MadGraph5/aMC@NLO

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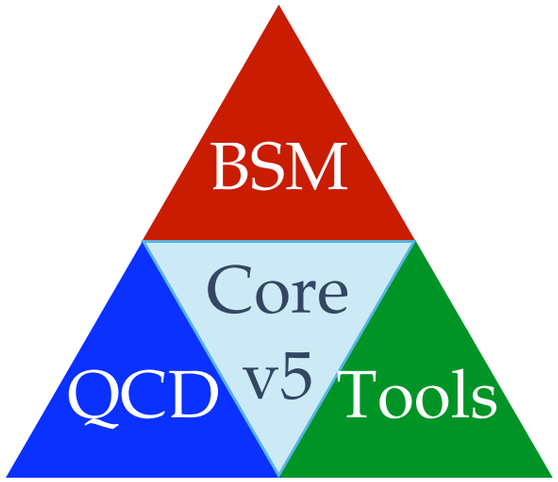
for the MadGraph/aMC@NLO team

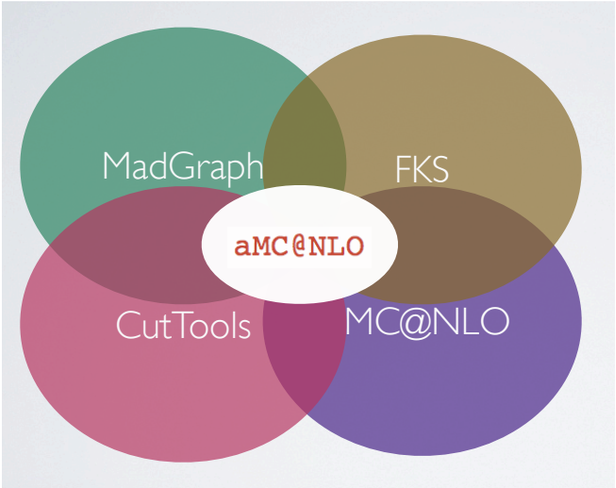
Full list of contributors:
http://amcatnlo.web.cern.ch/amcatnlo/people.htm

Plan

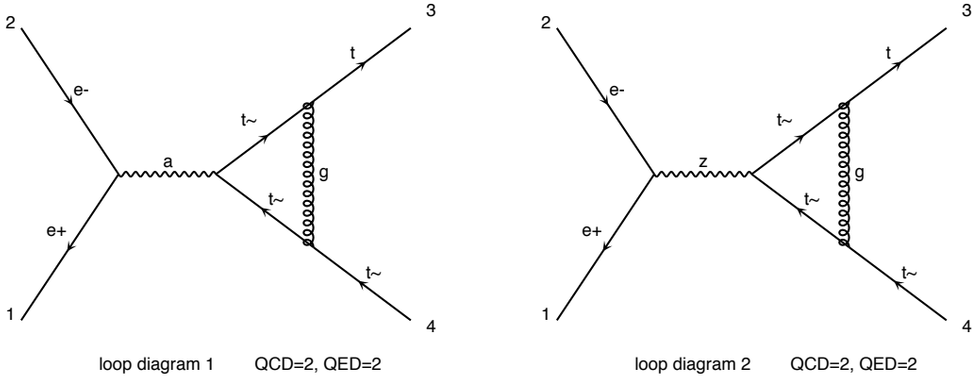
- MadGraph5



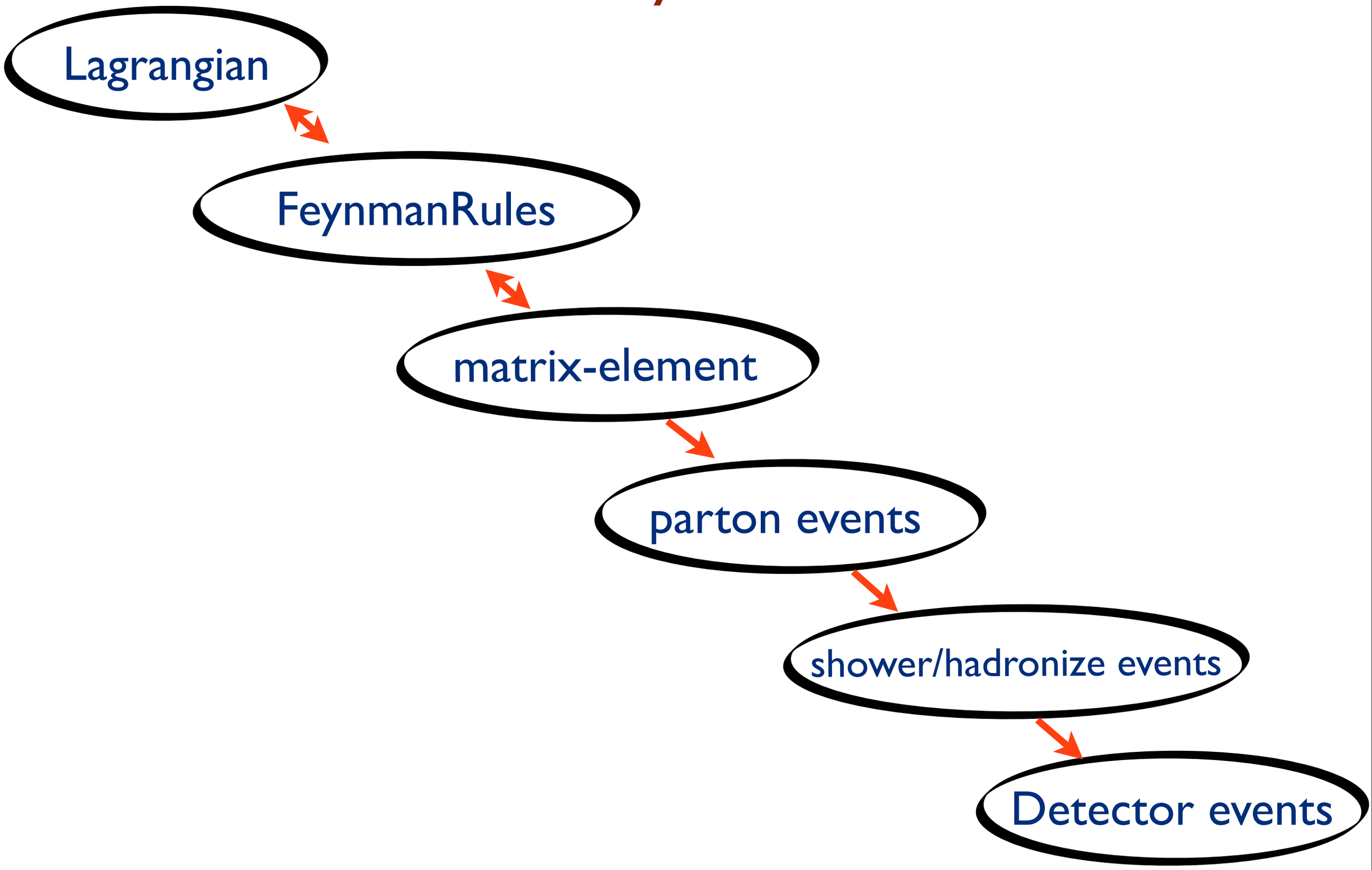
- aMC@NLO



- top pair production@NLO



From Theory to Detector



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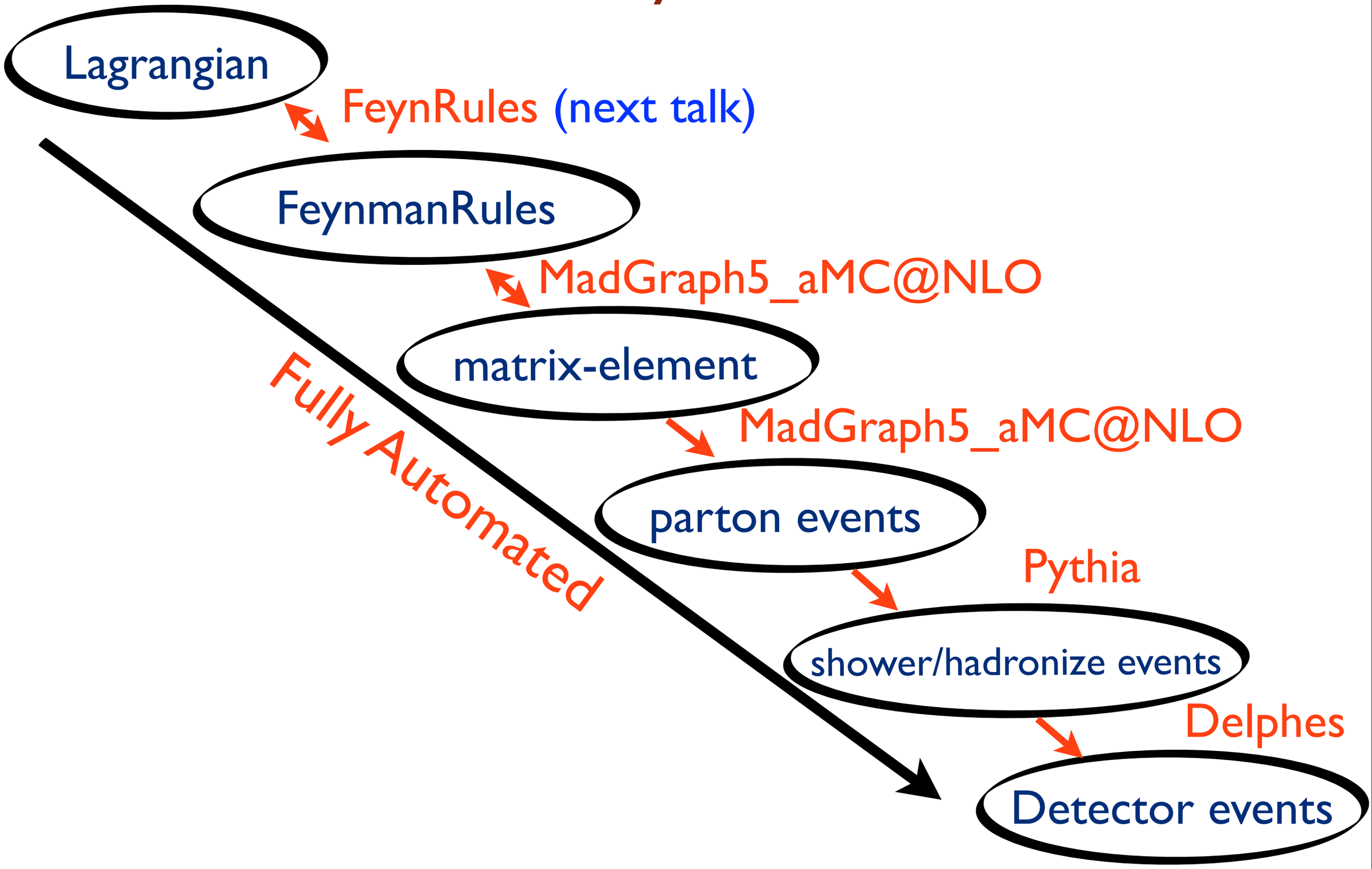

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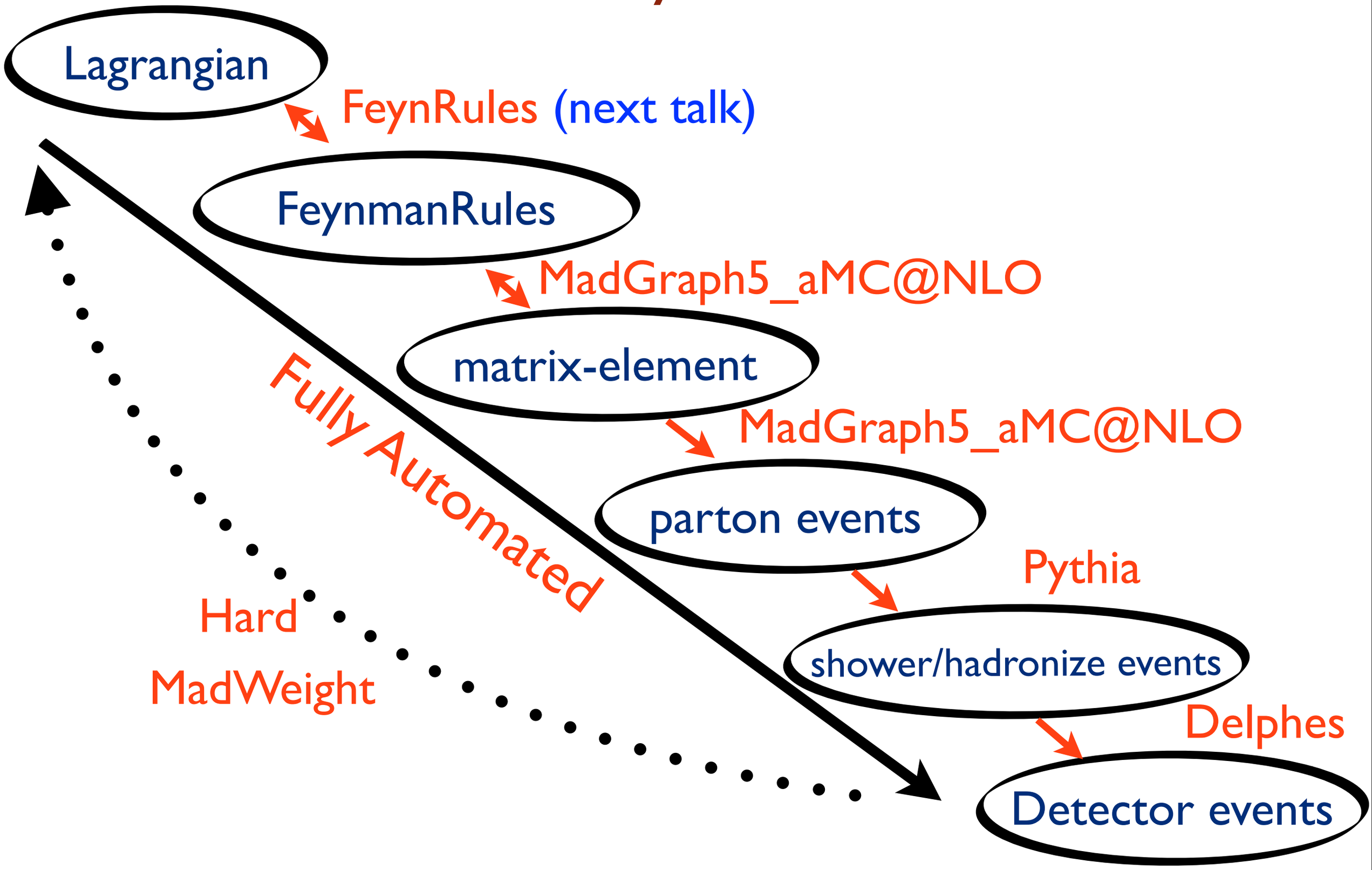
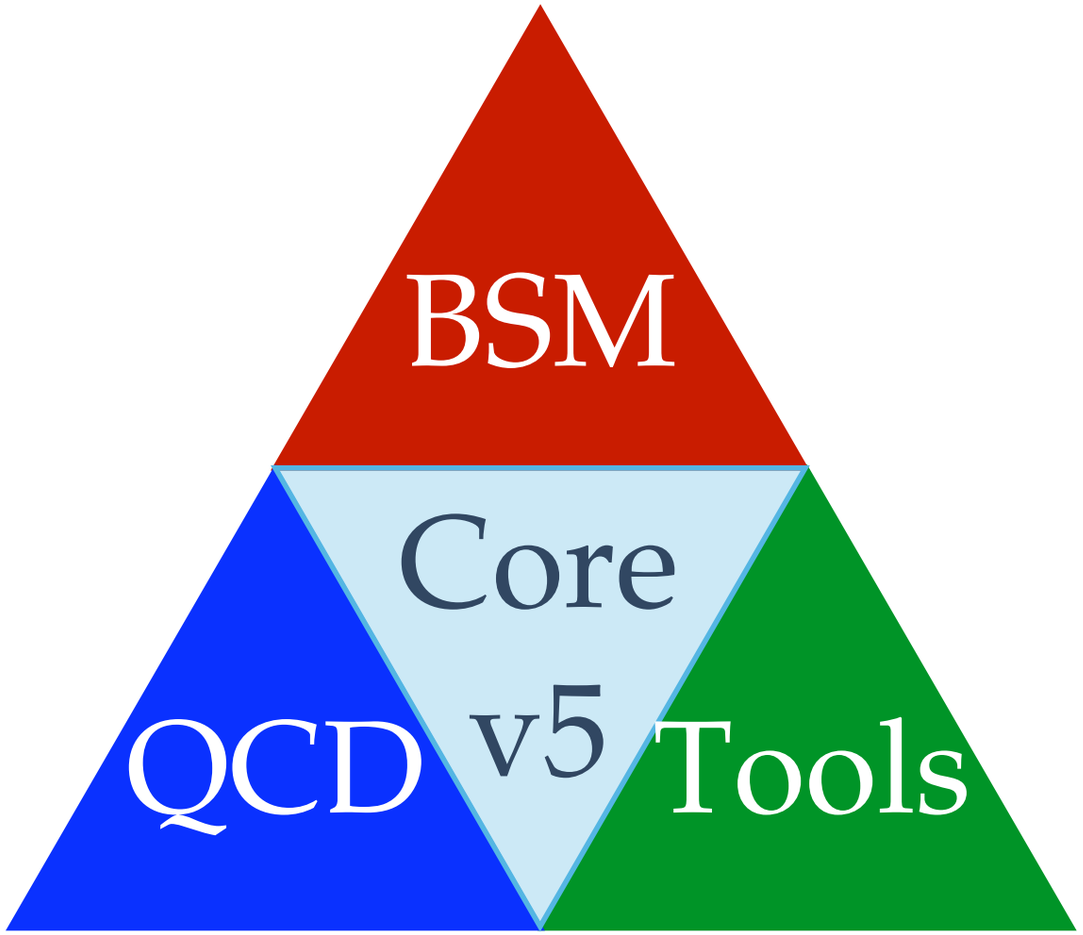
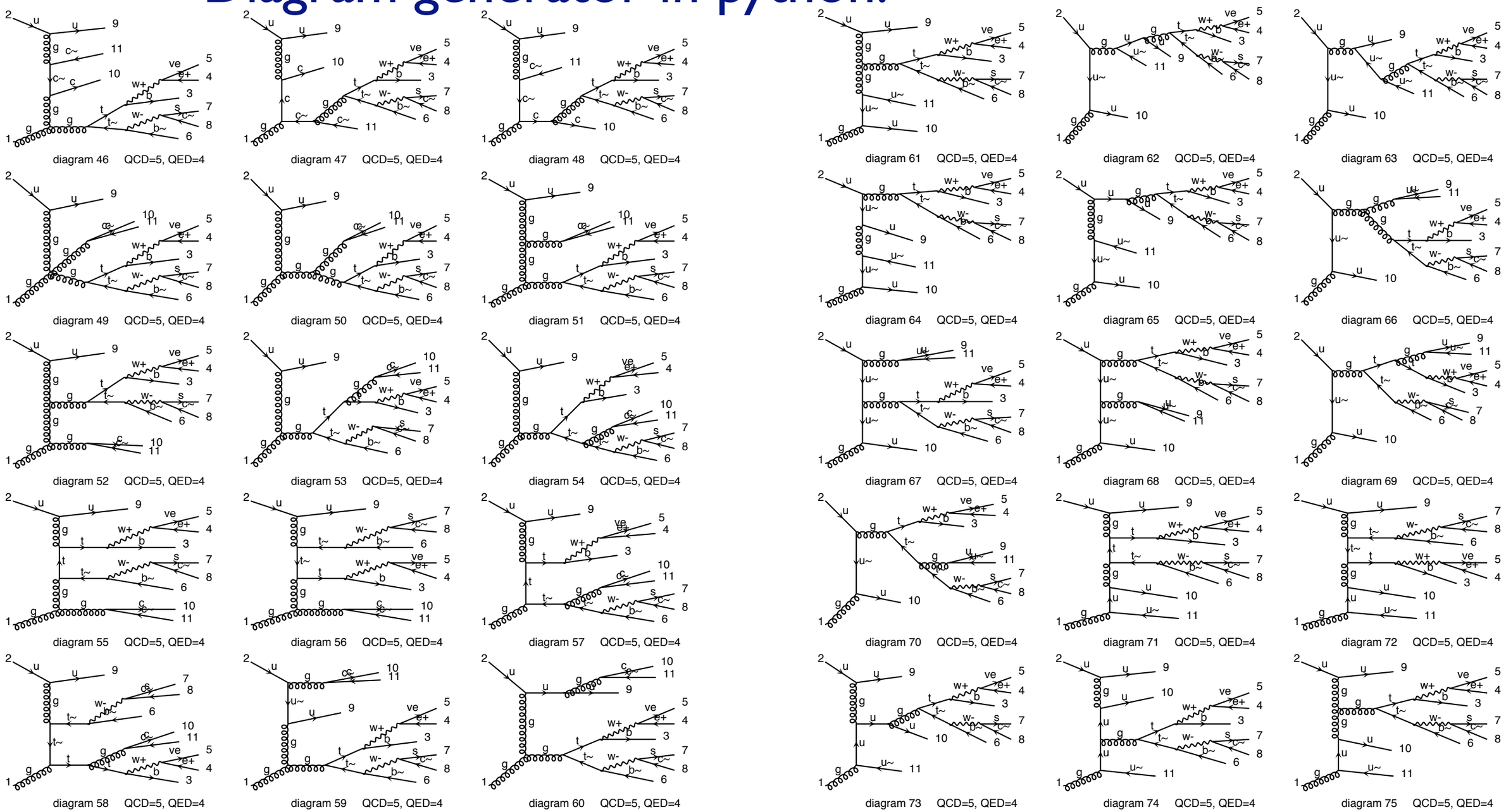



BSM
Core
v5
QCD
Tools

What is MG5_aMC?

What is MG5_aMC?

- Diagram generator in python.



What is MG5_aMC?

- Diagram generator in python.
- returns code to compute matrix-element based on the Helicity Amplitude formalism

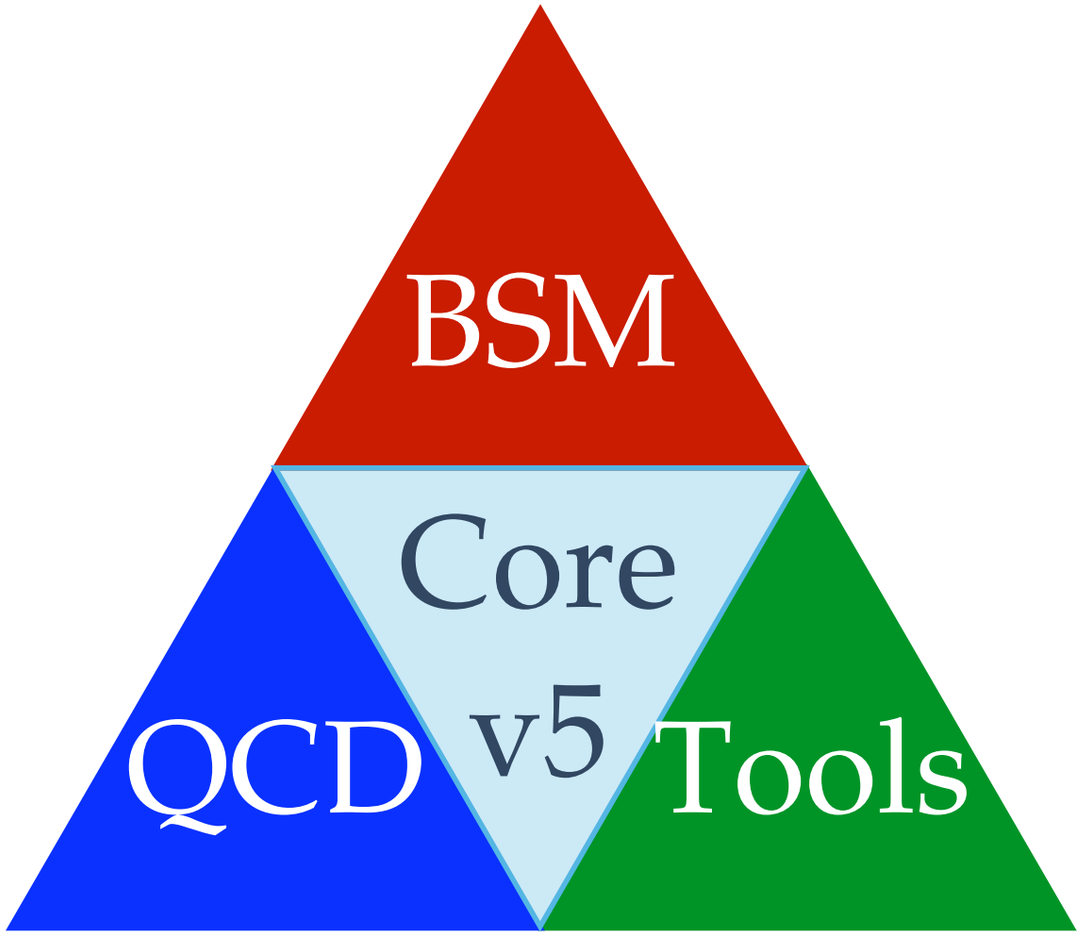
What is MG5_aMC?

- Diagram generator in python.
- returns code to compute matrix-element based on the Helicity Amplitude formalism
- Various output format
  - ➡ MadEvent: Leading-order cross-section and event generation
  - ➡ aMC@NLO: NLO cross-section and event generation (matched to the shower)
  - ➡ Pythia8: export the matrix element inside the pythia8 framework
  - ➡ Tools: MadSpin, MadWeight, MadDM, ...

Core news

- Lots of speedups and improvements, including
  - Huge speedup of gridpacks
  - Vast speedup for long decay chains with multiparticle decays
  - Huge i
  - Spin 3/2
- Complex mass scheme
- Feynman gauge
- Handling of negative weights
- On-the-fly body decay width calculations ("Auto width")

Completely automated simulations at next-to-leading order in QCD, matched to shower, now public (aMC@NLO in v. 2.0.0)!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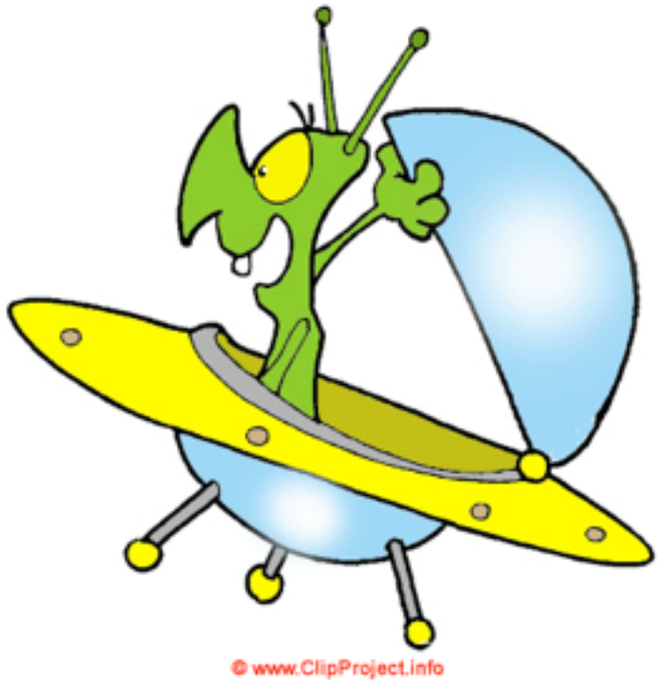
BSM



BSM

UFO = Universal Feynrules Output

- New Model Format
- Gosam/ Herwig++/ MG5
- Fully generic color/Lorentz/...

[Degrande et al, arXiv:1108.2040]

- Automatic Creation of HELAS routine for ANY BSM theory
  - Fortran / C++/Python

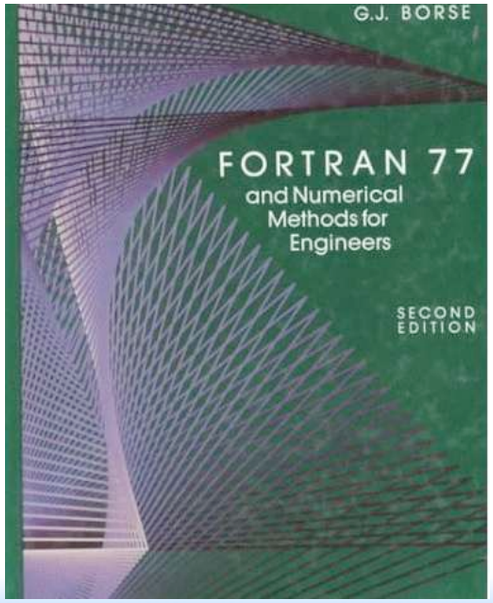
[OM et al, arXiv:1108.2041]

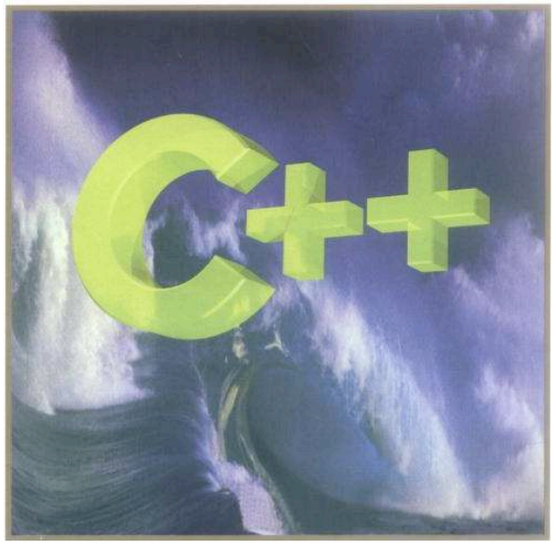
ALOHA

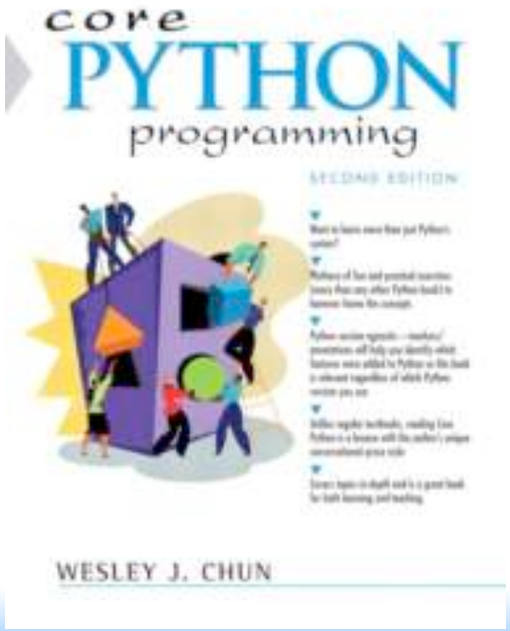
ALOHA
~~Google~~ translate

From: UFO ⇆ To: Helicity Translate

Type text or a website address or translate a document.



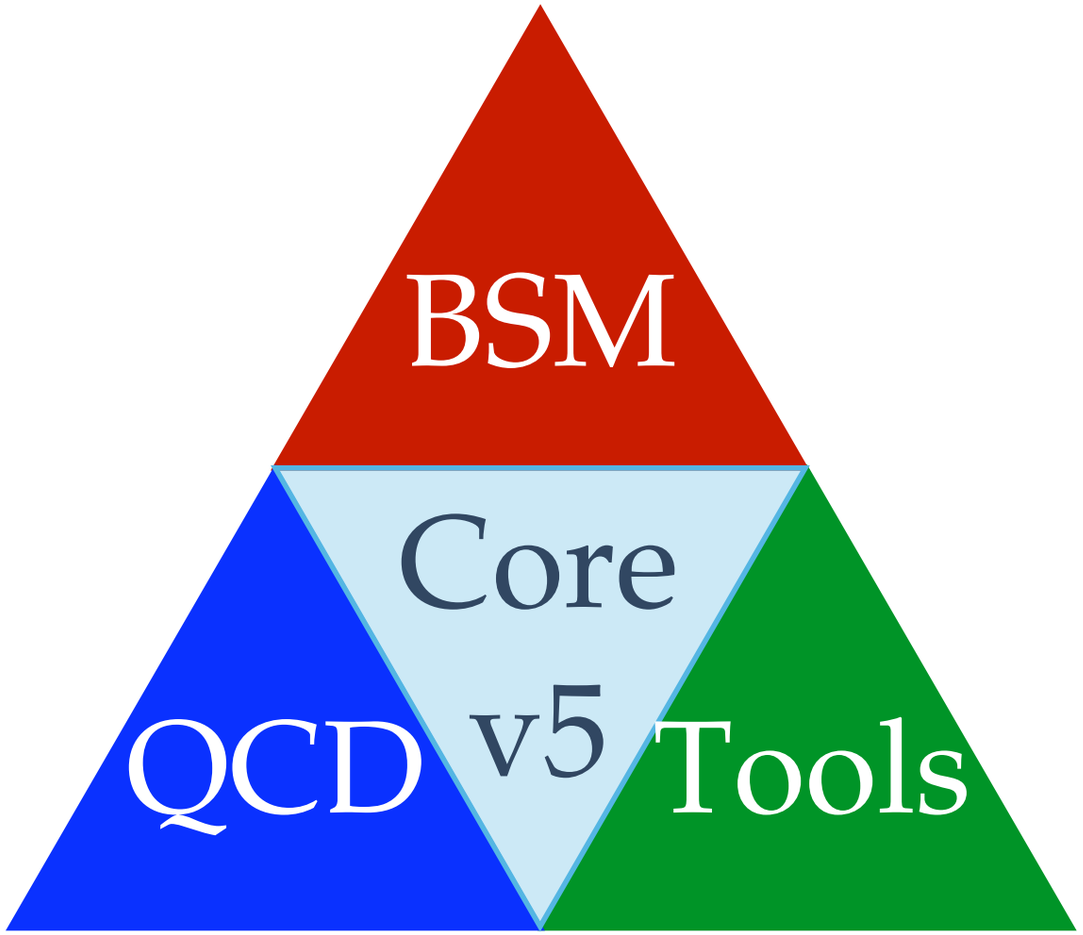




Any BSM should be possible in a fully automatic and efficient way!

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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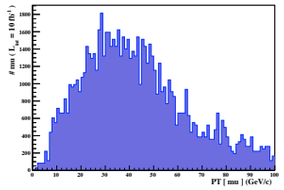
MG5_aMC

Tools

Tools	Utility	Progress
MadAnalysis5	Plotting distributions 	Released

[E.Conte, B. Fuks: CPC 184 (2013) 222-256]

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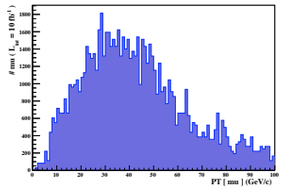
MadAnalysis5	Plotting distributions 	Released
MadWidth	Automatic width computation	Released

2-body decay

FeynRules

N-body decay

- New diagram generator
- a priori estimation of each channel of integration

Very FAST

[J.Alwall, C.Duhr, B.Fuks, OM, D.Ozturk, CH Shen arXiv:1402.1178]

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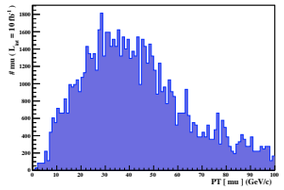
MadAnalysis5	Plotting distributions 	Released
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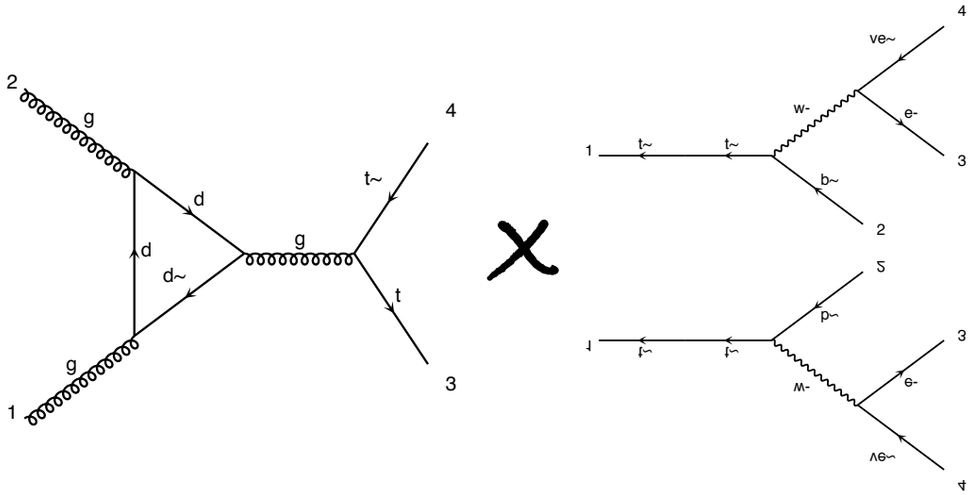
MadSpin	Decay with full (LO) spin-correlation	Released



[P. Artoisenet, R. Frederix, OM, R. Rietkerk: 1212.3460]

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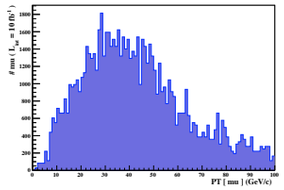
MadAnalysis5	Plotting distributions 	Released
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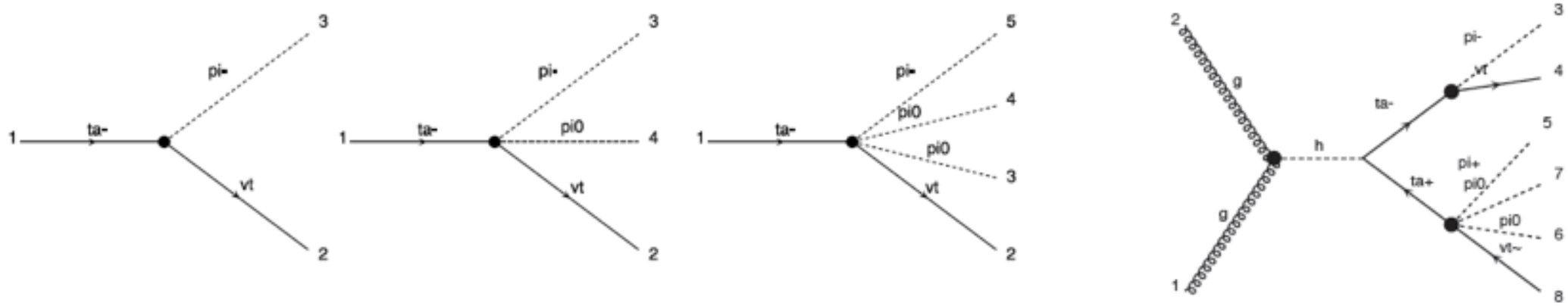

[Hagiwara, Li, Mawatari, Nakamura EPJC74 2489]

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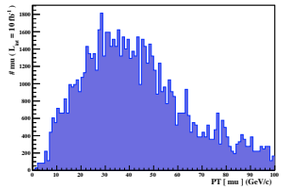
MadAnalysis5	Plotting distributions 	Released
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Reweight Module	Re-weigthing Module for multiple theoretical hypotheses	Released*

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

[OM]

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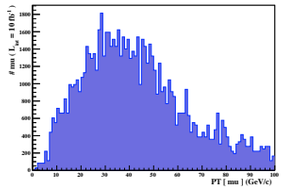
MadAnalysis5	Plotting distributions 	Released
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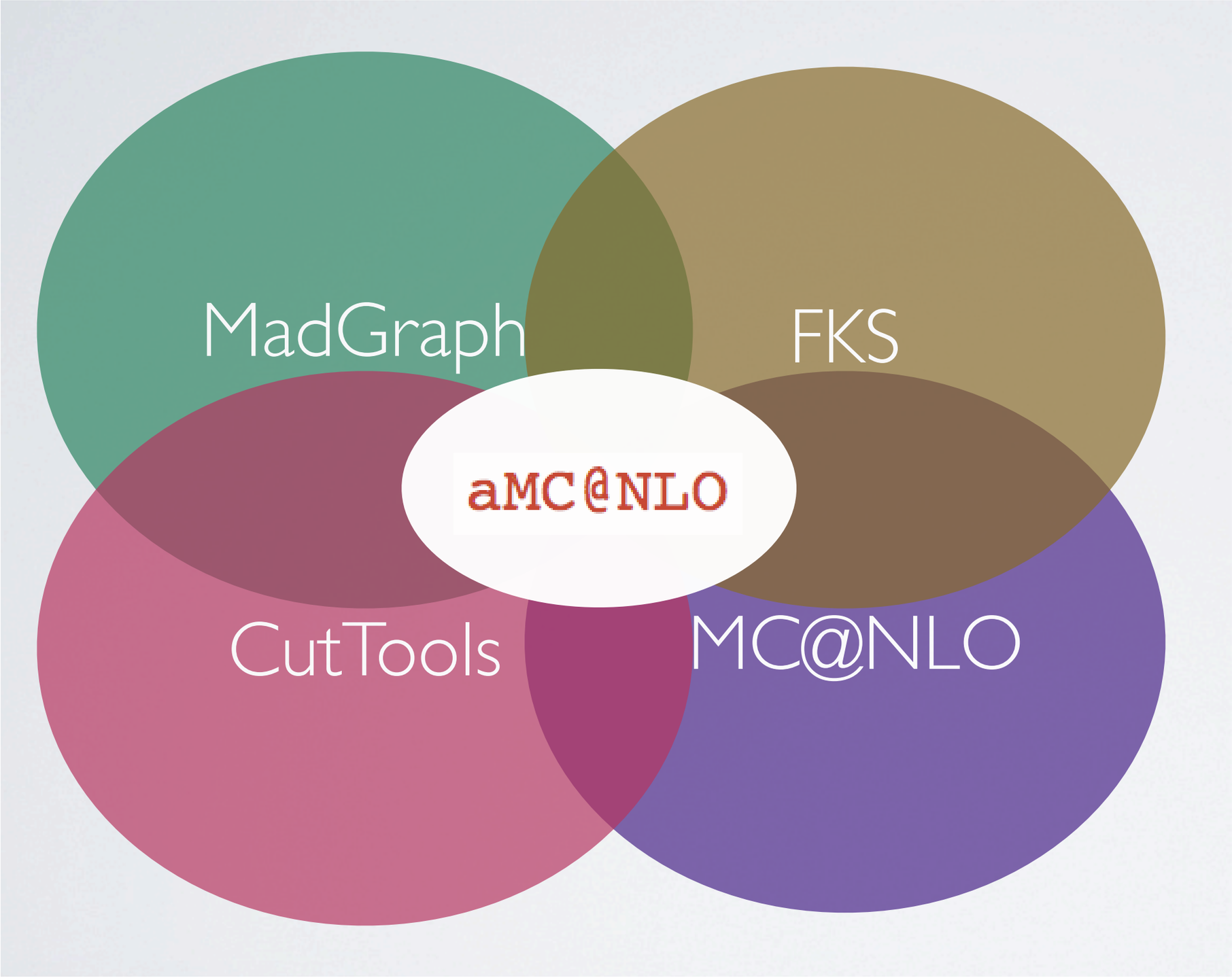
Reweight Module	Re-weigthing Module for multiple theoretical hypotheses	Released*
MadDM / MadWeigth/...	Relic density/ Matrix Element Method/...	

aMC@NLO: A Joint Venture



aMC@NLO

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

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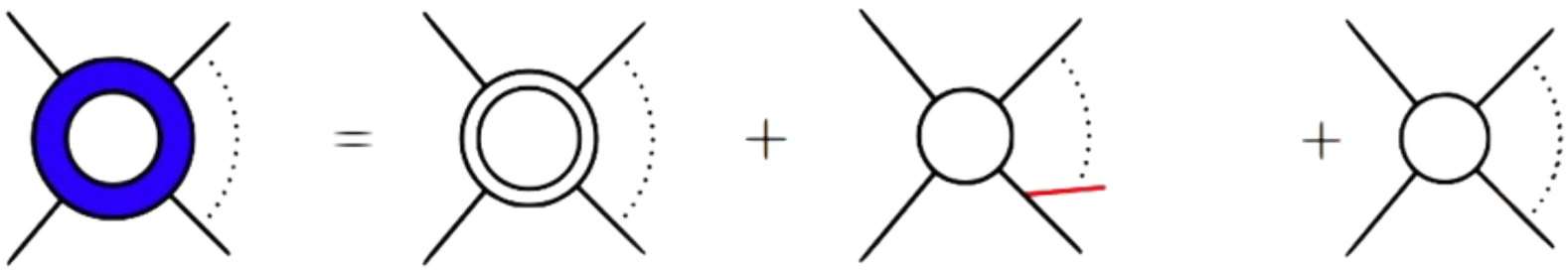
- Why NLO?
  - ➡ Reliable prediction of the total rate
  - ➡ Reduction of the theoretical uncertainty
- Why matched to the PS?
  - ➡ Parton are not an detector observables
  - ➡ Matching cure some fix-order ill behaved observables

NLO Basics

NLO Virtual Real Born



$$\sigma^{NLO} = \int_m d^{(d)}\sigma^V + \int_{m+1} d^{(d)}\sigma^R + \int_m d^{(4)}\sigma^B$$

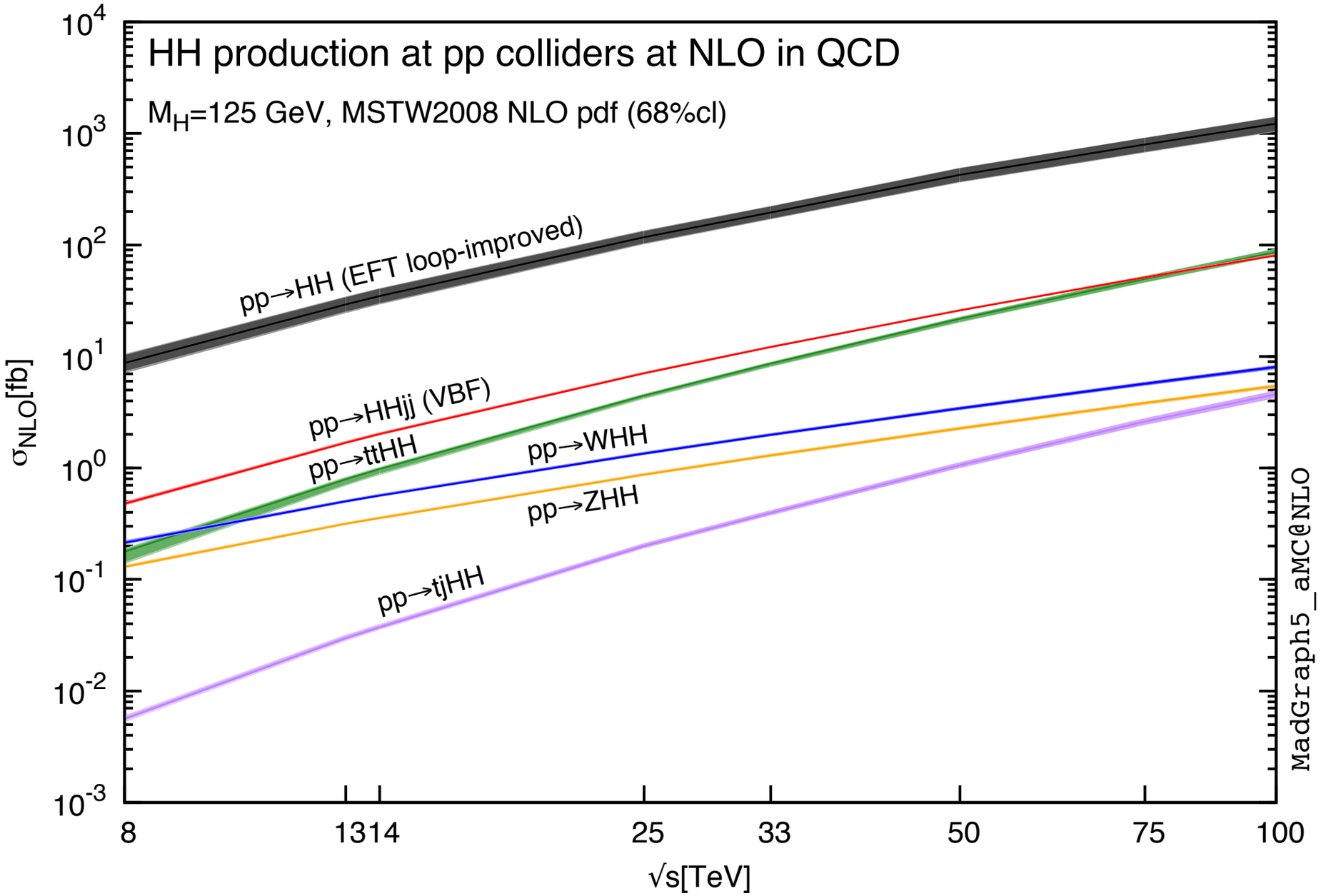
Need to deal with singularities

$$\sigma^{NLO} = \int_m d^{(d)}(\sigma^V + \int_1 d\phi_1 C) + \int_{m+1} d^{(d)}(\sigma^R - C) + \int_m d^{(4)}\sigma^B$$

MadLoop MadFKS MadGraph

Currently only for the SM and NLO in QCD

Pair Higgs Production



[Frederix, Frixione, Hirschi, Maltoni, Mattelaer, Torrielli, Vryonidou, Zaro (2014)]

Single Higgs Results: Double Higgs

Process		Syntax	Cross section (pb) NLO 13 TeV	
Single Higgs production				
g.1	$pp \to H$ (HEFT)	`p p > h`		
g.2	$pp \to Hj$ (HEFT)	`p p > h j`		
g.3	$pp \to Hjj$ (HEFT)	`p p > h j j`		
g.4	$pp \to Hjj$ (VBF)	`p p > h j j $$ w+ w- z`	$1.900 \pm 0.006 \cdot 10^{0}$	$^{+0.8\%}_{-0.9\%}$ $^{+2.0\%}_{-1.5\%}$
g.5	$pp \to Hjjj$ (VBF)	`p p > h j j j $$ w+ w- z`	$3.085 \pm 0.010 \cdot 10^{-1}$	$^{+2.0\%}_{-3.0\%}$ $^{+1.5\%}_{-1.1\%}$
g.6	$pp \to HW^{\pm}$	`p p > h wpm`	$1.419 \pm 0.005 \cdot 10^{0}$	$^{+2.1\%}_{-2.6\%}$ $^{+1.9\%}_{-1.4\%}$
g.7	$pp \to HW^{\pm}j$	`p p > h wpm j`	$4.842 \pm 0.017 \cdot 10^{-1}$	$^{+3.6\%}_{-3.7\%}$ $^{+1.2\%}_{-1.0\%}$
g.8*	$pp \to HW^{\pm}jj$	`p p > h wpm j j`	$1.574 \pm 0.014 \cdot 10^{-1}$	$^{+5.0\%}_{-6.5\%}$ $^{+0.9\%}_{-0.6\%}$
g.12	$pp \to HZ$	`p p > h z`	$7.674 \pm 0.027 \cdot 10^{-1}$	$^{+2.0\%}_{-2.5\%}$ $^{+1.9\%}_{-1.4\%}$
g.13	$pp \to HZj$	`p p > h z j`	$2.667 \pm 0.010 \cdot 10^{-1}$	$^{+3.5\%}_{-3.6\%}$ $^{+1.1\%}_{-0.9\%}$
g.14*	$pp \to HZjj$	`p p > h z j j`	$8.753 \pm 0.037 \cdot 10^{-2}$	$^{+4.8\%}_{-6.3\%}$ $^{+0.7\%}_{-0.6\%}$
g.15*	$pp \to HW^{+}W^{-}(4flav)$	`p p > h w+ w-`	$1.065 \pm 0.003 \cdot 10^{-2}$	$^{+2.5\%}_{-1.9\%}$ $^{+2.0\%}_{-1.5\%}$
g.16*	$pp \to HW^{\pm}\gamma$	`p p > h wpm a`	$3.309 \pm 0.011 \cdot 10^{-3}$	$^{+2.7\%}_{-2.0\%}$ $^{+1.7\%}_{-1.4\%}$
g.17*	$pp \to HZW^{\pm}$	`p p > h z wpm`	$5.292 \pm 0.015 \cdot 10^{-3}$	$^{+3.9\%}_{-3.1\%}$ $^{+1.8\%}_{-1.4\%}$
g.18*	$pp \to HZZ$	`p p > h z z`	$2.538 \pm 0.007 \cdot 10^{-3}$	$^{+1.9\%}_{-1.4\%}$ [illegible]
g.19	$pp \to Ht\bar{t}$	`p p > h t t~`	4.608 ± 0.0[illegible] $\cdot 10$[illegible]	[illegible]
g.20	$pp \to Htj$	`p p > h tt j`		
g.21	$pp \to Hb\bar{b}$	`p p > h b b~`		
g.22	$pp \to Ht\bar{t}j$	`p p > h t t~ j`	$3.244 \pm 0.025 \cdot 1$[illegible]$^{-1}$	$^{+3.5\%}_{-8.7\%}$ $^{+2.5\%}_{-2.9\%}$
g.23*	$pp \to Hb\bar{b}j$	`p p > h b b~ j`		

Process		Syntax	Cross section (pb) NLO 13 TeV	
Higgs pair production				
h.1	$pp \to HH$ (HEFT)	`p p > h h`		
h.2	$pp \to HHjj$ (VBF)	`p p > h h j j`		
h.3	$pp \to HHW^{\pm}$	`p p > h h wpm`	$5.002 \pm 0.014 \cdot 10^{-4}$	$^{+1.5\%}_{-1.2\%}$ $^{+2.0\%}_{-1.6\%}$
h.4	$pp \to HHZ$	`p p > h h z`	$3.130 \pm 0.008 \cdot 10^{-4}$	$^{+1.6\%}_{-1.2\%}$ $^{+2.0\%}_{-1.5\%}$
h.5	$pp \to HHt\bar{t}$	`p p > h h t t~`	$7.301 \pm 0.024 \cdot 10^{-4}$	$^{+1.4\%}_{-5.7\%}$ $^{+2.2\%}_{-2.3\%}$
h.6	$pp \to HHtj$	`p p > h h tt j`		

Preliminary

Double Gauge

Process		Syntax	Cross section (pb) NLO 13 TeV	
Vector-boson pair +jets				
b.1	$pp \to W^{+}W^{-}$ (4f)	`p p > w+ w-`	$1.028 \pm 0.003 \cdot 10^{2}$	$^{+4.0\%}_{-4.5\%}$ $^{+1.9\%}_{-1.4\%}$
b.2	$pp \to ZZ$	`p p > z z`	$1.415 \pm 0.005 \cdot 10^{1}$	$^{+3.1\%}_{-3.7\%}$ $^{+1.8\%}_{-1.4\%}$
b.3	$pp \to ZW^{\pm}$	`p p > z wpm`	$4.487 \pm 0.013 \cdot 10^{1}$	$^{+4.4\%}_{-4.4\%}$ $^{+1.7\%}_{-1.3\%}$
b.4	$pp \to \gamma\gamma$	`p p > a a`	$6.593 \pm 0.021 \cdot 10^{1}$	$^{+17.6\%}_{-18.8\%}$ $^{+2.0\%}_{-1.9\%}$
b.5	$pp \to \gamma Z$	`p p > a z`	$3.695 \pm 0.013 \cdot 10^{1}$	$^{+5.4\%}_{-7.1\%}$ $^{+1.8\%}_{-1.4\%}$
b.6	$pp \to \gamma W^{\pm}$	`p p > a wpm`	$7.124 \pm 0.026 \cdot 10^{1}$	$^{+9.7\%}_{-9.9\%}$ $^{+1.5\%}_{-1.3\%}$
b.7	$pp \to W^{+}W^{-}j$ (4f)	`p p > w+ w- j`	$3.730 \pm 0.013 \cdot 10^{1}$	$^{+4.9\%}_{-4.9\%}$ $^{+1.1\%}_{-0.8\%}$
b.8	$pp \to ZZj$	`p p > z z j`	$4.830 \pm 0.016 \cdot 10^{0}$	$^{+5.0\%}_{-4.8\%}$ $^{+1.1\%}_{-0.9\%}$
b.9	$pp \to ZW^{\pm}j$	`p p > z wpm j`	$2.086 \pm 0.007 \cdot 10^{1}$	$^{+4.9\%}_{-4.8\%}$ $^{+0.9\%}_{-0.7\%}$
b.10	$pp \to \gamma\gamma j$	`p p > a a j`	$2.292 \pm 0.010 \cdot 10^{1}$	$^{+17.2\%}_{-15.1\%}$ $^{+1.0\%}_{-1.4\%}$
b.11*	$pp \to \gamma Zj$	`p p > a z j`	$1.220 \pm 0.005 \cdot 10^{1}$	$^{+7.3\%}_{-7.4\%}$ $^{+0.9\%}_{-0.9\%}$
b.12*	$pp \to \gamma W^{\pm}j$	`p p > a wpm j`	$3.713 \pm 0.015 \cdot 10^{1}$	$^{+7.2\%}_{-7.1\%}$ $^{+0.9\%}_{-1.0\%}$
b.13	$pp \to W^{+}W^{+}jj$	`p p > w+ w+ j j`	$2.251 \pm 0.011 \cdot 10^{-1}$	$^{+10.5\%}_{-10.6\%}$ $^{+2.2\%}_{-1.6\%}$
b.14	$pp \to W^{-}W^{-}jj$	`p p > w- w- j j`	$1.003 \pm 0.003 \cdot 10^{-1}$	$^{+10.1\%}_{-10.4\%}$ $^{+2.5\%}_{-1.8\%}$
b.15	$pp \to W^{+}W^{-}jj$ (4f)	`p p > w+ w- j j`	$1.396 \pm 0.005 \cdot 10^{1}$	$^{+5.0\%}_{-6.8\%}$ $^{+0.7\%}_{-0.6\%}$
b.16	$pp \to ZZjj$	`p p > z z j j`	$1.706 \pm 0.011 \cdot 10^{0}$	$^{+5.8\%}_{-7.2\%}$ $^{+0.8\%}_{-0.6\%}$
b.17	$pp \to ZW^{\pm}jj$	`p p > z wpm j j`	$9.139 \pm 0.031 \cdot 10^{0}$	$^{+3.1\%}_{-5.1\%}$ $^{+0.7\%}_{-0.5\%}$
b.18	$pp \to \gamma\gamma jj$	`p p > a a j j`	$7.501 \pm 0.032 \cdot 10^{0}$	$^{+8.8\%}_{-10.1\%}$ $^{+0.6\%}_{-1.0\%}$
b.19*	$pp \to \gamma Zjj$	`p p > a z j j`	$4.242 \pm 0.016 \cdot 10^{0}$	$^{+6.5\%}_{-7.3\%}$ $^{+0.6\%}_{-0.6\%}$
b.20*	$pp \to \gamma W^{\pm}jj$	`p p > a wpm j j`	$1.448 \pm 0.005 \cdot 10^{1}$	$^{+3.6\%}_{-5.4\%}$ $^{+0.6\%}_{-0.7\%}$

Pair of heavy Quark

Process		Syntax	Cross section (pb) NLO 13 TeV	
Single-top				
f.1	$pp \to tj$ (t-channel)	`p p > tt j $$ w+ w-`	$1.563 \pm 0.005 \cdot 10^{2}$	$^{+1.4\%}_{-1.8\%}$ $^{+0.4\%}_{-0.6\%}$
f.2	$pp \to t\gamma j$ (t-channel)	`p p > tt a j $$ w+ w-`	$1.017 \pm 0.003 \cdot 10^{0}$	$^{+1.3\%}_{-1.2\%}$ $^{+0.8\%}_{-0.9\%}$
f.3	$pp \to tZj$ (t-channel)	`p p > tt z j $$ w+ w-`	$6.993 \pm 0.021 \cdot 10^{-1}$	$^{+1.6\%}_{-1.1\%}$ $^{+0.9\%}_{-1.0\%}$
f.4*	$pp \to tjj$ (t-channel)	`p p > tt j j $$ w+ w-`	POLES DO NOT CANCEL	
f.5*	$pp \to t\gamma jj$ (t-channel)	`p p > tt a j j $$ w+ w-`	POLES DO NOT CANCEL	
f.6*	$pp \to tZjj$ (t-channel)	`p p > tt z j j $$ w+ w-`	POLES DO NOT CANCEL	
f.7	$pp \to tbj$ (t-channel)	`p p > tt bb j $$ w+ w-`	$1.319 \pm 0.003 \cdot 10^{2}$	$^{+5.8\%}_{-5.2\%}$ $^{+0.4\%}_{-0.5\%}$
f.8*	$pp \to tbj\gamma$ (t-channel)	`p p > tt bb j a $$ w+ w-`	$8.612 \pm 0.025 \cdot 10^{-1}$	$^{+6.2\%}_{-6.6\%}$ $^{+0.8\%}_{-0.9\%}$
f.9*	$pp \to tbjZ$ (t-channel)	`p p > tt bb j z $$ w+ w-`	$5.657 \pm 0.014 \cdot 10^{-1}$	$^{+7.7\%}_{-7.9\%}$ $^{+0.9\%}_{-0.9\%}$
f.10	$pp \to tb$ (s-channel)	`p p > w+ > t b~, p p > w- > t~ b`	$1.001 \pm 0.004 \cdot 10^{1}$	$^{+3.7\%}_{-3.9\%}$ $^{+1.9\%}_{-1.5\%}$
f.11*	$pp \to tb\gamma$ (s-channel)	`p p > w+ > t b~ a, p p > w- > t~ b a`	$1.952 \pm 0.007 \cdot 10^{-2}$	$^{+2.6\%}_{-2.3\%}$ $^{+1.7\%}_{-1.4\%}$
f.12*	$pp \to tbZ$ (s-channel)	`p p > w+ > t b~ z, p p > w- > t~ b z`	$1.539 \pm 0.005 \cdot 10^{-2}$	$^{+3.9\%}_{-3.2\%}$ $^{+1.9\%}_{-1.5\%}$

But No Loop Induce

Top-quark pair production at LC

Preliminary

top-pair production at LC

- e+ e- > t t~ [QCD]
  - ➡ 6.23e-01pb (250GeV+250GeV)
  - ➡ less than 60s computation
- e+ e- > W+ b W- b~ [QCD]
  - ➡ require complex mass scheme
  - ➡ 5.44998365e-01 pb
  - ➡ couple of hours
- e+ e- > b b~ mu- vm ta+ vt [QCD]
  - ➡ require complex mass scheme
  - ➡ 5.591e-3 pb
  - ➡ 3 days of running

first time computed

Offshell effect at NLO

- Diagrams with unstable particles present in general an imaginary part in the Dyson-ressumed propagator:

$$P(p) = [p^2 - m_0^2 + Pi(p^2)]^{-1}$$

- Mixing of different perturbative orders breaks gauge invariance. Fine cancellations spoiled, leading to enhanced violation of unitarity
- No pole cancelation at NLO for fix-width scheme
- Solution: Complex Mass-Scheme: $M \to \sqrt{M^2 - iM\Gamma}$,

$$c_W^2 = \frac{M_w^2 + iM_W\Gamma_W}{M_Z^2 + iM_Z\Gamma_Z}$$

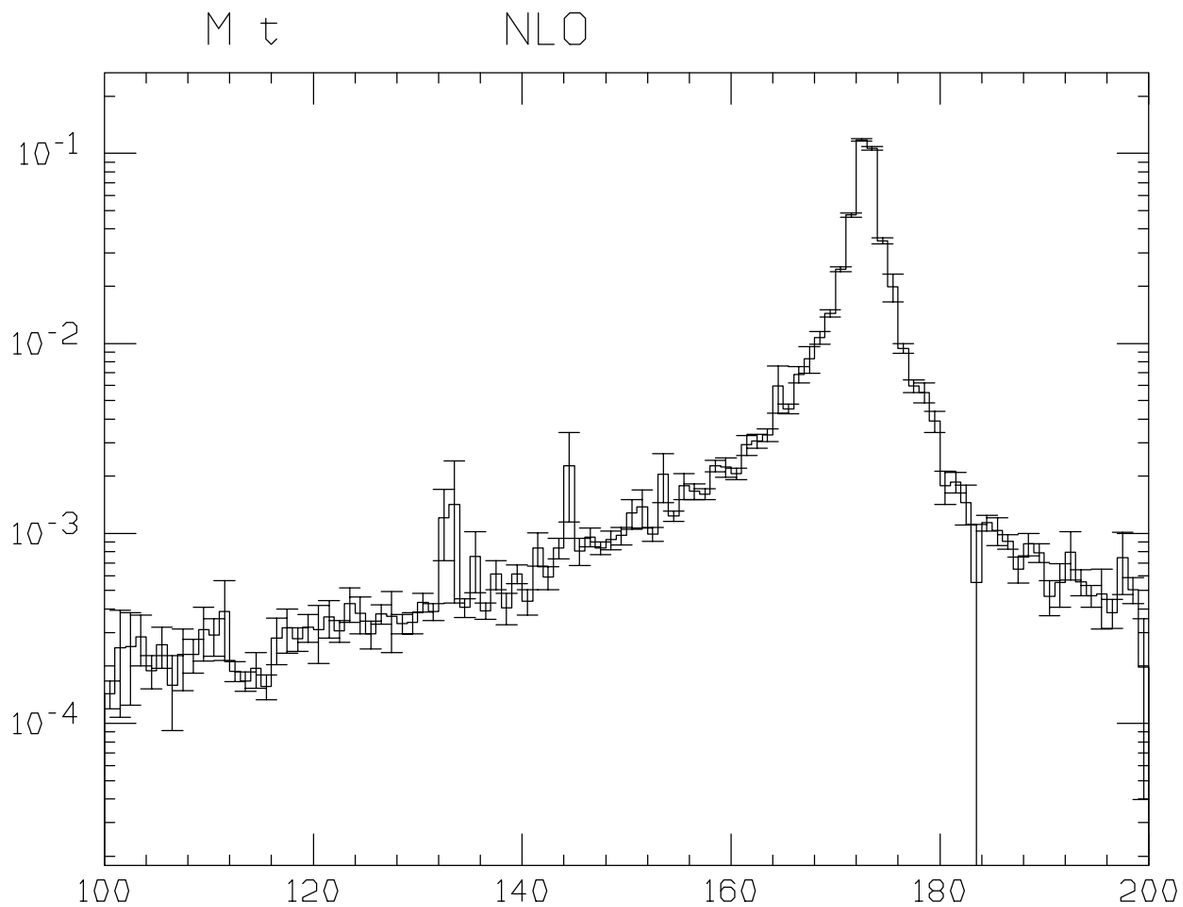
Gauge dependence at LO

$\|A\|^2$ - |Feynman-unitary|/unitary	complex mass	fixed width
$e^+e^- \to u\bar{u}d\bar{d}$	1.5334067678e-15	1.2312200197e-09
$u\bar{u} \to u\bar{u}d\bar{d}$	2.0862057616e-16	2.7696013365e-10
$u\bar{u} \to b\bar{b}e^+\nu_e\mu^-\nu_\mu$ (real Yuk)	1.7934842084e-06	2.2832833007e-05
"(complex Yuk)	8.5986902303e-16	2.2832833007e-05

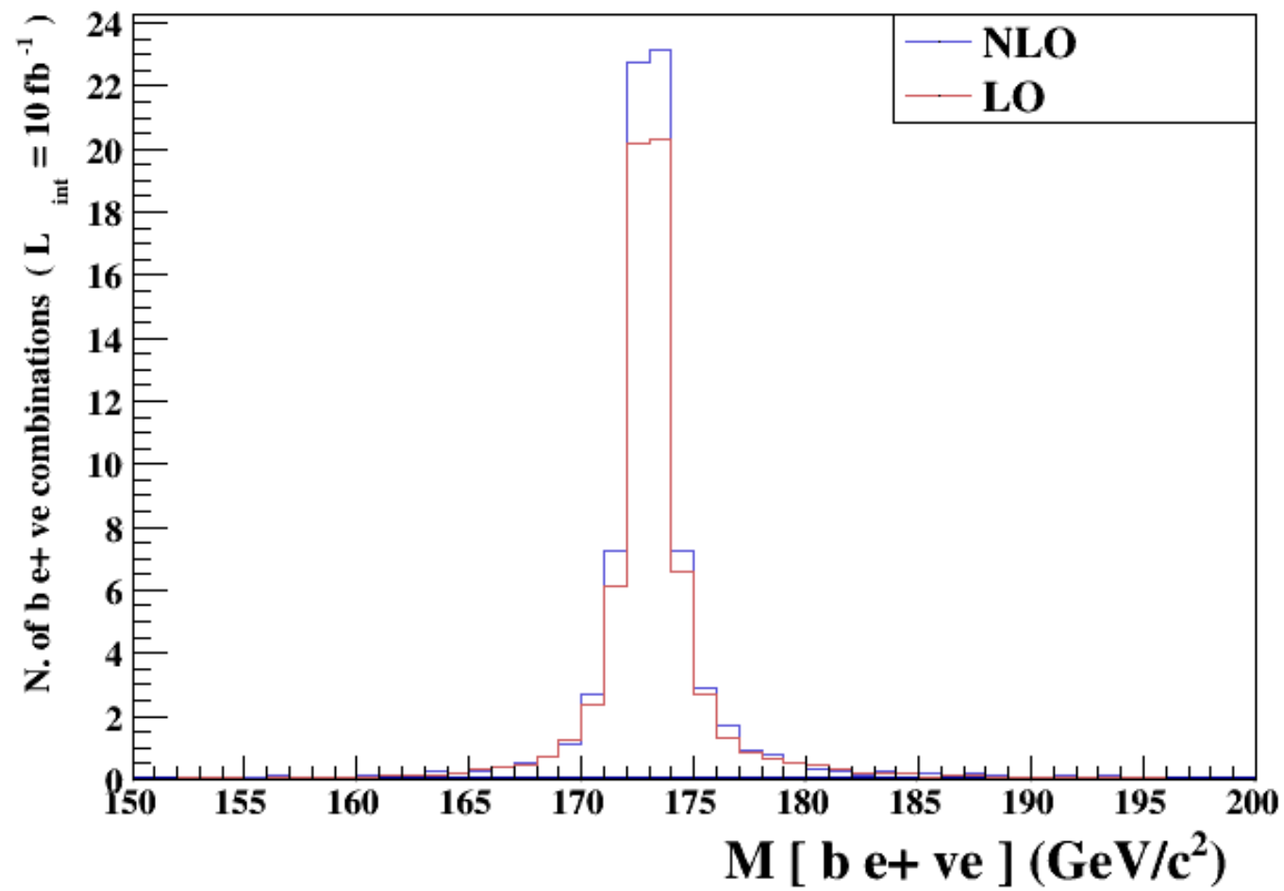
- Complex Mass Scheme restore gauge invariance
  - yukawa coupling must be promoted to complex parameter as well

Offshell effect at NLO

e+ e- > w+ w- b b~



e+ e- > t t~



Conclusion

- MG5_aMC is
  - ➡ public
  - ➡ automatic
  - ➡ flexible
  - ➡ for LHC and LC
- For LO and NLO Generation
  - ➡ Full BSM at LO
  - ➡ New Physics coming at NLO
- Lot of tools
  - ➡ Automatic computation of the width
  - ➡ Decay with Full-Spin correlation
- This is only the beginning of this Tool!