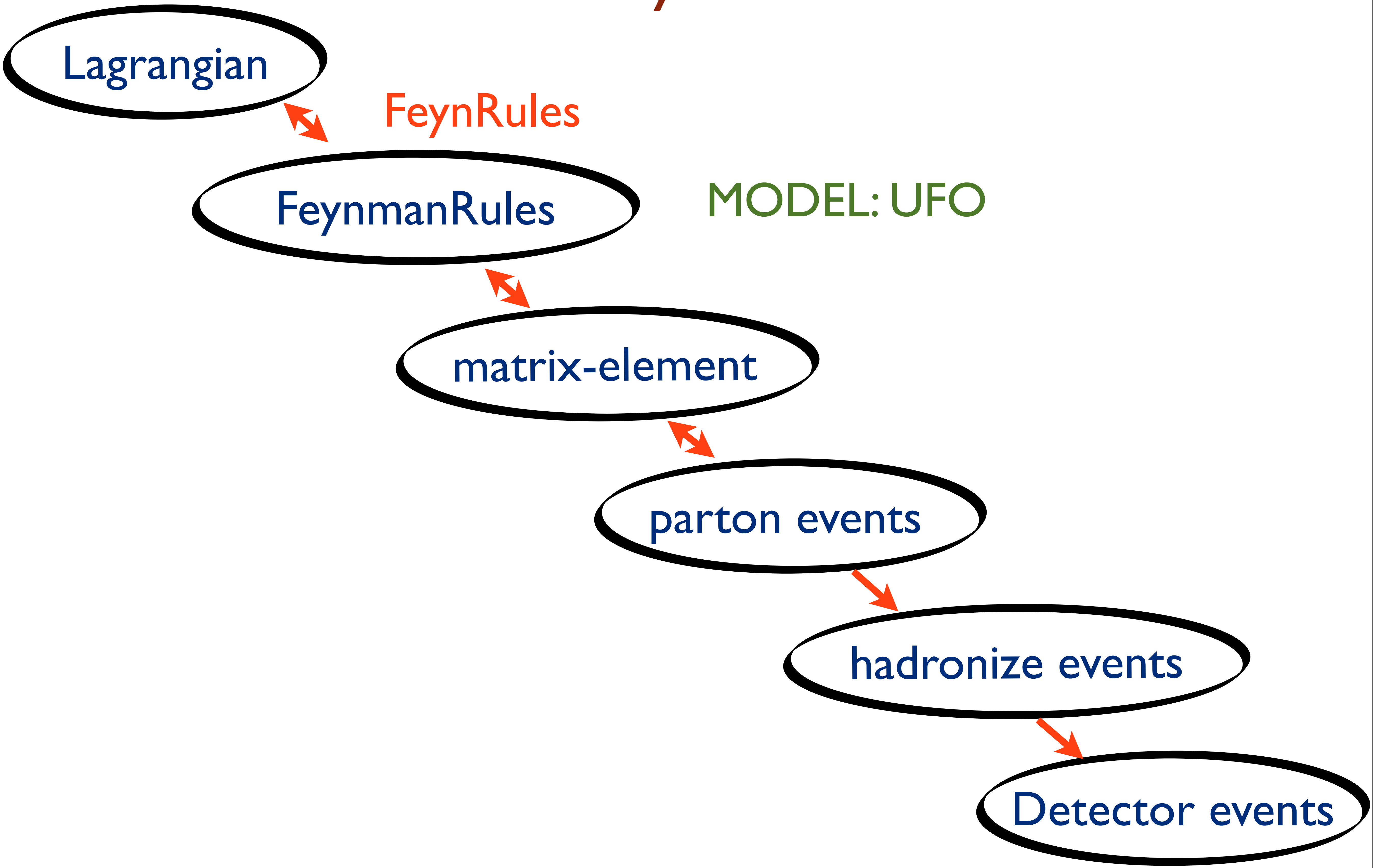
From Theory to Detector



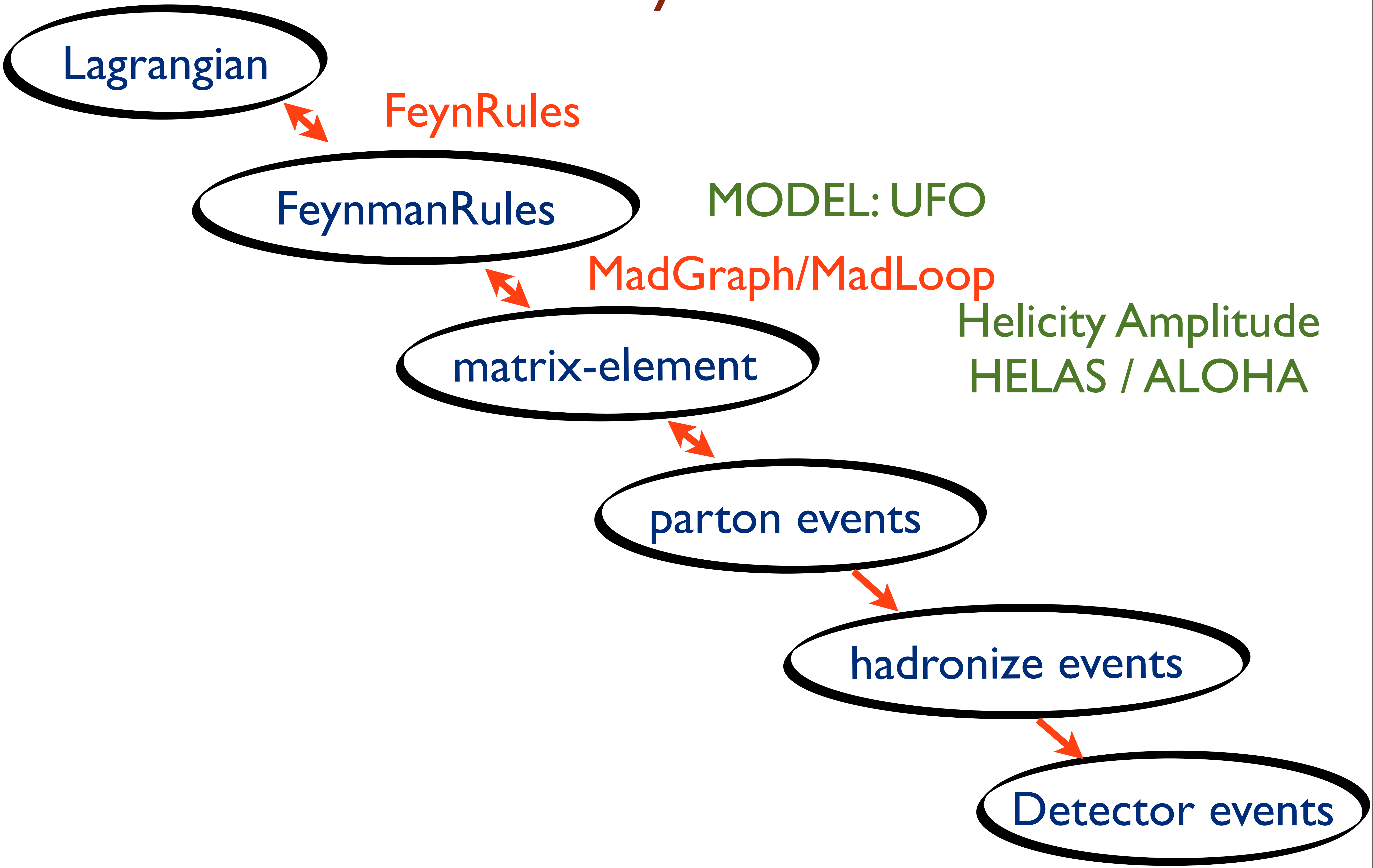
From Theory to Detector



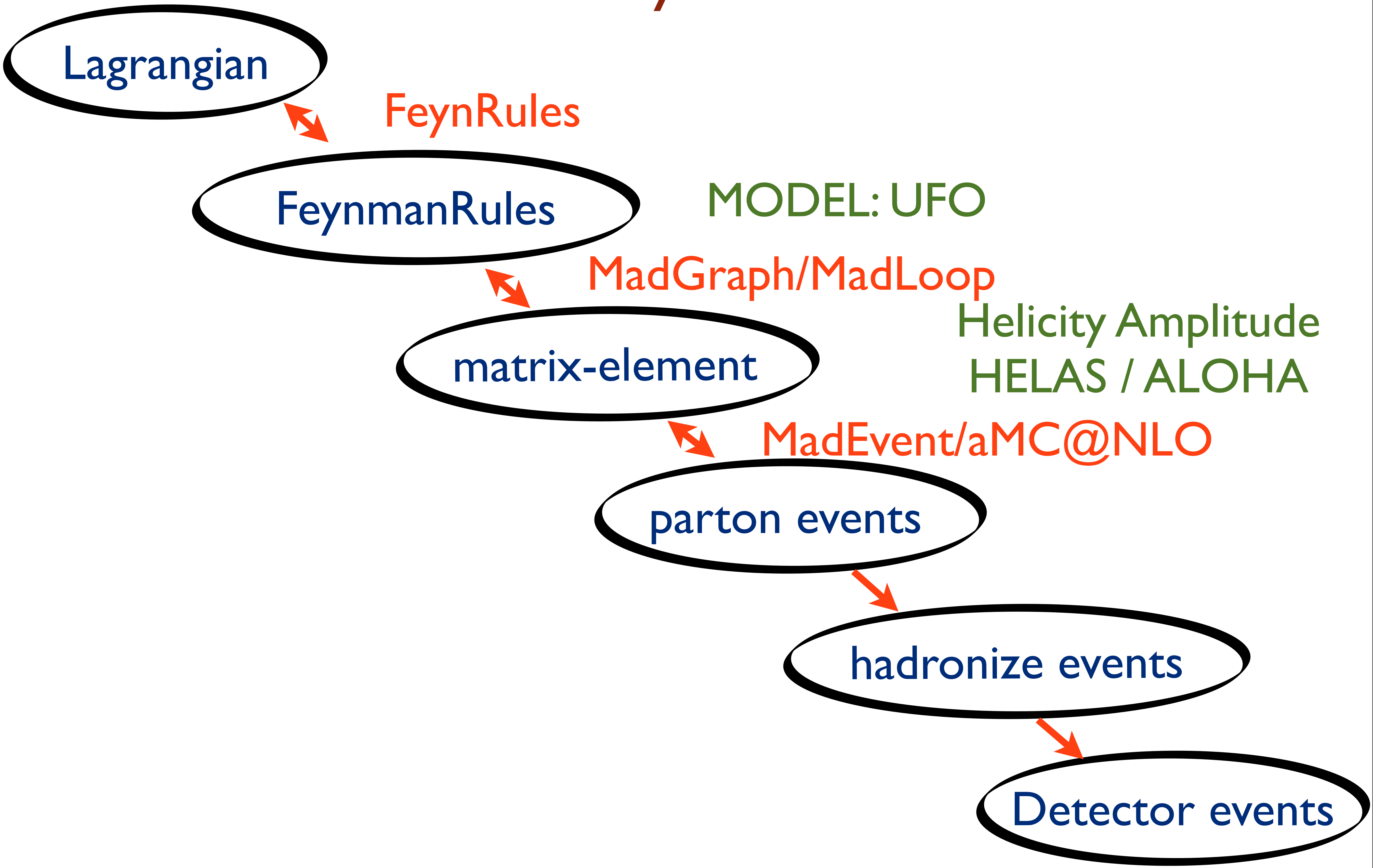
From Theory to Detector



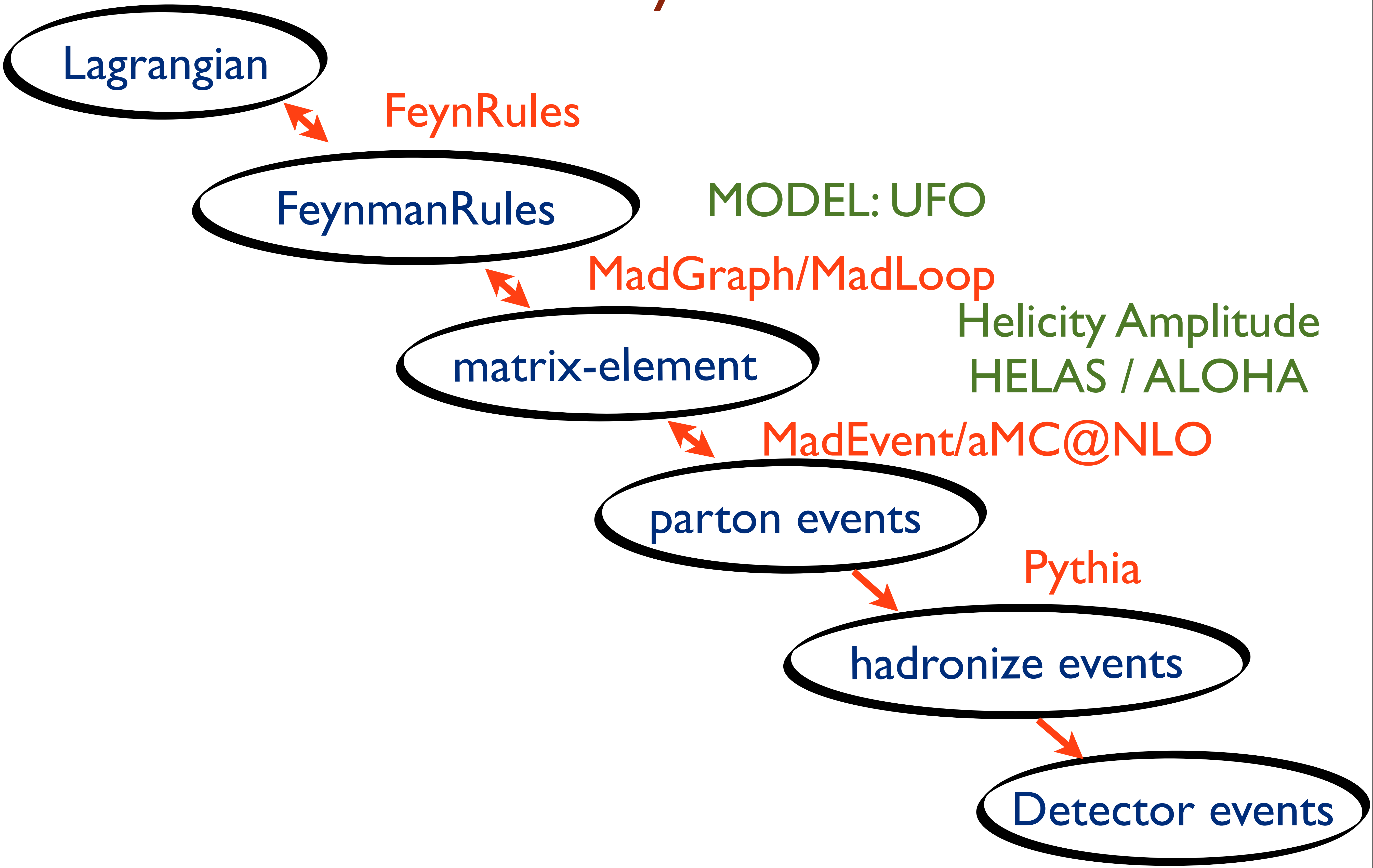
From Theory to Detector



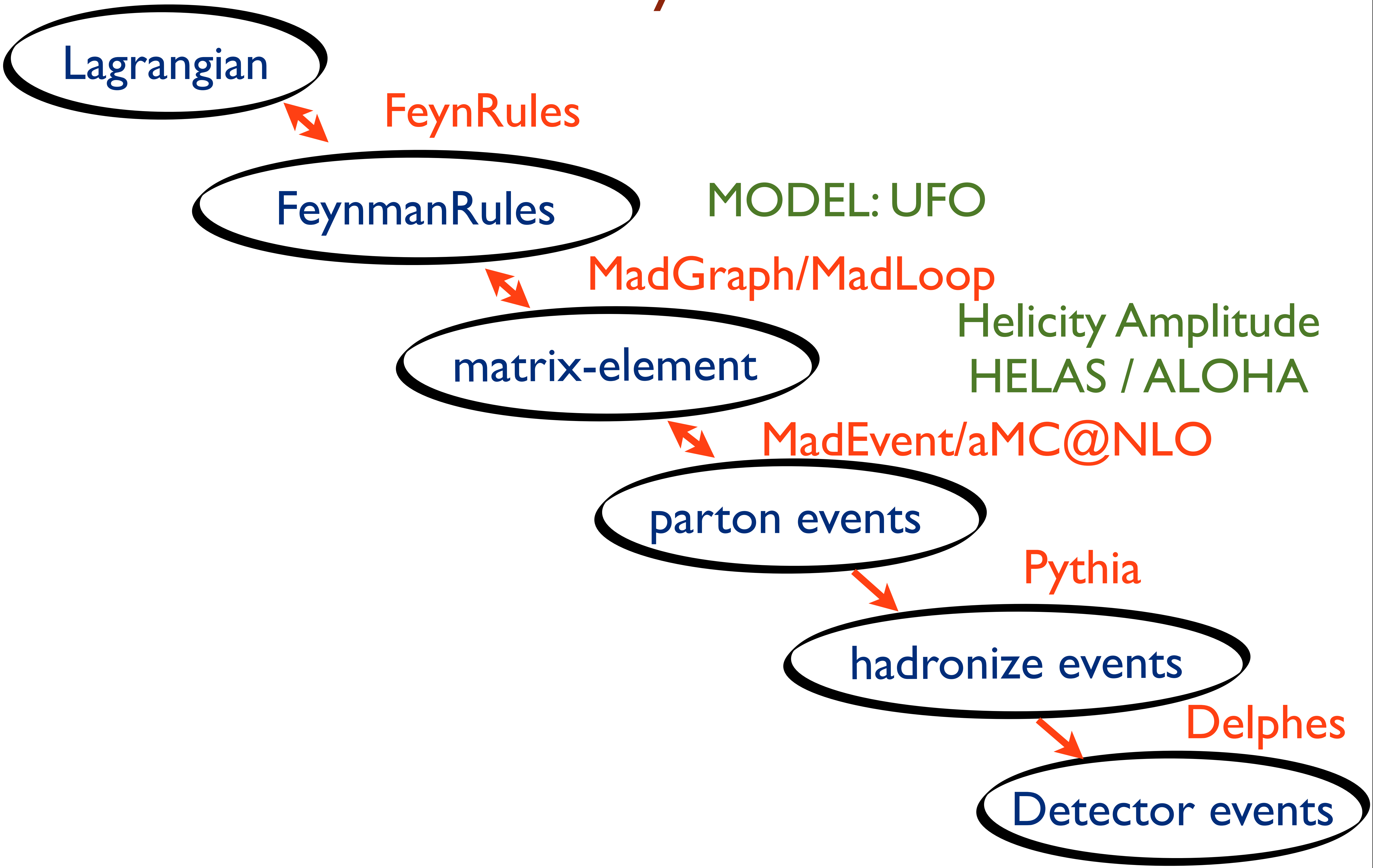
From Theory to Detector



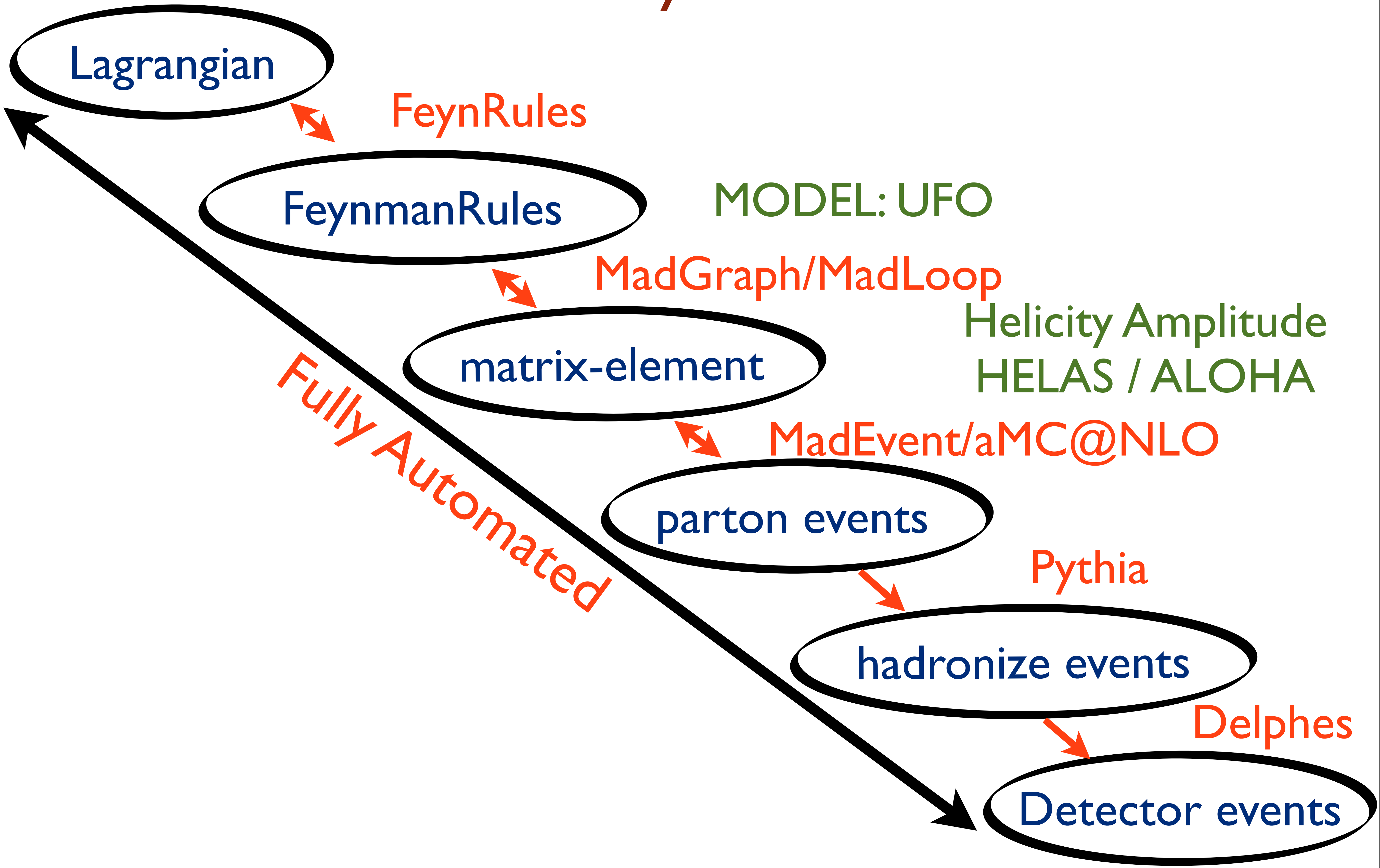
From Theory to Detector



From Theory to Detector

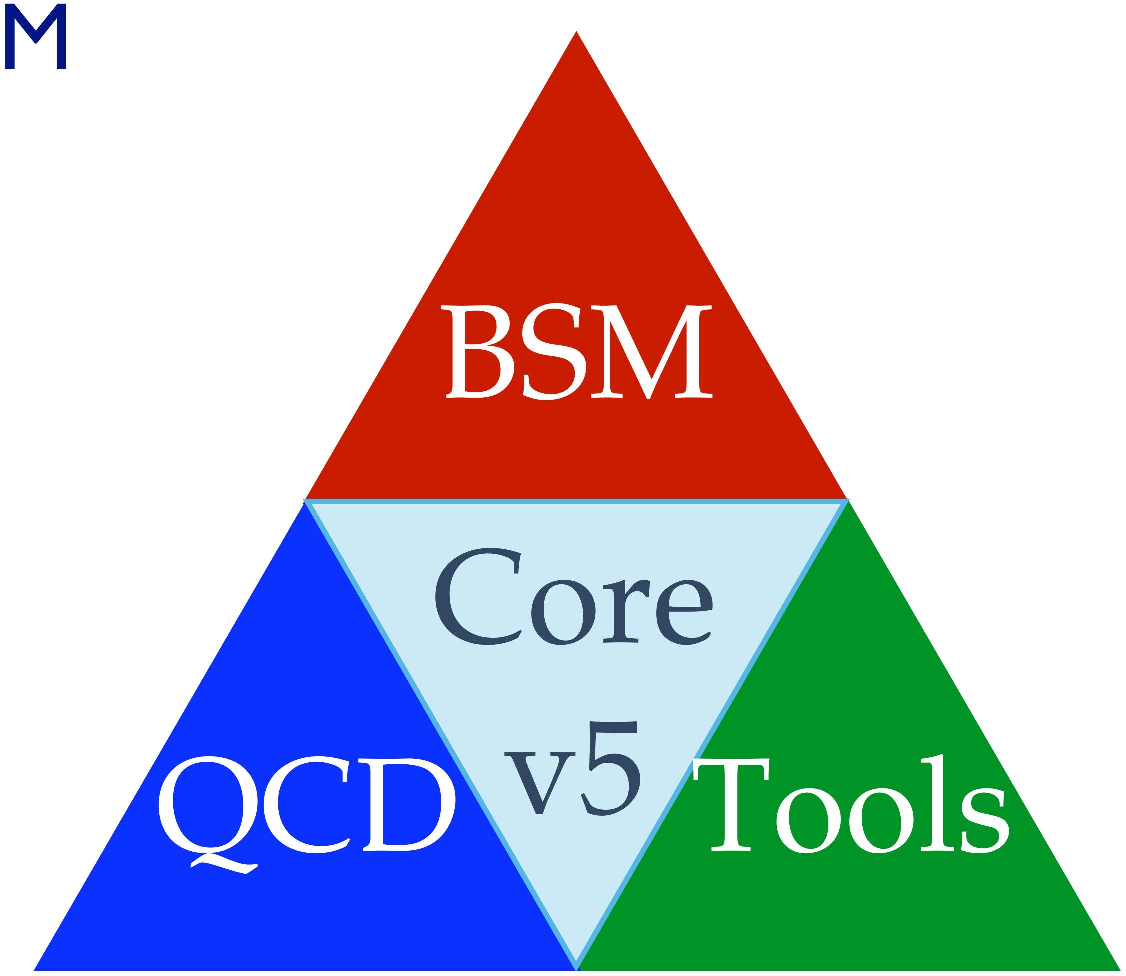


From Theory to Detector



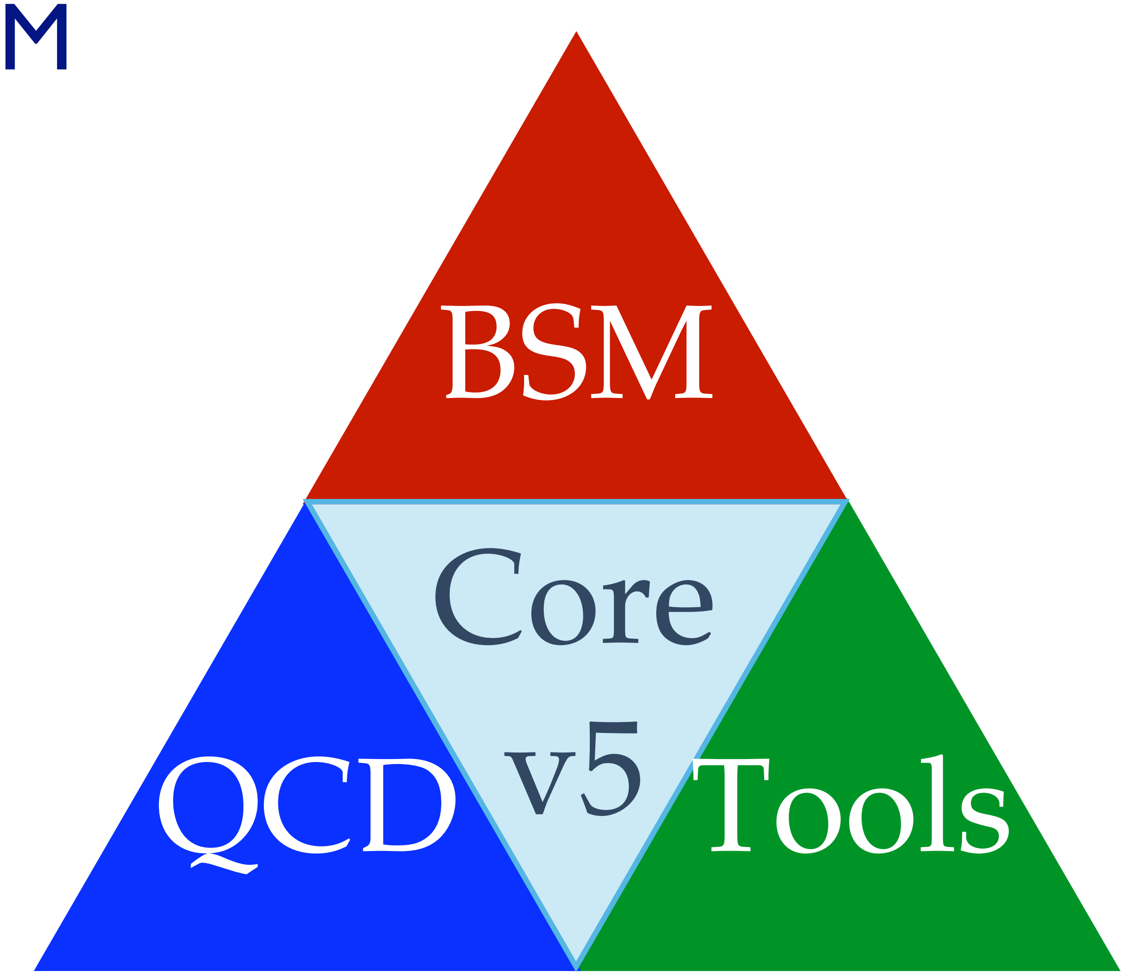
Plan

- BSM implementation: UFO and ALOHA
- MadGraph5 tools for BSM
  - ➡ MadSpin
  - ➡ re-weighting
- aMC@NLO



Plan

- BSM implementation: UFO and ALOHA
- MadGraph5 tools for BSM
  - ➡ MadSpin
  - ➡ re-weighting
- aMC@NLO



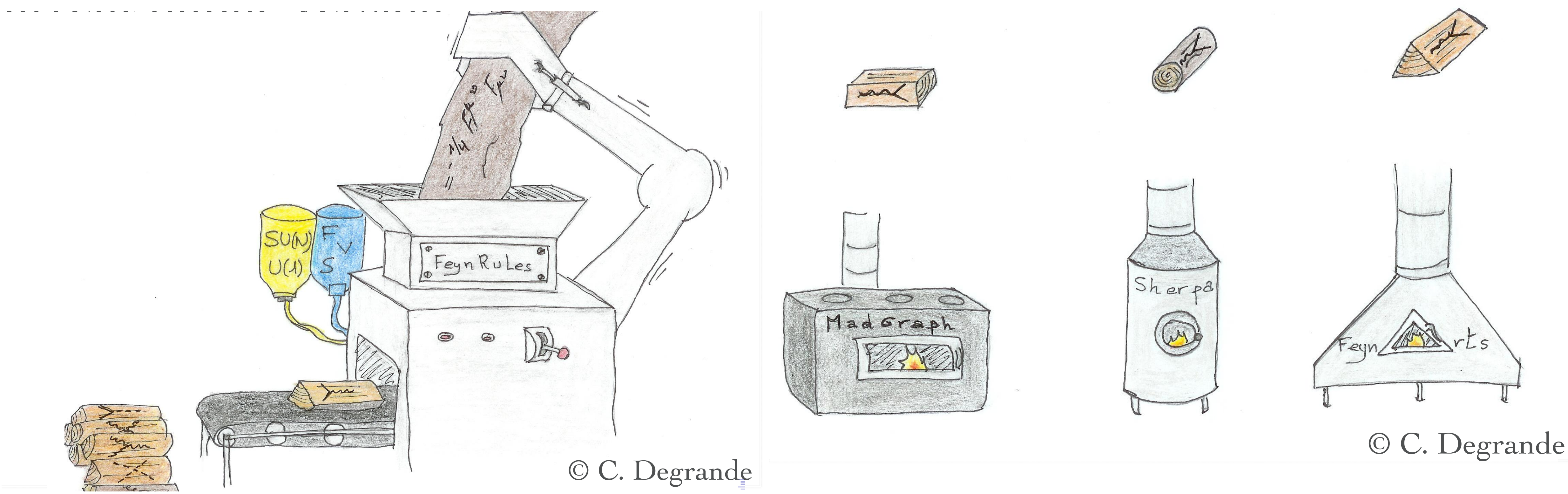
UFO: Motivations

UFO: Motivations

- Avoid multiple output model written by FR.

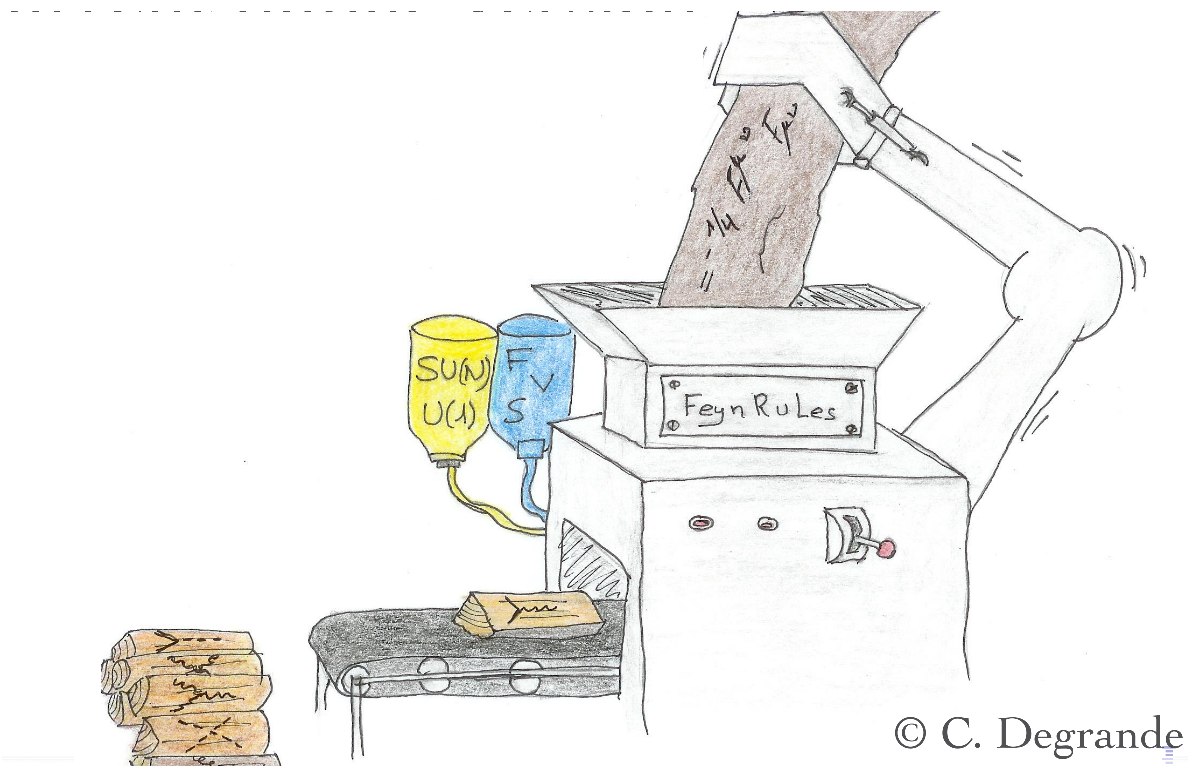
UFO: Motivations

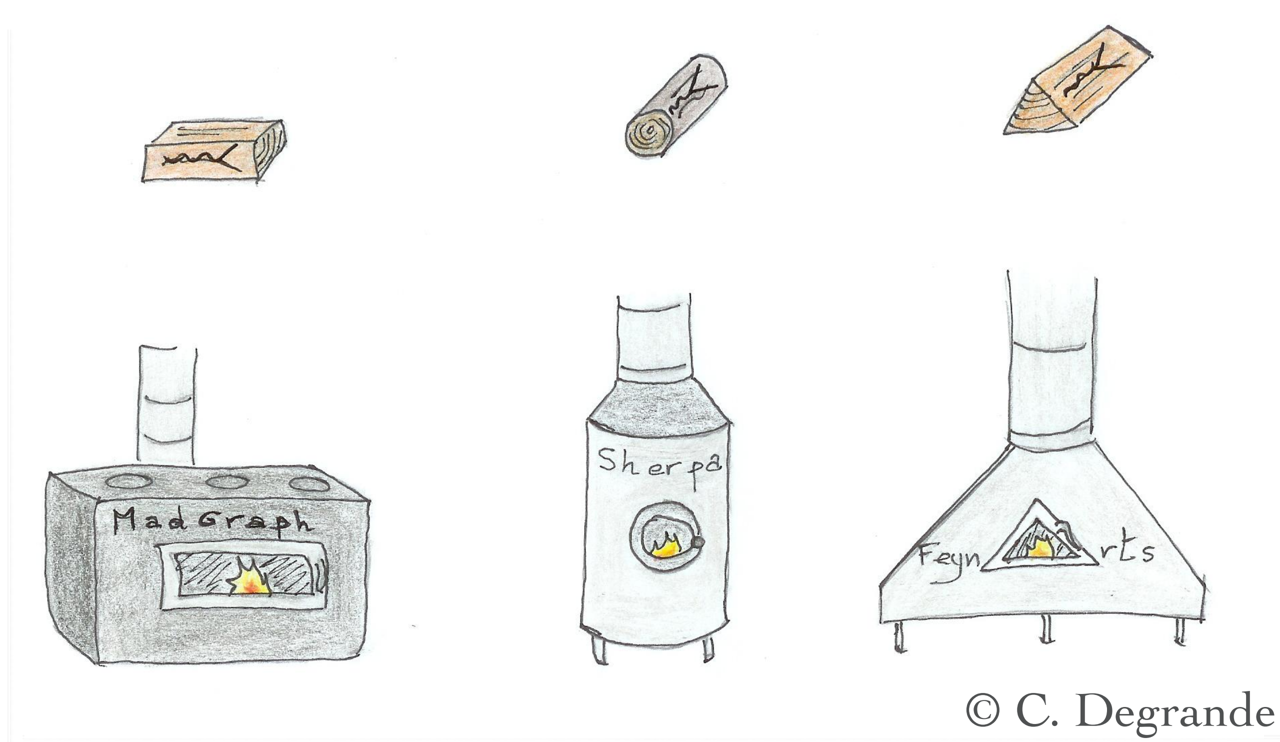
- Avoid multiple output model written by FR.



UFO: Motivations

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





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

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++

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++
- NEW:
  - ➡ Possibility to define custom propagators
  - ➡ Possibility to add form factors (beta)

Universal FeynRules Output (UFO)

particles.py:

```
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:

```
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:

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

vertices.py:

```
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})
```

Universal FeynRules Output (UFO)

particles.py:

```
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:

```
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:

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

vertices.py:

```
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})
```

Lorentz structure

- Idea: Evaluate $\mathcal{M}$ for fixed helicity of external particles.
  - Need HELAS routine (helicity amplitude routine)

Lorentz structure

- Idea: Evaluate $\mathcal{M}$ for fixed helicity of external particles.
  - Need HELAS routine (helicity amplitude routine)

Advantages

- speed

Limitations

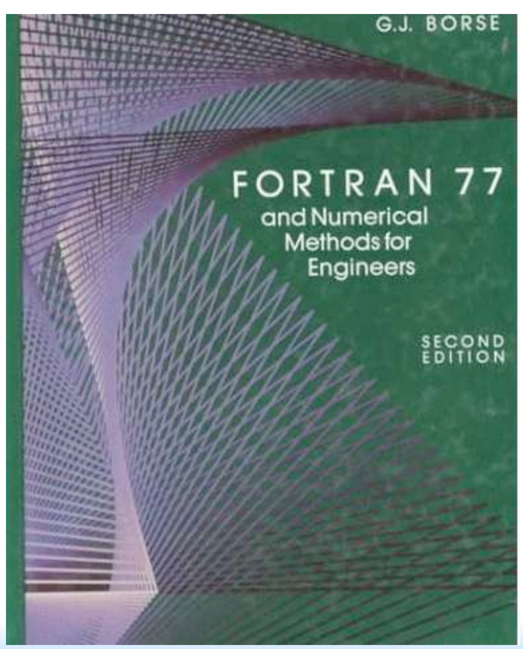
- One routine by Lorentz structure
  - ➡ MSSM [cho, al] hep-ph/0601063 (2006)
  - ➡ HEFT [Frederix] (2007)
  - ➡ Spin 2 [Hagiwara, al] 0805.2554 (2008)
  - ➡ Spin 3/2 [Mawatari, al] 1101.1289 (2011)

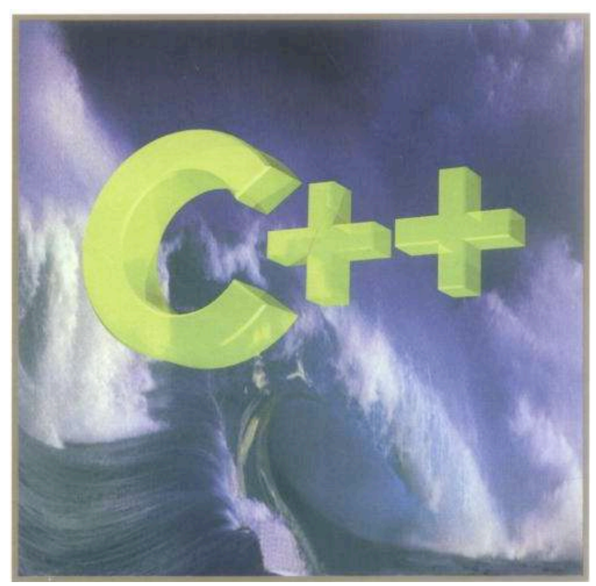
ALOHA

ALOHA
~~Google~~ translate

From: UFO ▾ To: Helicity [Translate]

Type text or a website address or translate a document.





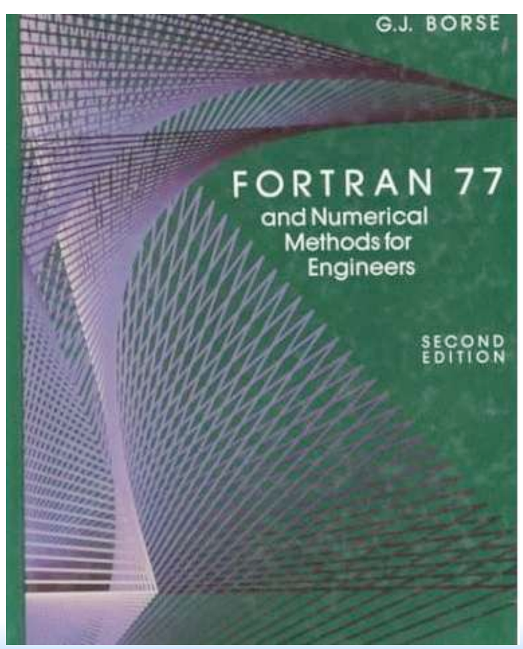
ALOHA

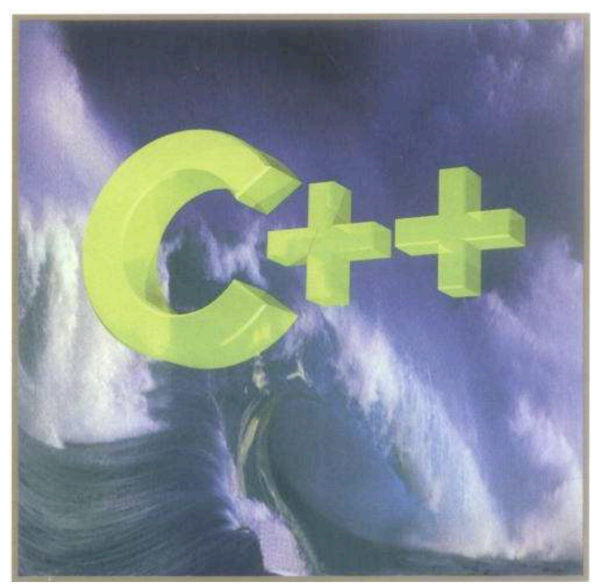
ALOHA ~~Google~~ translate

From: UFO ▾ To: Helicity Translate

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

Type text or a website address or translate a document.





Thanks to UFO/ALOHA

Any BSM should be possible in a fully automatic and efficient way in MG5!

Some restriction applies:

- Only local theory
- Theory should respect CPT and lorentz invariance (all indices should be contracted)
- Color supported up to dimension 8 (including sextet and epsilon structure)
- Spin supported up to spin 2 (including spin3/2)
- No four fermion interaction with fermion-flow violation / majorana in the same model

MODEL

- aTGC + aQGC (Dim6)
  - ➡ by default in MG5 (EWdim6)
  - ➡ 5 Operators

$$\mathcal{O}_{WWW} = \mathrm{Tr}[W_{\mu\nu}W^{\nu\rho}W_\rho^\mu]$$
$$\mathcal{O}_W = (D_\mu\Phi)^\dagger W^{\mu\nu}(D_\nu\Phi)$$
$$\mathcal{O}_B = (D_\mu\Phi)^\dagger B^{\mu\nu}(D_\nu\Phi)$$
$$\mathcal{O}_{\tilde{W}WW} = \mathrm{Tr}[\tilde{W}_{\mu\nu}W^{\nu\rho}W_\rho^\mu]$$
$$\mathcal{O}_{\tilde{W}} = (D_\mu\Phi)^\dagger \tilde{W}^{\mu\nu}(D_\nu\Phi)$$

[C. Degrande et al 1205.4231]

- nTGC (Dim8)
  - ➡ triple for neutral
  - ➡ 4 Operators
  - ➡ to download via FR website

$$\mathcal{O}_{BW} = i H^\dagger B_{\mu\nu} W^{\mu\rho}\{D_\rho, D^\nu\} H,$$
$$\mathcal{O}_{WW} = i H^\dagger W_{\mu\nu} W^{\mu\rho}\{D_\rho, D^\nu\} H,$$
$$\mathcal{O}_{BB} = i H^\dagger B_{\mu\nu} B^{\mu\rho}\{D_\rho, D^\nu\} H.$$
$$\mathcal{O}_{\tilde{B}B} = i H^\dagger \tilde{B}_{\mu\nu} B^{\mu\rho}\{D_\rho, D^\nu\} H.$$

[C. Degrande 1308.6323]

- aQGC (Dim8)
  - ➡ 18 operators
  - ➡ to download via FR website

$$\mathcal{L}_{T,0} = \mathrm{Tr}\left[\hat{W}_{\mu\nu}\hat{W}^{\mu\nu}\right] \times \mathrm{Tr}\left[\hat{W}_{\alpha\beta}\hat{W}^{\alpha\beta}\right]$$
$$\mathcal{L}_{T,1} = \mathrm{Tr}\left[\hat{W}_{\alpha\nu}\hat{W}^{\mu\beta}\right] \times \mathrm{Tr}\left[\hat{W}_{\mu\beta}\hat{W}^{\alpha\nu}\right]$$
$$\mathcal{L}_{T,2} = \mathrm{Tr}\left[\hat{W}_{\alpha\mu}\hat{W}^{\mu\beta}\right] \times \mathrm{Tr}\left[\hat{W}_{\beta\nu}\hat{W}^{\nu\alpha}\right]$$
$$\mathcal{L}_{T,5} = \mathrm{Tr}\left[\hat{W}_{\mu\nu}\hat{W}^{\mu\nu}\right] \times B_{\alpha\beta}B^{\alpha\beta}$$
$$\mathcal{L}_{T,6} = \mathrm{Tr}\left[\hat{W}_{\alpha\nu}\hat{W}^{\mu\beta}\right] \times B_{\mu\beta}B^{\alpha\nu}$$
$$\mathcal{L}_{T,7} = \mathrm{Tr}\left[\hat{W}_{\alpha\mu}\hat{W}^{\mu\beta}\right] \times B_{\beta\nu}B^{\nu\alpha}$$
$$\mathcal{L}_{T,8} = B_{\mu\nu}B^{\mu\nu}B_{\alpha\beta}B^{\alpha\beta}$$
$$\mathcal{L}_{T,9} = B_{\alpha\mu}B^{\mu\beta}B_{\beta\nu}B^{\nu\alpha}$$

[O.J.P. Eboli, M.C. Gonzalez-Garcia, J.K. Mizukoshi hep-ph/0606118]

Plan

- BSM implementation: UFO and ALOHA
- MadGraph5 tools for BSM
  - ➡ MadSpin
  - ➡ re-weighting
- aMC@NLO

MadSpin

- WISH-LIST:
  - ➡ For a sample of events include the decay of unstable final states particles.
  - ➡ Keep full spin correlations and finite width effect
  - ➡ Keep unweighted events

MadSpin

- WISH-LIST:
  - ➡ For a sample of events include the decay of unstable final states particles.
  - ➡ Keep full spin correlations and finite width effect
  - ➡ Keep unweighted events
- Solution:

[Frixione, Leanen, Motylinski, Webber (2007)]

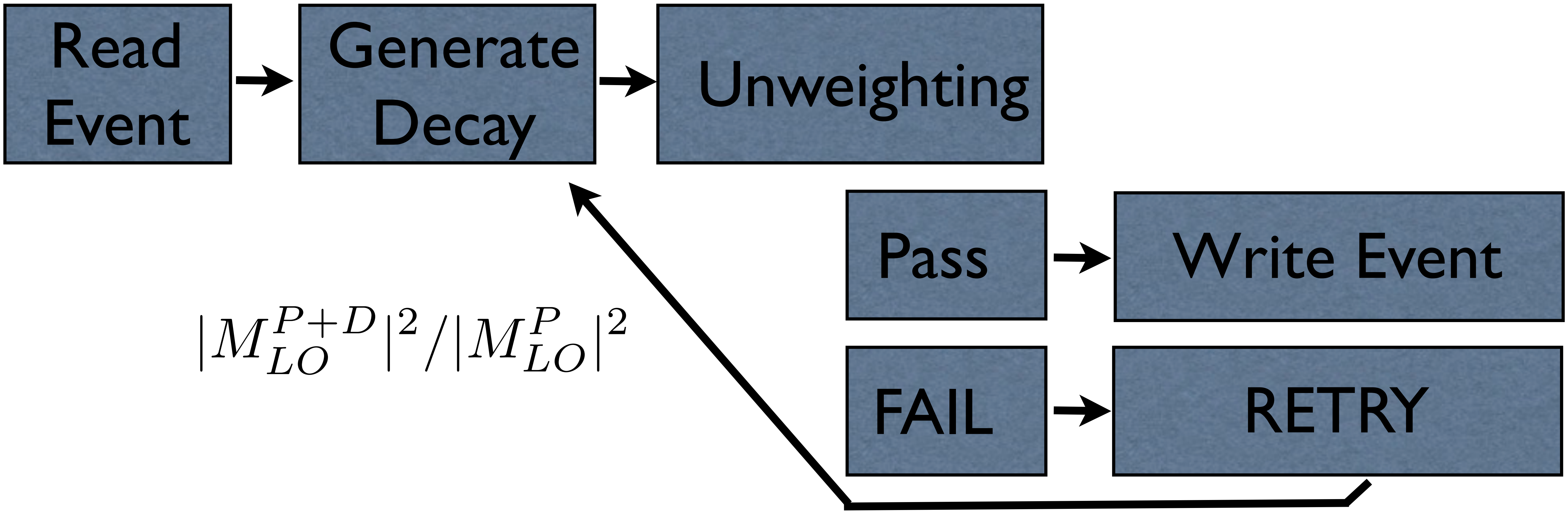
Read Event → Generate Decay → Unweighting

$$|M_{LO}^{P+D}|^2/|M_{LO}^{P}|^2$$

MadSpin

- WISH-LIST:
  - ➡ For a sample of events include the decay of unstable final states particles.
  - ➡ Keep full spin correlations and finite width effect
  - ➡ Keep unweighted events
- Solution:

[Frixione, Leanen, Motylinski, Webber (2007)]



$$|M_{LO}^{P+D}|^2/|M_{LO}^{P}|^2$$

MadSpin

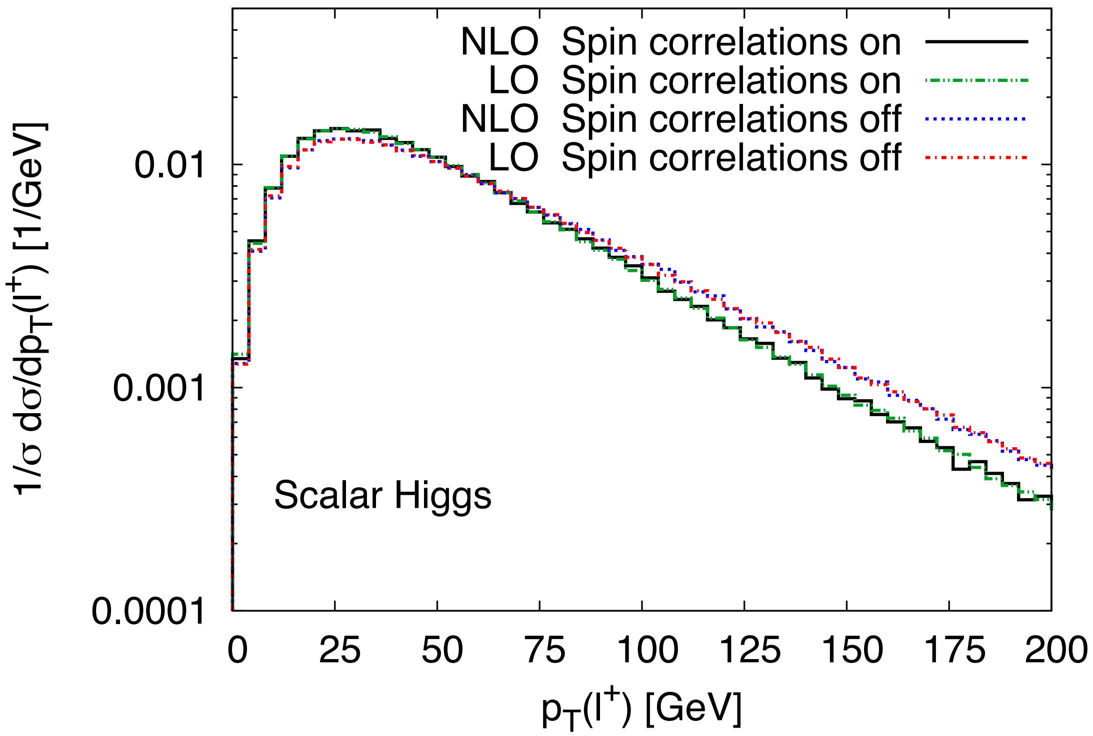
- Fully automatic
  - ➡ Fully integrated in MG5 [LO and NLO]
  - ➡ Can be run on the flight or in StandAlone

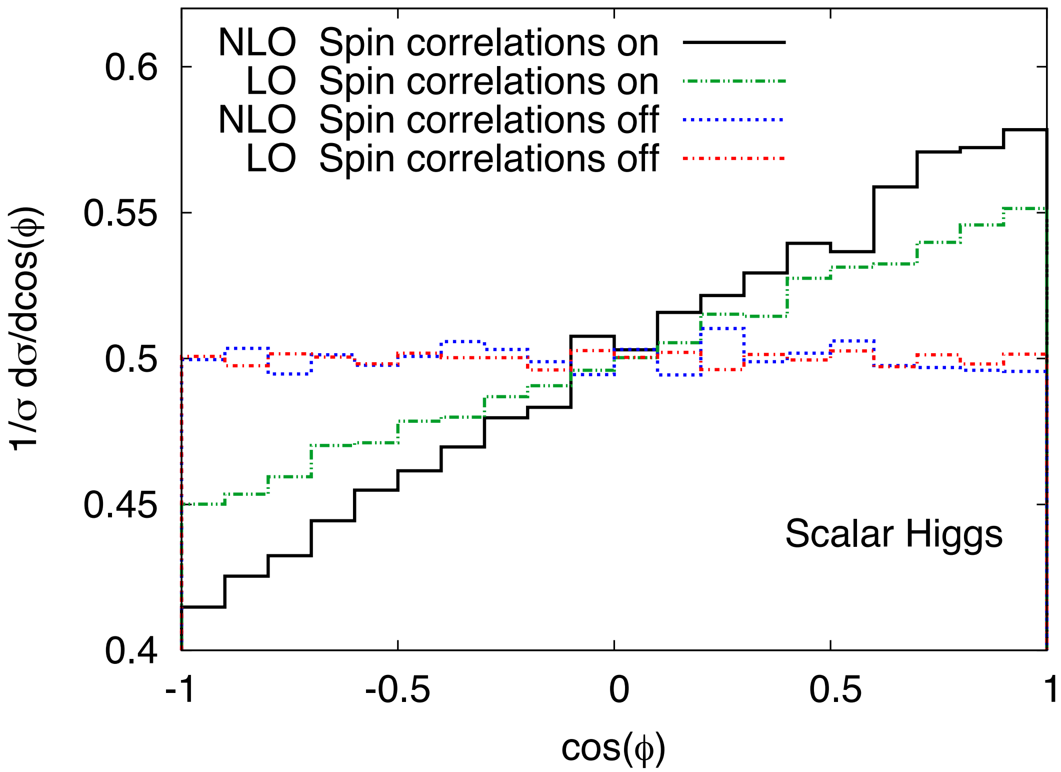
MadSpin

- Fully automatic
  - ➡ Fully integrated in MG5 [LO and NLO]
  - ➡ Can be run on the flight or in StandAlone
- we are going to release a speed up version (15x faster)

MadSpin

- Fully automatic
  - ➡ Fully integrated in MG5 [LO and NLO]
  - ➡ Can be run on the flight or in StandAlone
- we are going to release a speed up version (15x faster)
- Example t t~ h (first time done!):





Wednesday, October 2, 13

reweighting

- Idea: use one (un)weighted generations and associate additional weights from different hypothesis.

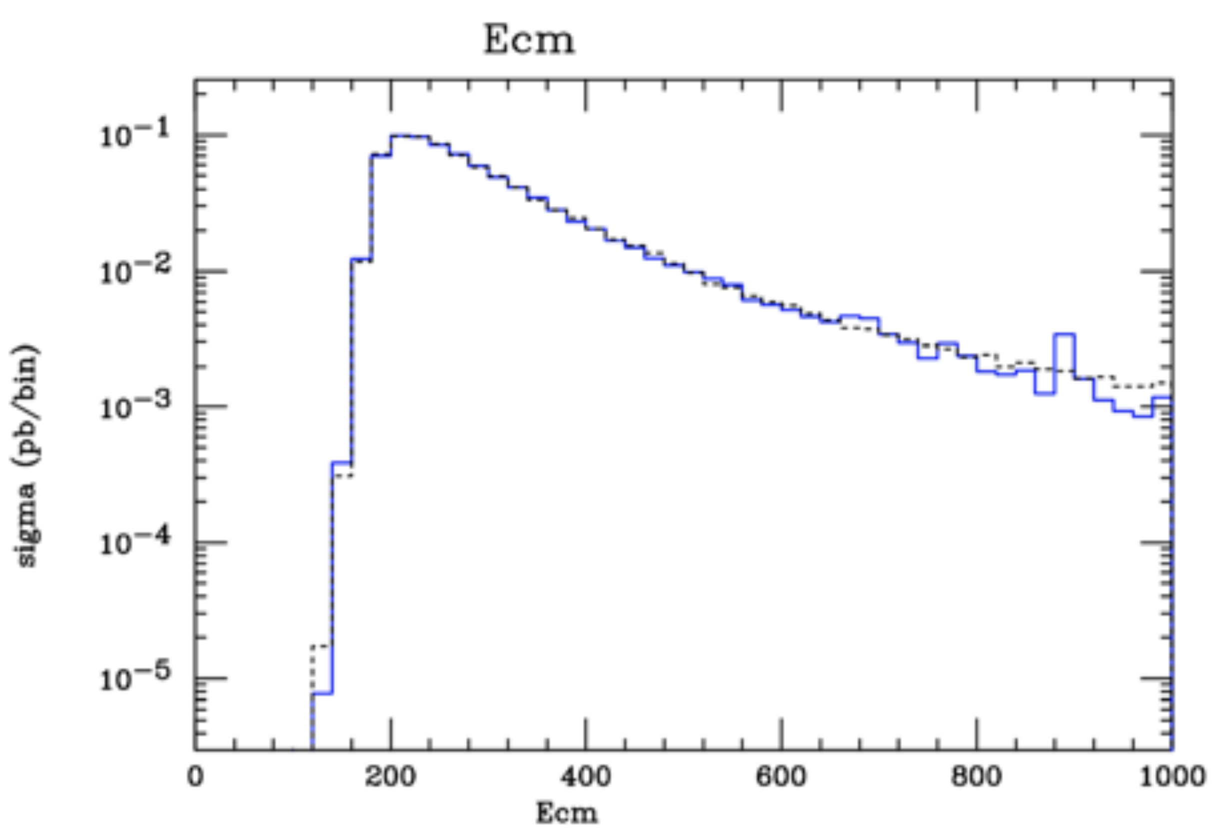
$$W_{new} = \frac{|M_{new}|^2}{|M_{old}|^2} * W_{old}$$

- Can be run on the flight inside MG5
- Simple input (reweight_card.dat):

```
launch
   set Dim6 1 10
   set Dim6 2 0
   set Dim6 3 0
launch
   set Dim6 1 0
   set Dim6 2 10
   set Dim6 3 0
```

⟶ 2 weights in the event file

```
<event>
 8      0 +7.9887000e-06 1.24664300e+02 7.95774700e-02 1.23856500e-01
        1 -1    0    0  501    0 +0.0000000e+00 +0.0000000e+00 +1.3023196e+03 1.30231957e+03
       -2 -1    0    0    0  501 +0.0000000e+00 +0.0000000e+00 -1.4499581e+02 1.44995814e+02
      -24  2    1    2    0    0 -1.2793809e+01 -8.3954553e+01 -1.1792566e+02 1.65987064e+02
       23  2    1    2    0    0 +1.2793809e+01 +8.3954553e+01 +1.2752494e+03 1.28132832e+03
       11  1    3    3    0    0 -1.2462673e+01 +1.3647422e+01 -2.6083861e+01 3.19677669e+01
      -12  1    3    3    0    0 -3.3113586e-01 -9.7601975e+01 -9.1841804e+01 1.34019297e+02
        4  1    4    4  502    0 -1.8321803e+01 +9.0929609e+01 +9.3905973e+02 9.43629724e+02
       -4  1    4    4    0  502 +3.1115612e+01 -6.9750557e+00 +3.3618969e+02 3.37698598e+02
<rwgt>
<wgt id='mg_reweight_1'> 4.55278761371e-06 </wgt>
<wgt id='mg_reweight_2'> 2.65941887458e-06 </wgt>
</rwgt>
</event>
```

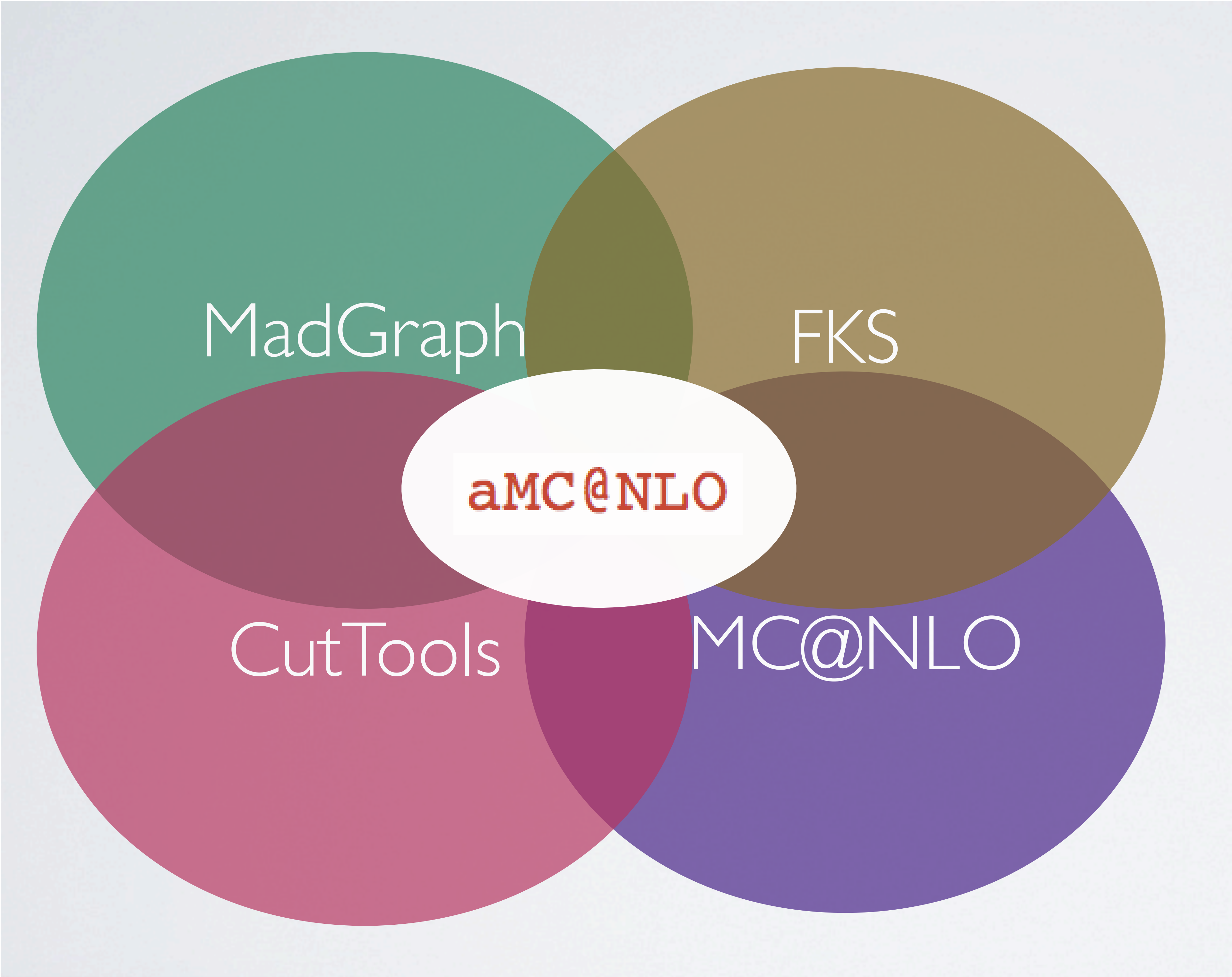


https://cp3.irmp.ucl.ac.be/projects/madgraph/wiki/Reweight

Plan

- BSM implementation: UFO and ALOHA
- MadGraph5 tools for BSM
  - ➡ Model customization
  - ➡ re-weighting
- aMC@NLO

aMC@NLO: A Joint Venture



aMC@NLO

aMC@NLO

- Why automation?
  - ➡ Time: Less tools, means more time for physics
  - ➡ Robust: Easier to test, to trust
  - ➡ Easy: One framework/tool to learn

aMC@NLO

- Why automation?
  - ➡ Time: Less tools, means more time for physics
  - ➡ Robust: Easier to test, to trust
  - ➡ Easy: One framework/tool to learn
- Why NLO?
  - ➡ Reliable prediction of the total rate
  - ➡ Reduction of the theoretical uncertainty

aMC@NLO

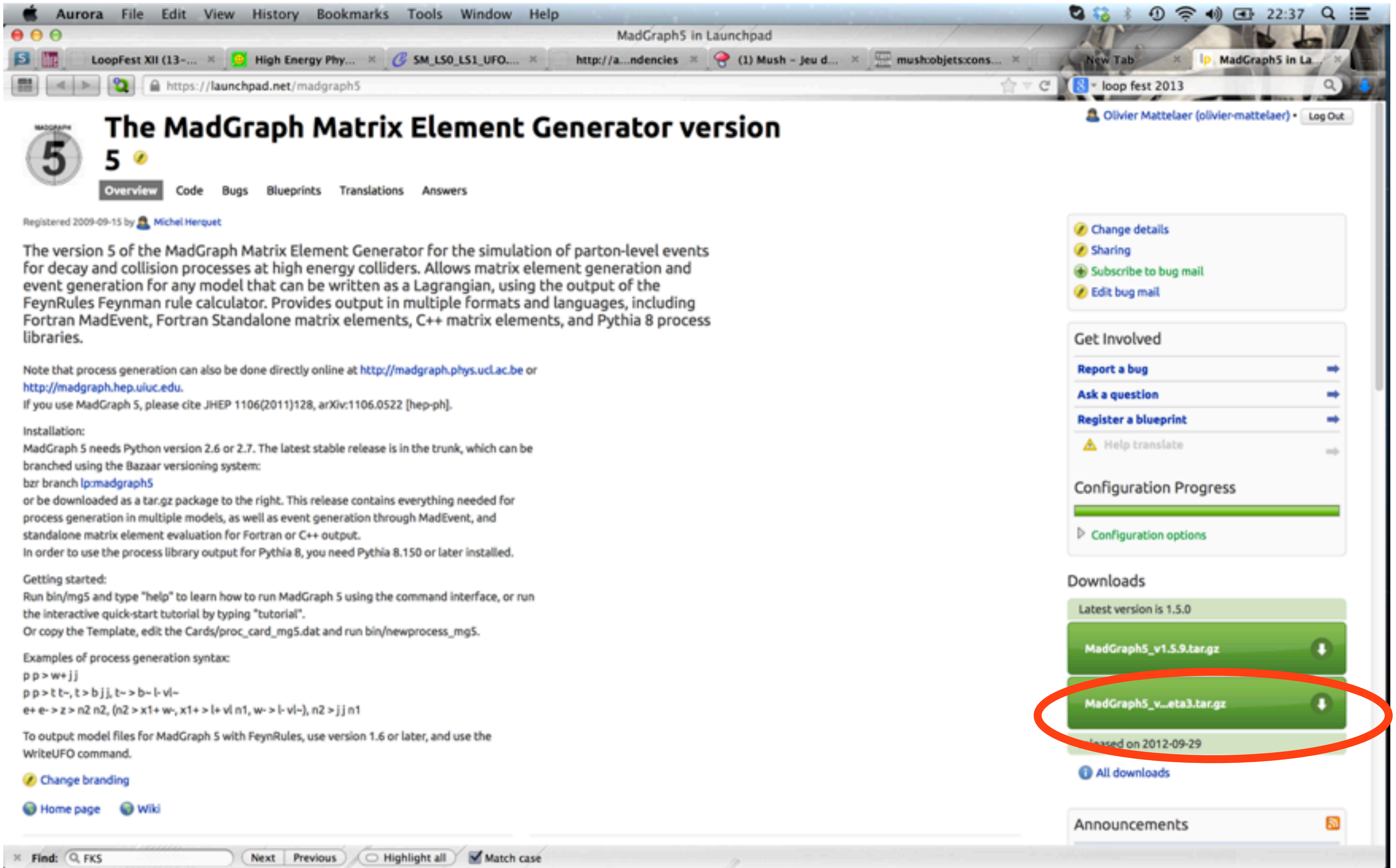
- Why automation?
  - ➡ Time: Less tools, means more time for physics
  - ➡ Robust: Easier to test, to trust
  - ➡ Easy: One framework/tool to learn
- Why NLO?
  - ➡ Reliable prediction of the total rate
  - ➡ Reduction of the theoretical uncertainty
- Why matched to the PS?
  - ➡ Parton are not an detector observables
  - ➡ Matching cure some fix-order ill behaved observables

DEMO

Is it really automatic?

DEMO

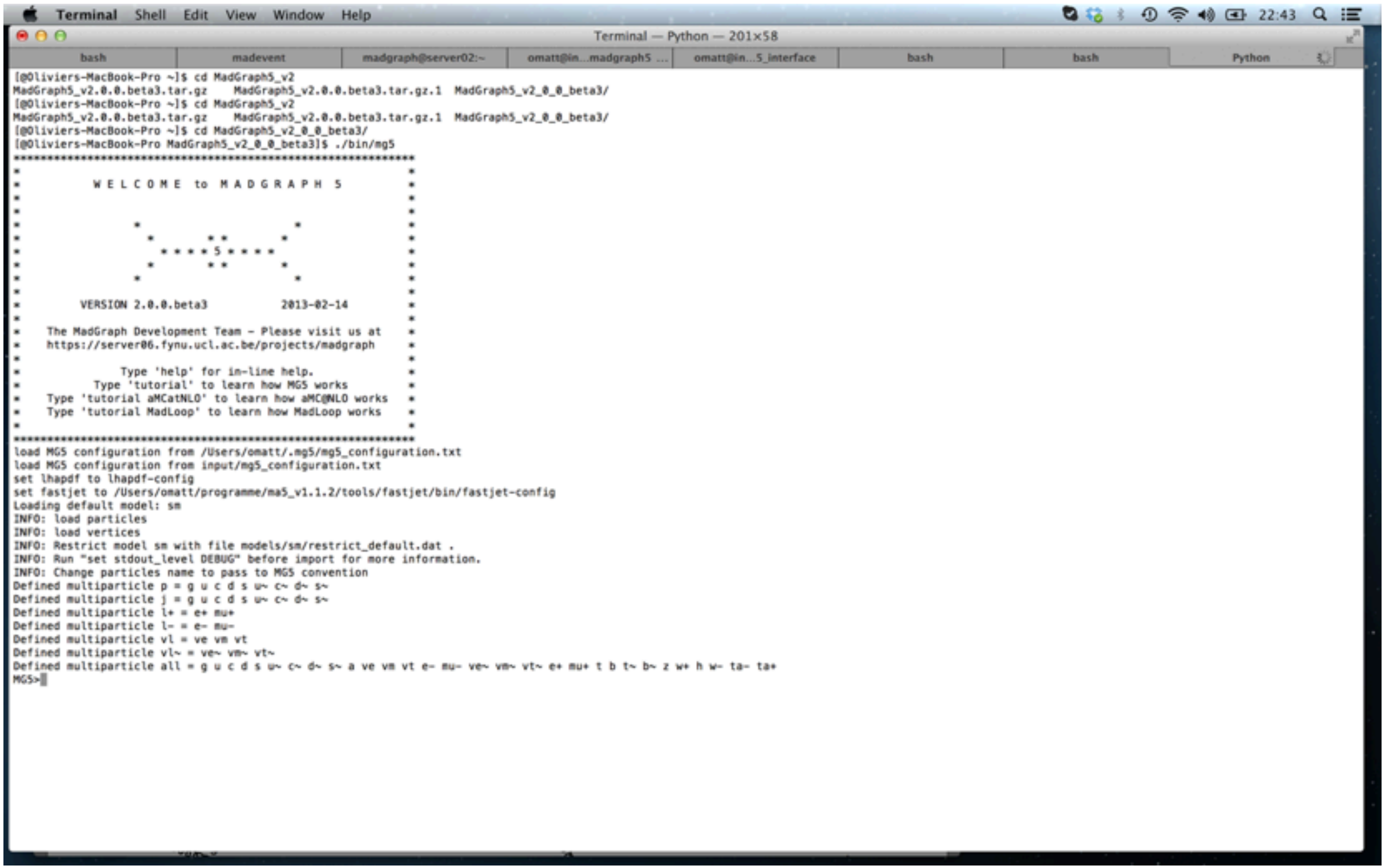
- 1) Download the code



Wednesday, October 2, 13

DEMO

- launch the code [./bin/mg5]
  - ➡ Exactly like MG5 !!!



- You can enter ANY process!
  - ➡ add [QCD] for NLO functionalities
    - ✦ generate p p > t t~ [QCD]
    - ✦ generate p p > e+ e- mu+ mu- [QCD]
    - ✦ generate p p > w+ w- j j [QCD]

```
MG5>generate p p > t t~ [QCD]
Switching from interface MG5 to aMC@NLO
The default sm model does not allow to generate loop processes. MG5 now loads 'loop_sm' instead.
 import model loop_sm
INFO: load particles
INFO: load vertices
INFO: Restrict model loop_sm with file models/loop_sm/restrict_default.dat .
INFO: Run "set stdout_level DEBUG" before import for more information.
INFO: Change particles name to pass to MG5 convention
Kept definitions of multiparticles l- / j / vl / l+ / p / vl~ unchanged
Defined multiparticle all = g gh gh~ d u s c d~ u~ s~ c~ a ve vm vt e- mu- ve~ vm~ vt~ e+ mu+ b t b~ t~ z w+ h w- ta- ta+
INFO: Generating FKS-subtracted matrix elements for born process: g g > t t~  [ QCD ]
INFO: Generating FKS-subtracted matrix elements for born process: u u~ > t t~  [ QCD ]
INFO: Generating FKS-subtracted matrix elements for born process: c c~ > t t~  [ QCD ]
INFO: Generating FKS-subtracted matrix elements for born process: d d~ > t t~  [ QCD ]
INFO: Generating FKS-subtracted matrix elements for born process: s s~ > t t~  [ QCD ]
INFO: Generating FKS-subtracted matrix elements for born process: u~ u > t t~  [ QCD ]
INFO: Generating FKS-subtracted matrix elements for born process: c~ c > t t~  [ QCD ]
INFO: Generating FKS-subtracted matrix elements for born process: d~ d > t t~  [ QCD ]
INFO: Generating FKS-subtracted matrix elements for born process: s~ s > t t~  [ QCD ]
INFO: Generating virtual matrix elements using MadLoop:
INFO: Generating virtual matrix element with MadLoop for process: g g > t t~ [ QCD ]
INFO: Generating virtual matrix element with MadLoop for process: u u~ > t t~ [ QCD ]
INFO: Generating virtual matrix element with MadLoop for process: c c~ > t t~ [ QCD ]
INFO: Generating virtual matrix element with MadLoop for process: d d~ > t t~ [ QCD ]
INFO: Generating virtual matrix element with MadLoop for process: s s~ > t t~ [ QCD ]
INFO: Generating virtual matrix element with MadLoop for process: u~ u > t t~ [ QCD ]
INFO: Generating virtual matrix element with MadLoop for process: c~ c > t t~ [ QCD ]
INFO: Generating virtual matrix element with MadLoop for process: d~ d > t t~ [ QCD ]
INFO: Generating virtual matrix element with MadLoop for process: s~ s > t t~ [ QCD ]
INFO: Generated 9 subprocesses with 136 real emission diagrams, 11 born diagrams and 157 virtual diagrams
aMC@NLO>
```

- Create your aMC@NLO code
  - ➡ output PATH
- Run it:
  - ➡ launch [PATH]

- Create your aMC@NLO code
  - ➡ output PATH
- Run it:
  - ➡ launch [PATH]

```
aMC@NLO>launch
INFO: ************************************************************
*                                                          *
*          W E L C O M E  to  M A D G R A P H  5           *
*                     a M C @ N L O                        *
*                                                          *
*                 *                       *                *
*                   *        * *        *                  *
*                     * * * * 5 * * * *                    *
*                   *        * *        *                  *
*                 *                       *                *
*                                                          *
*          VERSION 2.0.0.beta3          2013-02-14         *
*                                                          *
*     The MadGraph Development Team - Please visit us at   *
*                 http://amcatnlo.cern.ch                  *
*                                                          *
*               Type 'help' for in-line help.              *
*                                                          *
************************************************************
INFO: load configuration from /Users/omatt/.mg5/mg5_configuration.txt
INFO: load configuration from /Users/omatt/MadGraph5_v2_0_0_beta3/PROCNLO_loop_sm_0/Cards/amcatnlo_configuration.txt
INFO: load configuration from /Users/omatt/MadGraph5_v2_0_0_beta3/input/mg5_configuration.txt
INFO: load configuration from /Users/omatt/MadGraph5_v2_0_0_beta3/PROCNLO_loop_sm_0/Cards/amcatnlo_configuration.txt
set group_subprocesses Auto
set ignore_six_quark_processes False
set loop_optimized_output True
set gauge unitary
set complex_mass_scheme False
launch auto
Which programs do you want to run?
  0 / auto       : NLO event generation and -if cards exist- shower and madspin.
  1 / NLO        : Fixed order NLO calculation (no event generation).
  2 / aMC@NLO    : NLO event generation (include running the shower).
  3 / noshower   : NLO event generation (without running the shower).
  4 / LO         : Fixed order LO calculation (no event generation).
  5 / aMC@LO     : LO event generation (include running the shower).
  6 / noshowerLO : LO event generation (without running the shower).
+10 / +madspin   : Add decays with MadSpin (before the shower).
 [0, auto, 1, NLO, 2, aMC@NLO, 12, aMC@NLO+madspin, 3, ... ][60s to answer]
>
```

- Create your aMC@NLO code
  - ➡ output PATH
- Run it:
  - ➡ launch [PATH]

First Question:

```
The following switches determine which operations are executed:
 1 Perturbative order of the calculation:                             order=NLO
 2 Fixed order (no event generation and no MC@[N]LO matching):   fixed_order=OFF
 3 Shower the generated events:                                      shower=ON
 4 Decay particles with the MadSpin module:                          madspin=OFF
  Either type the switch number (1 to 4) to change its default setting,
  or set any switch explicitly (e.g. type 'order=LO' at the prompt)
  Type '0', 'auto', 'done' or just press enter when you are done.
 [0, 1, 2, 3, 4, auto, done, order=LO, order=NLO, ... ][60s to answer]
>[timer stopped]
```

- Create your aMC@NLO code
  - ➡ output PATH
- Run it:
  - ➡ launch [PATH]

Second Question:

```
INFO: will run in mode: aMC@NLO
Do you want to edit a card (press enter to bypass editing)?
  1 / param      : param_card.dat
  2 / run        : run_card.dat
  3 / madspin    : madspin_card.dat
  4 / shower     : shower_card.dat
 you can also
   - enter the path to a valid card or banner.
   - use the 'set' command to modify a parameter directly.
     The set option works only for param_card and run_card.
     Type 'help set' for more information on this command.
 [0, done, 1, param, 2, run, 3, madspin, 4, enter path, ... ][60s to answer]
>
```

- The code runs:

```
INFO: For gauge cancellation, the width of 't' has been set to zero.
```

- The code runs:

```
INFO: For gauge cancellation, the width of 't' has been set to zero.
INFO: Using built-in libraries for PDFs
INFO: Compiling source...
INFO:            ...done, continuing with P* directories
INFO: Compiling directories...
INFO: Compiling on 8 cores
INFO:  Compiling P0_gg_ttx...
INFO:  Compiling P0_uux_ttx...
INFO:  Compiling P0_uxu_ttx...
INFO:     P0_uux_ttx done.
INFO:     P0_uxu_ttx done.
INFO:     P0_gg_ttx done.
```

Compilation

- The code runs:

```
INFO: For gauge cancellation, the width of 't' has been set to zero.
INFO: Using built-in libraries for PDFs
INFO: Compiling source...
INFO:           ...done, continuing with P* directories
INFO: Compiling directories...
INFO: Compiling on 8 cores
INFO:  Compiling P0_gg_ttx...
INFO:  Compiling P0_uux_ttx...
INFO:  Compiling P0_uxu_ttx...
INFO:     P0_uux_ttx done.
INFO:     P0_uxu_ttx done.
INFO:     P0_gg_ttx done.
INFO: Checking test output:
INFO: P0_gg_ttx
INFO:  Result for test_ME:
INFO:    Passed.
INFO:  Result for test_MC:
INFO:    Passed.
INFO:  Result for check_poles:
INFO:    Poles successfully cancel for 20 points over 20 (tolerance=1.0e-05)
INFO: P0_uux_ttx
INFO:  Result for test_ME:
INFO:    Passed.
INFO:  Result for test_MC:
INFO:    Passed.
INFO:  Result for check_poles:
INFO:    Poles successfully cancel for 20 points over 20 (tolerance=1.0e-05)
INFO: P0_uxu_ttx
INFO:  Result for test_ME:
INFO:    Passed.
INFO:  Result for test_MC:
INFO:    Passed.
INFO:  Result for check_poles:
INFO:    Poles successfully cancel for 20 points over 20 (tolerance=1.0e-05)
```

Compilation

Check Poles cancelation

```
INFO: Starting run
INFO: Using 8 cores
INFO: Cleaning previous results
INFO: Doing NLO matched to parton shower
INFO: Setting up grid
INFO:  Idle: 2,  Running: 8,  Completed: 0 [ current time: 22h58 ]
INFO:  Idle: 1,  Running: 8,  Completed: 1 [  7.1s  ]
INFO:  Idle: 0,  Running: 8,  Completed: 2 [  7.2s  ]
INFO:  Idle: 0,  Running: 7,  Completed: 3 [  13.6s  ]
INFO:  Idle: 0,  Running: 6,  Completed: 4 [  21s  ]
INFO:  Idle: 0,  Running: 5,  Completed: 5 [  21s  ]
INFO:  Idle: 0,  Running: 4,  Completed: 6 [  1m 5s  ]
INFO:  Idle: 0,  Running: 3,  Completed: 7 [  1m 5s  ]
INFO:  Idle: 0,  Running: 2,  Completed: 8 [  6m 38s  ]
INFO:  Idle: 0,  Running: 1,  Completed: 9 [  6m 43s  ]
INFO:  Idle: 0,  Running: 0,  Completed: 10 [  6m 52s  ]
INFO: Determining the number of unweighted events per channel

      Intermediate results:
      Random seed: 33
      Total cross-section:      1.775e+02 +- 2.1e+00 pb
      Total abs(cross-section): 2.633e+02 +- 1.6e+00 pb


INFO: Computing upper envelope
INFO:  Idle: 2,  Running: 8,  Completed: 0 [ current time: 23h05 ]
INFO:  Idle: 1,  Running: 8,  Completed: 1 [  8.7s  ]
INFO:  Idle: 0,  Running: 8,  Completed: 2 [  8.9s  ]
INFO:  Idle: 0,  Running: 7,  Completed: 3 [  16.3s  ]
INFO:  Idle: 0,  Running: 6,  Completed: 4 [  25.7s  ]
INFO:  Idle: 0,  Running: 5,  Completed: 5 [  25.7s  ]
INFO:  Idle: 0,  Running: 4,  Completed: 6 [  1m 16s  ]
INFO:  Idle: 0,  Running: 3,  Completed: 7 [  1m 18s  ]
INFO:  Idle: 0,  Running: 2,  Completed: 8 [  6m 38s  ]
INFO:  Idle: 0,  Running: 1,  Completed: 9 [  6m 46s  ]
INFO:  Idle: 0,  Running: 0,  Completed: 10 [  7m 4s  ]
INFO: Updating the number of unweighted events per channel

      Intermediate results:
      Random seed: 33
      Total cross-section:      1.770e+02 +- 1.7e+00 pb
      Total abs(cross-section): 2.630e+02 +- 1.2e+00 pb


INFO: Generating events
INFO:  Idle: 2,  Running: 8,  Completed: 0 [ current time: 23h12 ]
INFO:  Idle: 1,  Running: 8,  Completed: 1 [  0.52s  ]
INFO:  Idle: 0,  Running: 8,  Completed: 2 [  0.71s  ]
INFO:  Idle: 0,  Running: 7,  Completed: 3 [  1.7s  ]
INFO:  Idle: 0,  Running: 6,  Completed: 4 [  1.8s  ]
INFO:  Idle: 0,  Running: 5,  Completed: 5 [  3.9s  ]
INFO:  Idle: 0,  Running: 4,  Completed: 6 [  14.5s  ]
INFO:  Idle: 0,  Running: 3,  Completed: 7 [  19.7s  ]
INFO:  Idle: 0,  Running: 2,  Completed: 8 [  21.4s  ]
INFO:  Idle: 0,  Running: 1,  Completed: 9 [  31.7s  ]
INFO:  Idle: 0,  Running: 0,  Completed: 10 [  36.4s  ]
INFO:    Doing reweight
```

Integration

Events Generation

```
INFO:    Doing reweight
INFO:  Idle: 0,  Running: 4,  Completed: 6 [ current time: 23h13 ]
INFO:  Idle: 0,  Running: 3,  Completed: 7 [  0.51s  ]
INFO:  Idle: 0,  Running: 2,  Completed: 8 [  0.53s  ]
INFO:  Idle: 0,  Running: 1,  Completed: 9 [  1.6s  ]
INFO:  Idle: 0,  Running: 0,  Completed: 10 [  1.8s  ]
INFO: Collecting events
INFO:
```

Unweight Events

```
      Summary:
      Process p p > t t~ [QCD]
      Run at p-p collider (4000 + 4000 GeV)
      Total cross-section: 1.770e+02 +- 1.7e+00 pb
      Ren. and fac. scale uncertainty: +13.5% -13.0%
      Number of events generated: 10000
      Parton shower to be used: HERWIG6
      Fraction of negative weights: 0.16
      Total running time :  15m 42s
```

Main Results

```
INFO: The /Users/omatt/MadGraph5_v2_0_0_beta3/PROCNLO_loop_sm_0/Events/run_01/events.lhe.gz file has been generated.
```

```
decay_events -from_cards
INFO:    Prepairing MCatNLO run
INFO:    Compiling MCatNLO for HERWIG6...
INFO:                      ... done
INFO: Running MCatNLO in /Users/omatt/MadGraph5_v2_0_0_beta3/PROCNLO_loop_sm_0/MCatNLO/RUN_HERWIG6_1 (this may take some time)...
gzip: /Users/omatt/MadGraph5_v2_0_0_beta3/PROCNLO_loop_sm_0/Events/run_01/events_HERWIG6_0.hep has 1 other link  -- unchanged
INFO: The file /Users/omatt/MadGraph5_v2_0_0_beta3/PROCNLO_loop_sm_0/Events/run_01/events_HERWIG6_0.hep.gz has been generated.
```

The Shower

Next release will be much faster

4 times faster for this simple process

DEMO

Is it really automatic?

DEMO

Is it really automatic?

As much as LO!

Status of aMC@NLO

- Only NLO in QCD (Electroweak well in progress)
- Only the SM
  - ➡ R2 computation to any model close to completion
  - ➡ aTGC/aQGC can be run with no problem!
- New release is coming to be release very soon
  - ➡ much faster than previous version (10 times)
  - ➡ Support of NLO merging
  - ➡ Interface to Pythia8 for the shower
  - ➡ ...

Conclusion

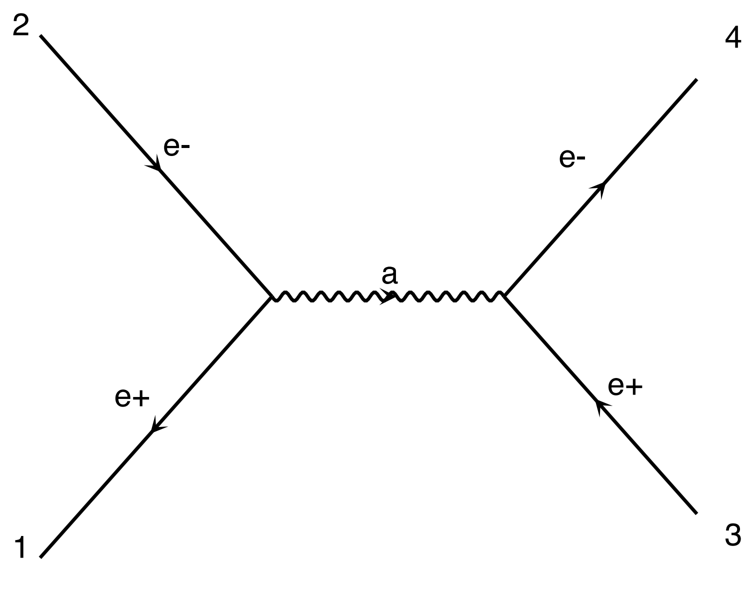
- MadGraph
  - ➡ (nearly) All BSM
  - ➡ re-weighting
- MadSpin
  - ➡ decay with full spin correlations
  - ➡ keep finite width effect
- aMC@NLO is
  - ➡ public
  - ➡ automatic
  - ➡ flexible

	Process	μ	n_{lf}	Cross section (pb) LO	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

Thanks

HELAS

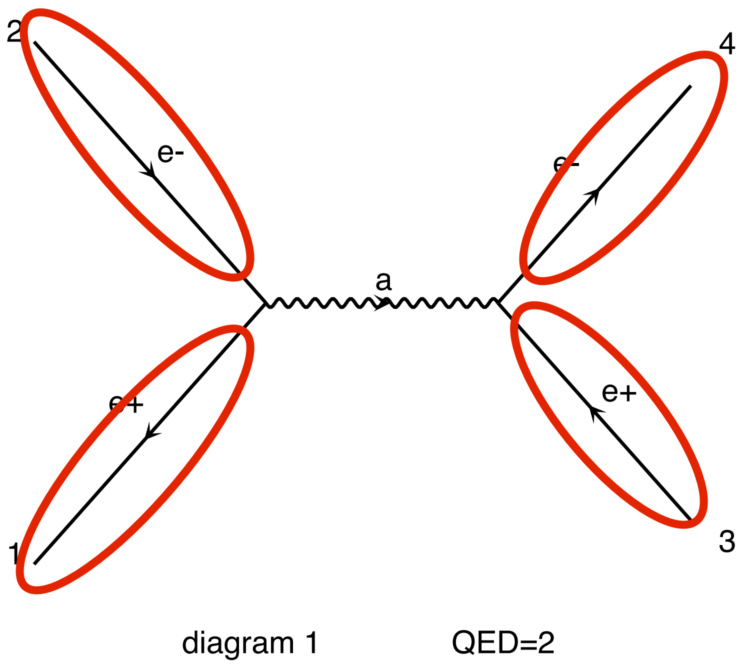
- Idea: Evaluate $\mathcal{M}$ for fixed helicity of external particles.



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

HELAS

- Idea: Evaluate $\mathcal{M}$ for fixed helicity of external particles.

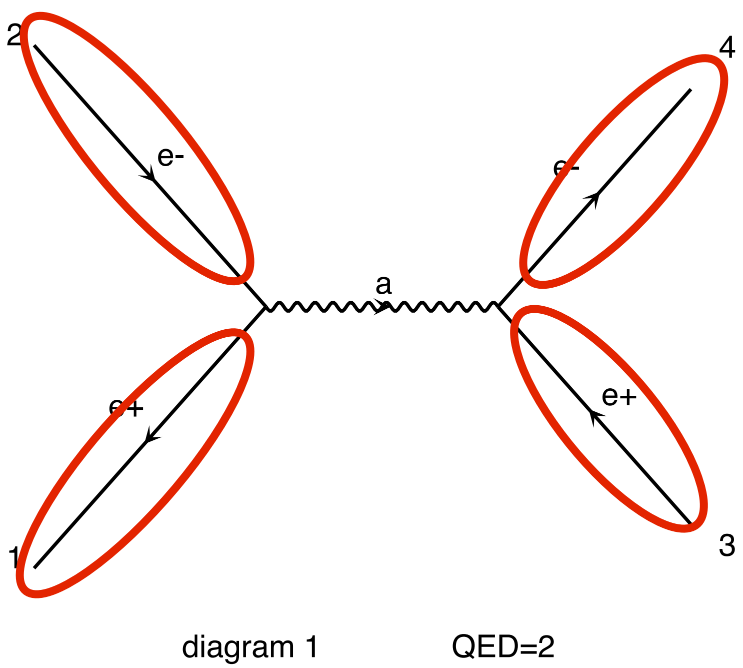


$$M = \bar{u}\gamma^\mu v \, P_{\mu\nu} \, \bar{u}\gamma^\nu v$$

→ Number for a given helicity

HELAS

- Idea: Evaluate $\mathcal{M}$ for fixed helicity of external particles.



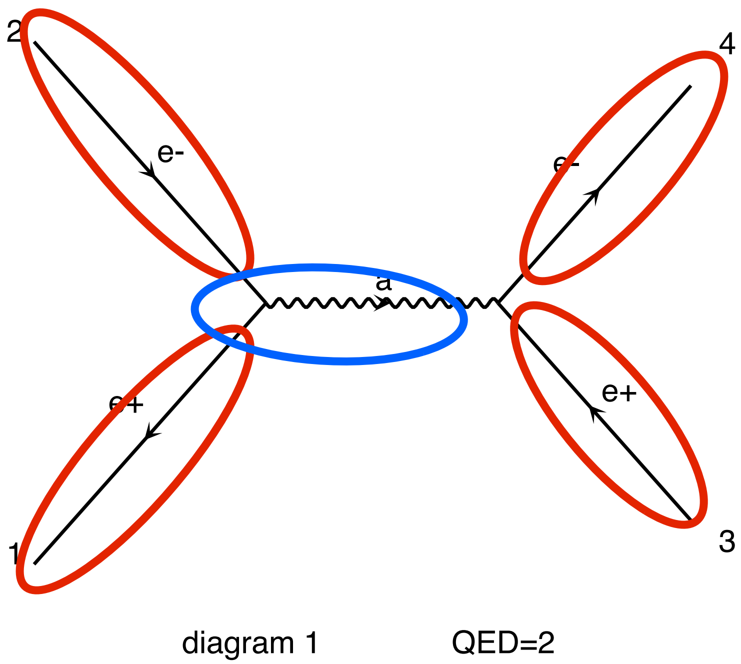
$$M = \bar{u}\gamma^\mu v \, P_{\mu\nu} \, \bar{u}\gamma^\nu v$$

→ Number for a given helicity

```
CALL IXXXXX(P(0,1),ZERO,NHEL(1),+1*IC(1),W(1,1))
CALL OXXXXX(P(0,2),ZERO,NHEL(2),-1*IC(2),W(1,2))
CALL OXXXXX(P(0,3),MT,NHEL(3),+1*IC(3),W(1,3))
CALL IXXXXX(P(0,4),MT,NHEL(4),-1*IC(4),W(1,4))
```

HELAS

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



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

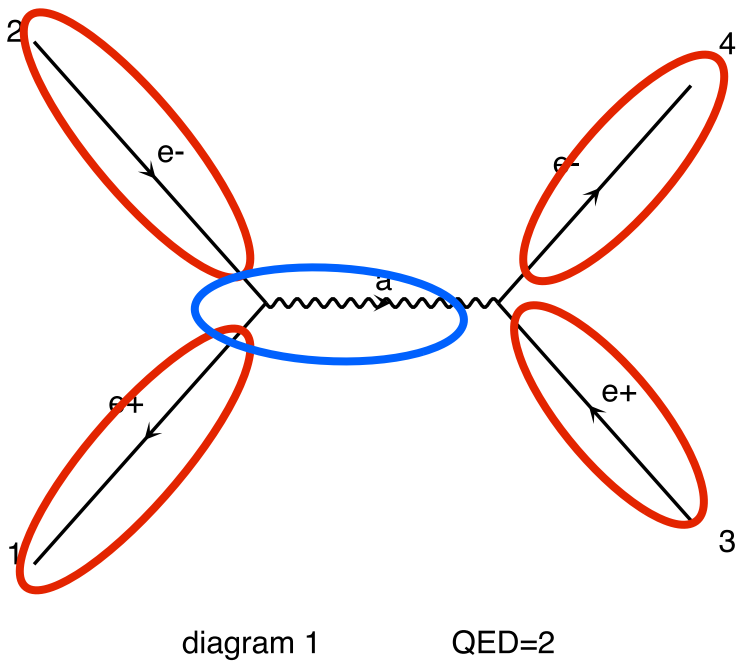
→ Number for a given helicity

→ Evaluate interaction by interaction

```
CALL IXXXXX(P(0,1),ZERO,NHEL(1),+1*IC(1),W(1,1))
CALL OXXXXX(P(0,2),ZERO,NHEL(2),-1*IC(2),W(1,2))
CALL OXXXXX(P(0,3),MT,NHEL(3),+1*IC(3),W(1,3))
CALL IXXXXX(P(0,4),MT,NHEL(4),-1*IC(4),W(1,4))
```

HELAS

- Idea: Evaluate $\mathcal{M}$ for fixed helicity of external particles.



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

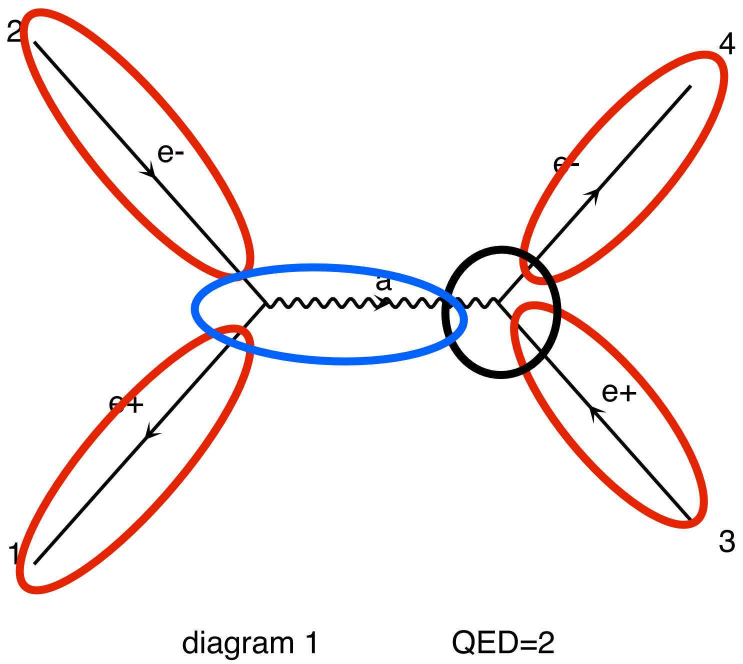
→ Number for a given helicity

→ Evaluate Interaction by interaction

```
CALL IXXXXX(P(0,1),ZERO,NHEL(1),+1*IC(1),W(1,1))
CALL OXXXXX(P(0,2),ZERO,NHEL(2),-1*IC(2),W(1,2))
CALL OXXXXX(P(0,3),MT,NHEL(3),+1*IC(3),W(1,3))
CALL IXXXXX(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))
```

HELAS

- Idea: Evaluate $\mathcal{M}$ 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

```
CALL IXXXXX(P(0,1),ZERO,NHEL(1),+1*IC(1),W(1,1))
CALL OXXXXX(P(0,2),ZERO,NHEL(2),-1*IC(2),W(1,2))
CALL OXXXXX(P(0,3),MT,NHEL(3),+1*IC(3),W(1,3))
CALL IXXXXX(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))
```

HELAS

- Idea: Evaluate $\mathcal{M}$ for fixed helicity of external particles.

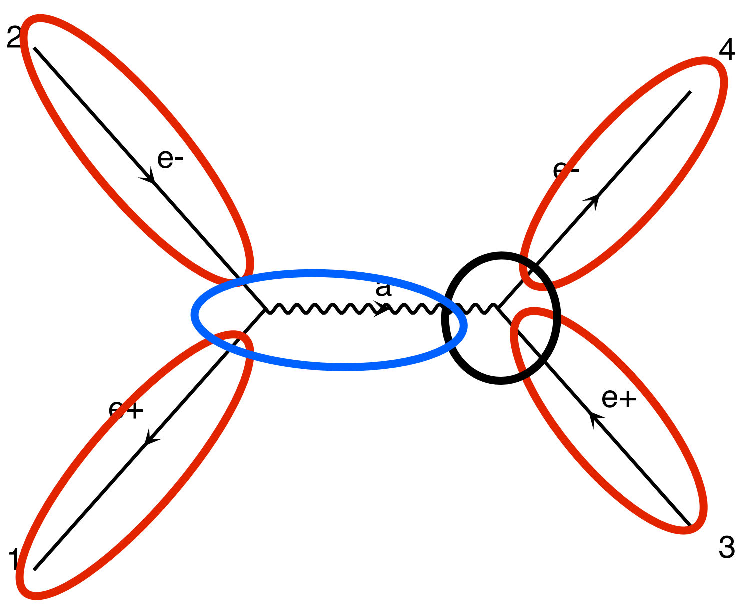


diagram 1 QED=2

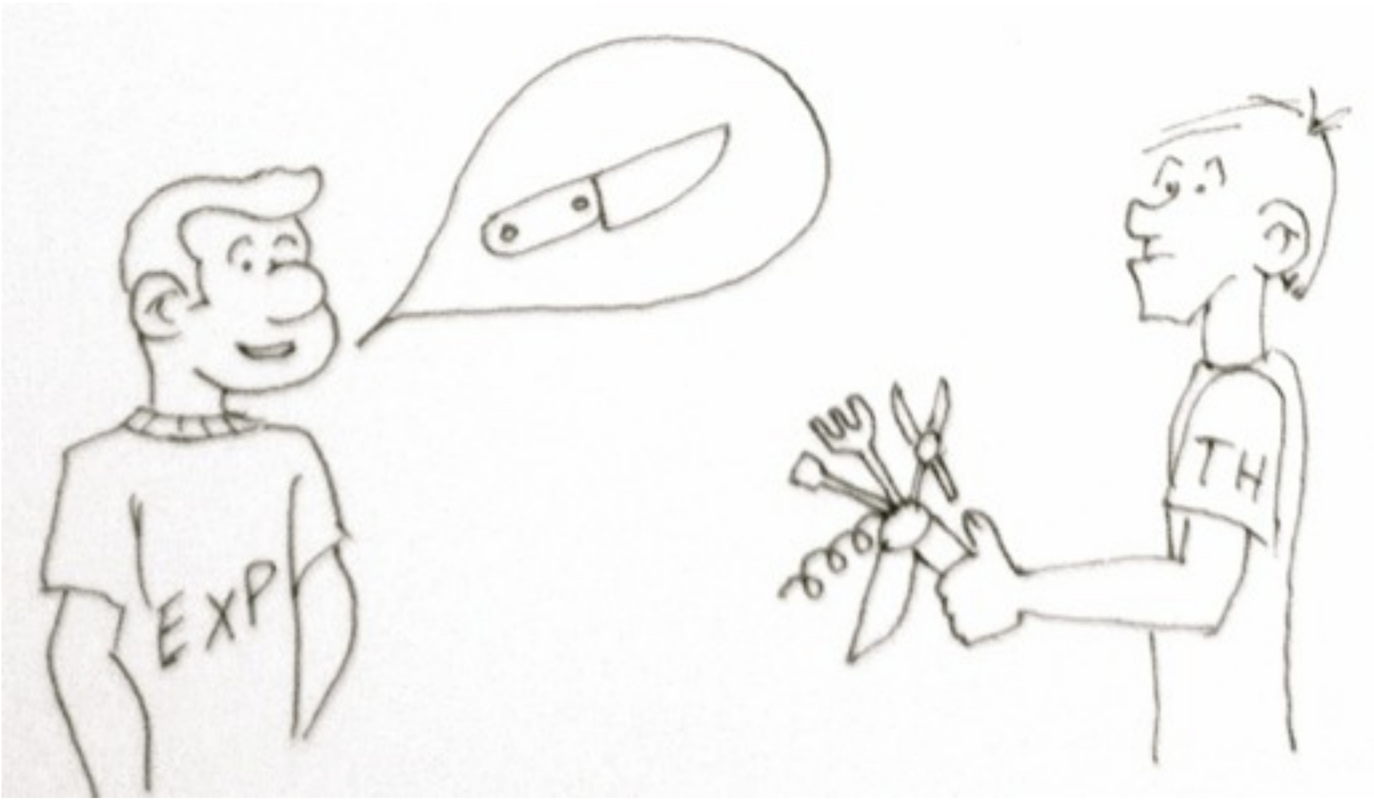
$$M = \bar{u}\gamma^\mu v \, P_{\mu\nu} \, \bar{u}\gamma^\nu v$$

→ Number for a given helicity

→ Evaluate interaction by interaction

```
CALL IXXXXX(P(0,1),ZERO,NHEL(1),+1*IC(1),W(1,1))
CALL OXXXXX(P(0,2),ZERO,NHEL(2),-1*IC(2),W(1,2))
CALL OXXXXX(P(0,3),MT,NHEL(3),+1*IC(3),W(1,3))
CALL IXXXXX(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))
```

Make an efficient generation



- When studying Operators, we want to study those one (or two) at the time.
- Theoretician wants to provide a single model with a lot of operators!

→ How to have an efficient generation?

restriction_card

restrict_cww.dat

```
#####################################
## INFORMATION FOR DIM6
#####################################
BLOCK DIM6 #
      1 9.999999e-01 #   cwwwl2
      2 0.000000e+00 #   cwl2
      3 0.000000e+00 #   cbl2
      4 0.000000e+00 #   cpwwwl2
      5 0.000000e+00 #   cpwl2
```

- standard param_card
- inside model directory
- name: restrict_XXX.dat
- loaded via:
  import model EWDIM6-XXX

- all interactions with zero couplings are removed from the model
  - So no diagram associate to Ow
- all parameters with value zero/one are removed from the models