MadGraph 5 – The All-New Matrix Element generator for Everything

Johan Alwall
National Center for Theoretical Sciences
National Taiwan University

For the MadGraph 5 team:
J.A. Michel Herquet (NIKHEF)
Fabio Maltoni (Louvain) Olivier Mattelaer (Louvain)
Tim Stelzer (UIUC)

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What will we need for the LHC?

What will we need for the LHC?

NLO

Exp-TH communication

Very exotic models

Multi-jet samples

Exotic models

Effective theories

Decay chains

Matrix Elements

Advanced analysis techniques

Real corrections

Decay Packages

Merging ME/PS

Cluster/Grid computing

User friendliness

Testing/robustness

MadGraph/MadEvent 4

- One of the most widely used automatized matrix element generators
  - Specify any process using simple syntax
  - > 1500 registered users (+ CDF/D0/CMS/ATLAS/...)
- Originally written by Tim Stelzer in 1994
- Phase space integrator/event generator MadEvent by F. Maltoni and T. Stelzer in 2002
- MadGraph/MadEvent v. 4 in 2006

MadGraph 4

Leading order matrix element generation	$\leq$ 8 FS, <10000 diag Max. W+4 jet/$t\bar{t}$+3 jet
BSM, any renormalizable model	Yes
Decay Chains	Max 8 FS, slow
Color structures	Singlet/triplet/octet
Extended color structures (6, 27, ε^{ijk})	No
Effective theories (>4-particle vx)	No
Recursion relations for multijet generation	No
NLO real corrections	Yes
NLO loop calculations	In progress
Output in any language/format	Only Fortran

Why new MadGraph?

- First version of core code from 1994
- Written in Fortran 77
  - – Fixed array sizes
  - – Limited (no) libraries
  - – No recursion
  - – Complicated file output
  - – Difficult to modularize (no OO, dynamic libraries,...)
  - – Difficult to extend
  - \+ Intrinsically very fast

MadGraph 5

- Development started November 2009
- Modular program structure
  - Diagram generation / Color algebra / Helas objects / Diagram drawing / I/O libraries / ...
- Modern programming techniques
  - "Extreme programming"
  - Complete test suite including extensive module/function testing and integration/parallel tests
  - Functionality first, easy to modify/refactor/optimize/extend

MadGraph 5

Programming language: Python

- (Very) high level (Object Oriented, functional programming, ...)
- Easy to learn/write/maintain, concise (x4 compared to F77)
- Easily available on all platforms and no compilation required
- Slow, but fast standard library (99% of calculations) and easily extendable
- Automatic documentation

Innovations

- Completely new diagram generation algorithm
  - Makes optimal use of model information
  - Improves Helas call optimization by up to 90%
- Efficient multiprocesses (keep full track of discarded process crossings)
- Generic and "smart" new color calculation library
- New, faster and generic diagram drawing library
- Improved fermion flow treatment with Majorana particles
- Very efficient generation of decay chains
- Output formats: Fortran, C++, ...
- User friendly command line interface
- ... and (much) more to come !!!

MadGraph 5

Leading order matrix element generation	No limitations except time W+5 jets/$t\bar{t}$+4 jets realistic
BSM, any renormalizable model	Yes
Decay Chains	No limitations, fast
Color structures	No limitations
Extended color structures (6, 27, ϵ^{ijk})	Available (not yet tested)
Effective theories (>4-particle vx)	Yes, no limitations
Recursion relations for multijets	To be implemented
NLO real corrections	To be implemented
NLO loop calculations	To be implemented
Output in any language/format	No limitations, Fortran (MG/ME 4) available

Present status

Beta v. 0.4.0 available next week!

- Full matrix element generation for any model that is available for MadGraph 4
- Complete Majorana particle treatment
- Full decay chain generation
- Complete MadGraph Standalone and MadEvent output
- Extensively tested against MG 4 (SM+MSSM)

Speed benchmarks

Full MadEvent subprocess directory output, including diagram drawing

Computer: Sony Vaio TZ

Process	MG4	MG5	Definitions	Subprocs (after combine)	Diagrams	Comments
pp > jjj	29.02 s	54.38 s	p, j=u/u~/c/c~/d/d~/s/s~/g	34	307	
pp > jj l+l-	341 s (5:41 min)	258 s (4:18 min)	p, j=u/u~/c/c~/d/d~/s/s~/g l+-=e+-/mu+-/ta+-	108	1216	
pp > jjj e+e-	2444 s (40:44 min)	993 s (16:33 min)	p, j=u/u~/c/c~/d/d~/s/s~b/b~/g	141	9012	
uu~>e+e-e+e-e+e-	772 s (12:52 min)	175 s (2:55 min)		1	3474	MG4: 3194 wavefunctions MG5: 301 wavefunctions
gg > ggggg	2788 s (46:28 min)	1049 s (17:29 min)		1	7245	MadGraph standalone output MG4: 3745 wavefunctions MG5: 898 wavefunctions
pp > jj (W+ > l+vl)	146 s (2:26 min)	70 s (1:10 min)	p, j=u/u~/c/c~/d/d~/s/s~/g l+=e+/mu+/ta+, vl=ve/vm/vt	82	304	
pp > t t~ with full decays	5640 s (1:34 h)	22.0 s	p=u/u~/c/c~/d/d~/s/s~/g W+/W->du/sc/eve/muvm/tavt	27	45	MG4: 12 proc defs MG5: single proc def
pp>sq sq	222 s (3:42 min)	286 s (4:46 min)	p=u/u~/c/c~/d/d~/s/s~/g sq=go/ul/ur/cl/cr/dl/dr/sl/sr+conj	313	475	
gg>(go>u(ul~>u~(n2>Zn1)))(go>ud~x1-)	383 s (7:23 min)	5.2 s		1	6	7 FS decay chain, single diagram
gg>(go>uu~n1)(go>uu~n1)	70 s	5.5 s		1	48	6 FS decay chain, mult.diag.
pp>(go>jjn1)(go>jjn1)	3 h - >>1 year	551 s (9:11 min)	p, j=u/u~/c/c~/d/d~/s/s~/g	144	11008	

Speed benchmarks

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pp > tt~ + decays	1:34 h	22 s	p=u/u~/c/c~/d/d~/s/s~/g W+/W->du/sc/eve/muvm/tavt	27	45	12 proc defs single proc def
pp>sq sq	222 s (3:42 min)	286 s (4:46 min)	p=u/u~/c/c~/d/d~/s/s~/g sq=go/ul/ur/cl/cr/dl/dr/sl/sr+conj	313	475	
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gg>(go>uu~n1)(go>uu~n1)	70 s	5.5 s		1	48	6 FS decay chain, mult.diag.
pp > $(go>jj\chi^0)(go>jj\chi^0)$	>> 1 year	9 min	p, j=u/u~/c/c~/d/d~/s/s~/g	144	11008	

~ 2.5 times faster evaluation for produced matrix elements

Diagram examples

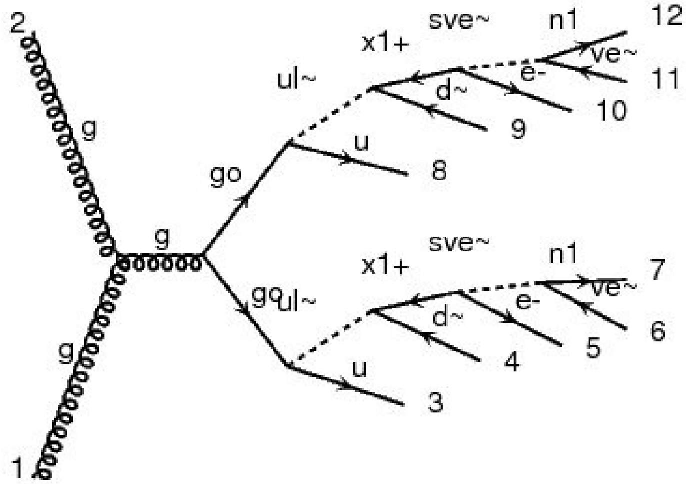


diagram 1

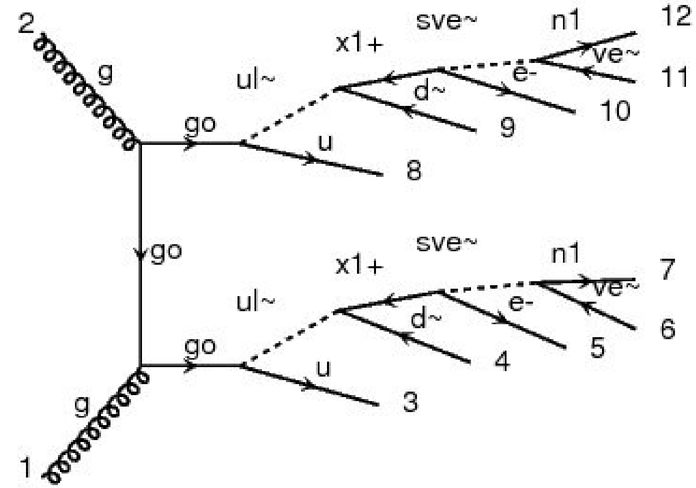


diagram 2

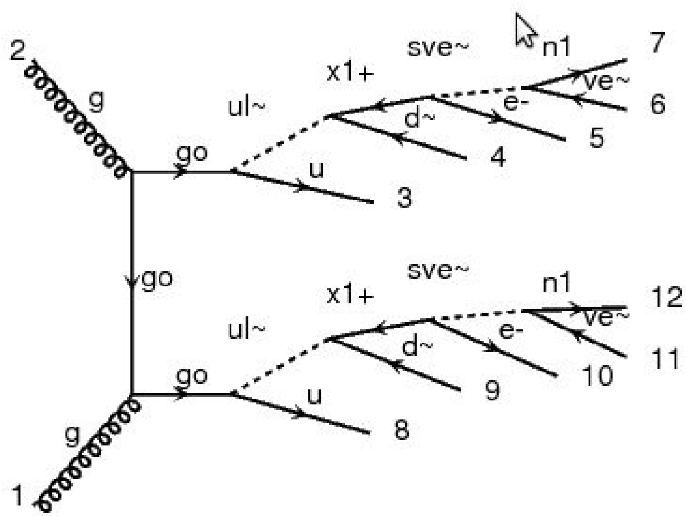
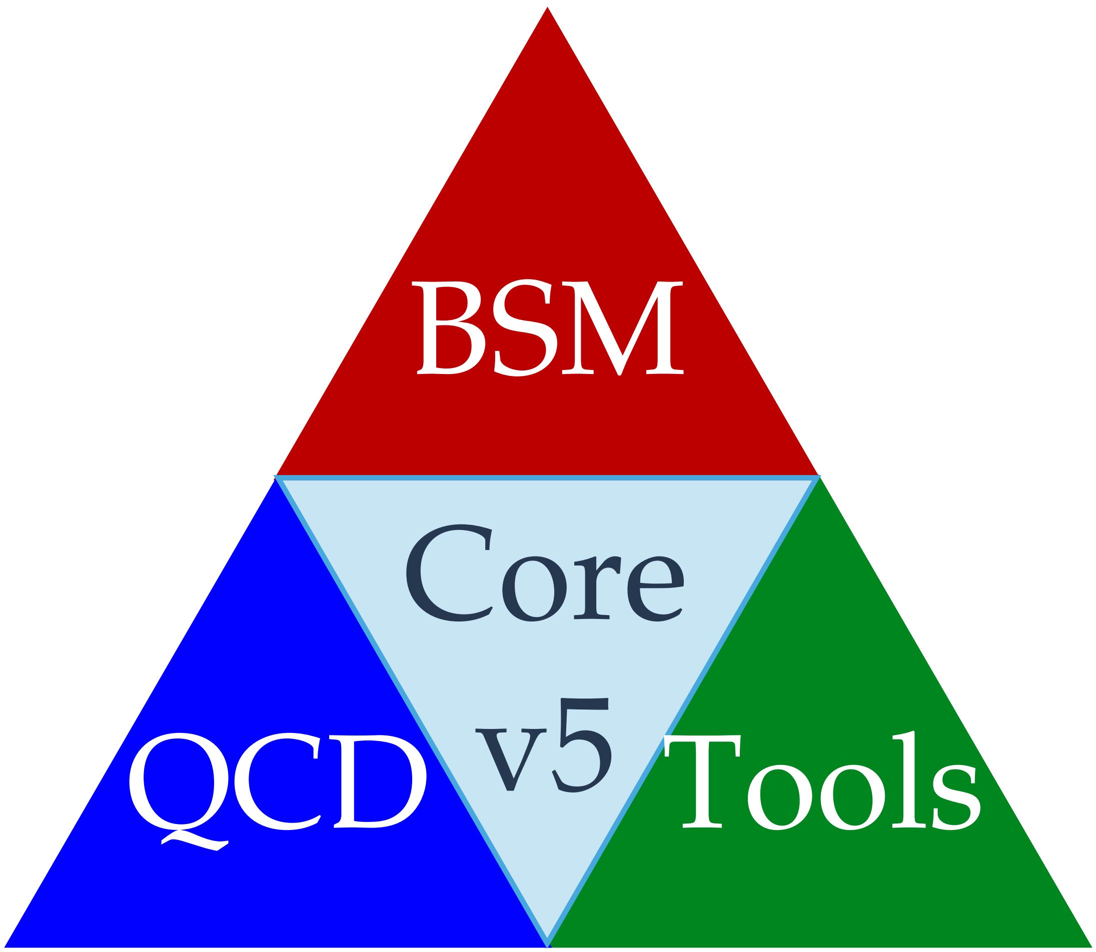


diagram 3

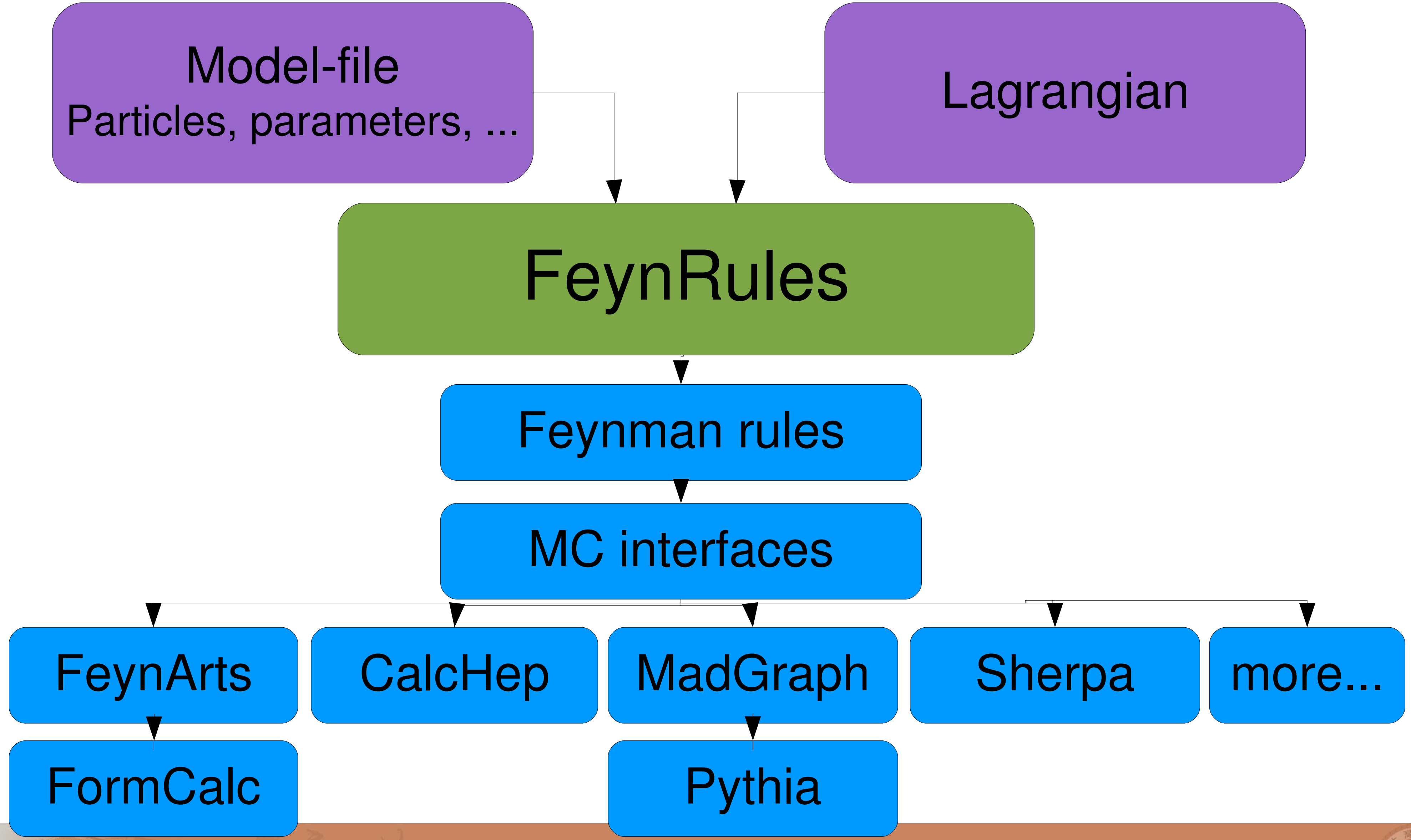
Process: g g > go go
  Decay: go > u ul~
    Decay: ul~ > d~ x1-
      Decay: x1- > e- sve~
        Decay: sve~ > ve~ n1
  Decay: go > u ul~
    Decay: ul~ > d~ x1-
      Decay: x1- > e- sve~
        Decay: sve~ > ve~ n1
(10 FS particles. Generation time: 5 s)

Development directions



Sidenote: FeynRules

[Christiansen, Duhr, arXiv:0806.4194]



MadGraph 5 BSM

- New FeynRules interface including color and Lorentz structures [C. Duhr, M. Herquet, et al]
- Automatic Helicity Amplitude (HELAS) output for any new model (including effective theories)

  [P. de Aquino, W. Link, O. Mattelaer]
- Automatic HELAS routines in Fortran/C/C++/…

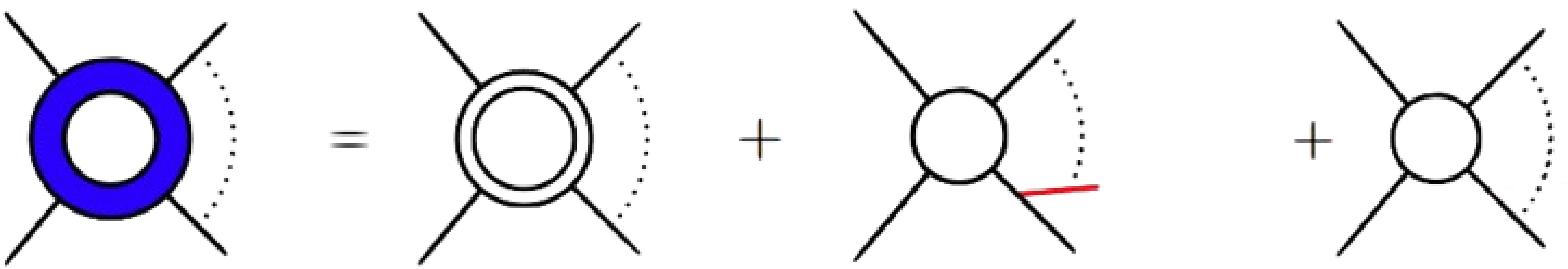
From Lagrangean to matrix elements/ decays/event generation in ANY model!

MadGraph 5 Multijets

- For multijet generation ($\gtrsim$ 4 jets), Feynman diagram formalism expensive (factorial growth)
- Helicity amplitude optimization (in MG4/5) reduces run times by factor ~ 10 for complex processes
- Recursion relations (such as Berhrends-Giele) can reduce run times by additional orders of magnitude
- MG5 perfect framework for implementation and development
- Work started with exciting prospects in near future!

MadGraph NLO

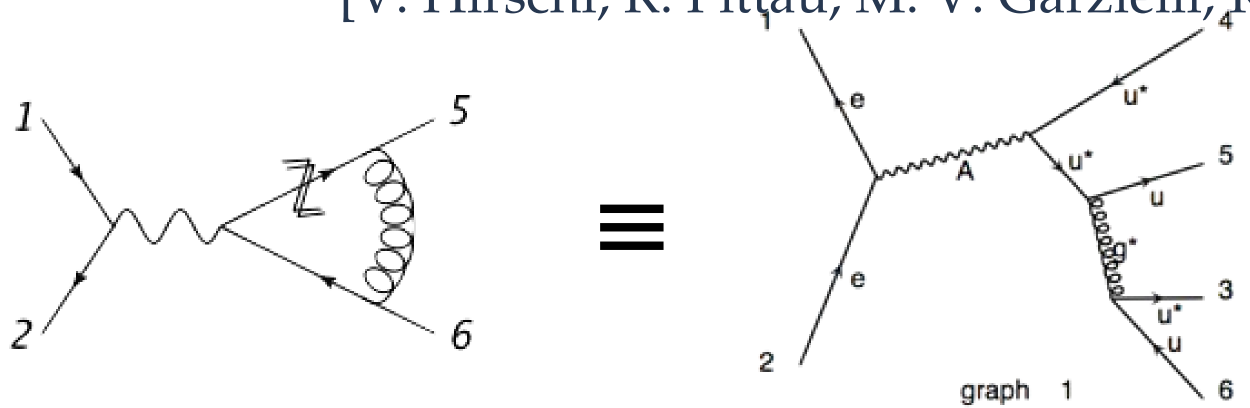
NLO Virtual Real Born



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

MadGraph NLO

- Virtuals: two (complementary) approaches:
  - Use MG to generate diagrams and calculate n+2 amplitudes to build the NLO result (CutTools technique), e+e- $\to$ 2 and 3 jets already checked (MG4). Advantages: valid for any BSM model
    [V. Hirschi, R. Pittau, M. V. Garzielli; R. Frederix]



  - Rely on external tool(s) (BlackHat, Rocket, Golem, ...) using the Binoth-LHA accord. Various e+e- and hadronic processes checked. Advantage: strong optimization possibilities.

MadGraph NLO

- Real contributions: two approaches:

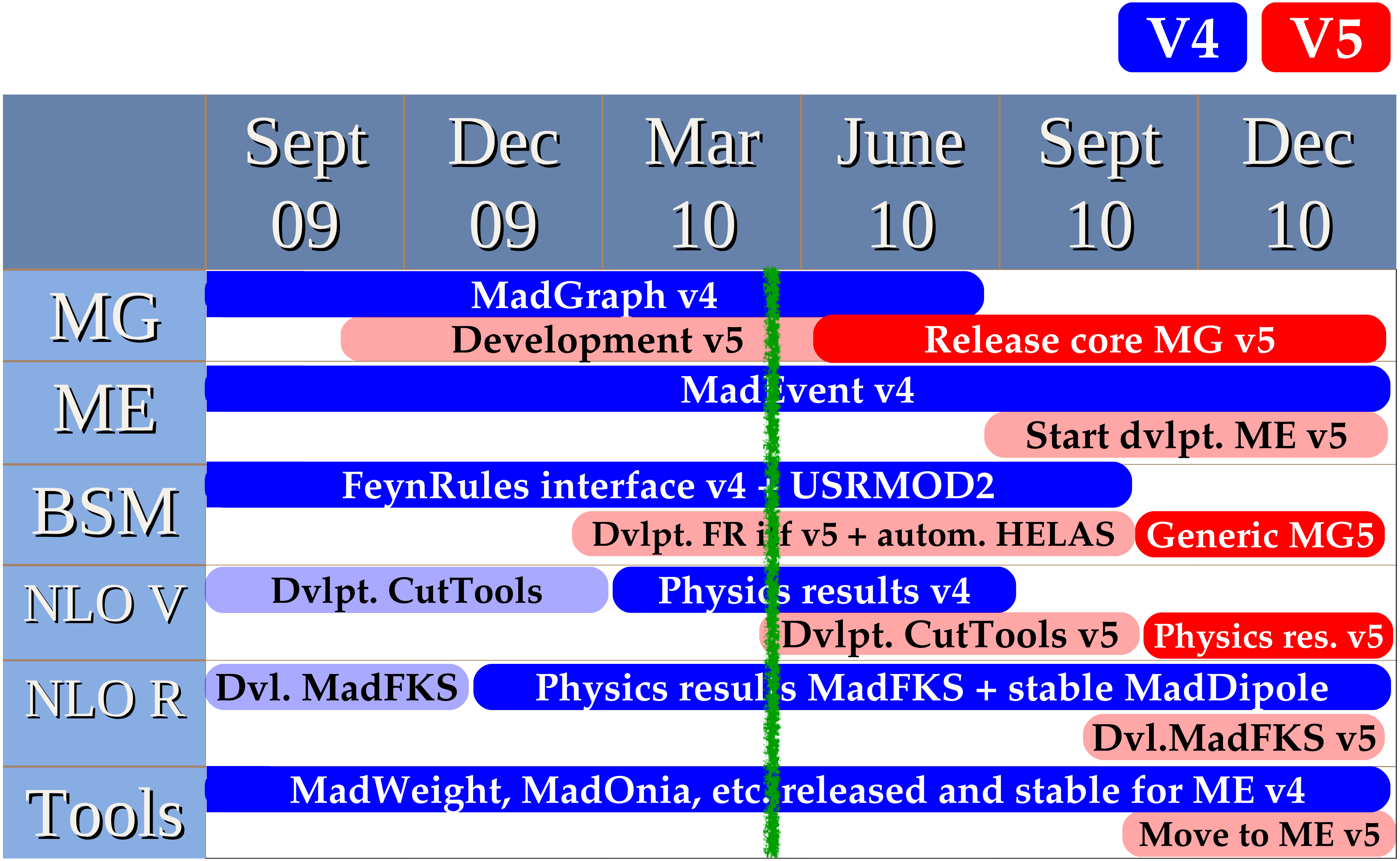
  [R. Frederix, S. Frixione, et al]

  - MadDipole: Catani-Seymour dipole substraction scheme, standalone implementation (TH), cancellation of singularities checked, and dipoles checked against MCFM
  - MadFKS: Frixione-Kunszt-Signer substraction scheme, integration is available (TH+PH), cancellation of singularities checked
- Both: usable both for SM and BSM processes, and for massless and massive external particles

MadGraph 5 NLO

- MadGraph 5 will significantly simplify the continued development efforts for both virtual and real contributions:
  - Clear structure – easy to extract exactly what is needed
  - Modular – Easy to extend with new features
  - Flexible – Output not limited to Fortran

Timeline for MadGraph 5



Conclusions

- MG/ME v4 is a mature, well established and stable code with many features for BSM and QCD physics, and numerous peripheral tools
- MG/ME v5 is here, with important and unprecedented improvements in all directions.
- Beta release of core MadGraph 5 v. 0.4.0 already next week, many developments in the near future!