MADGRAPH 5

The All New Matrix Element Generator for Everything

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F. Maltoni (CP3)
T. Sletzer (UIUC)

J. Alwall (Taiwan)
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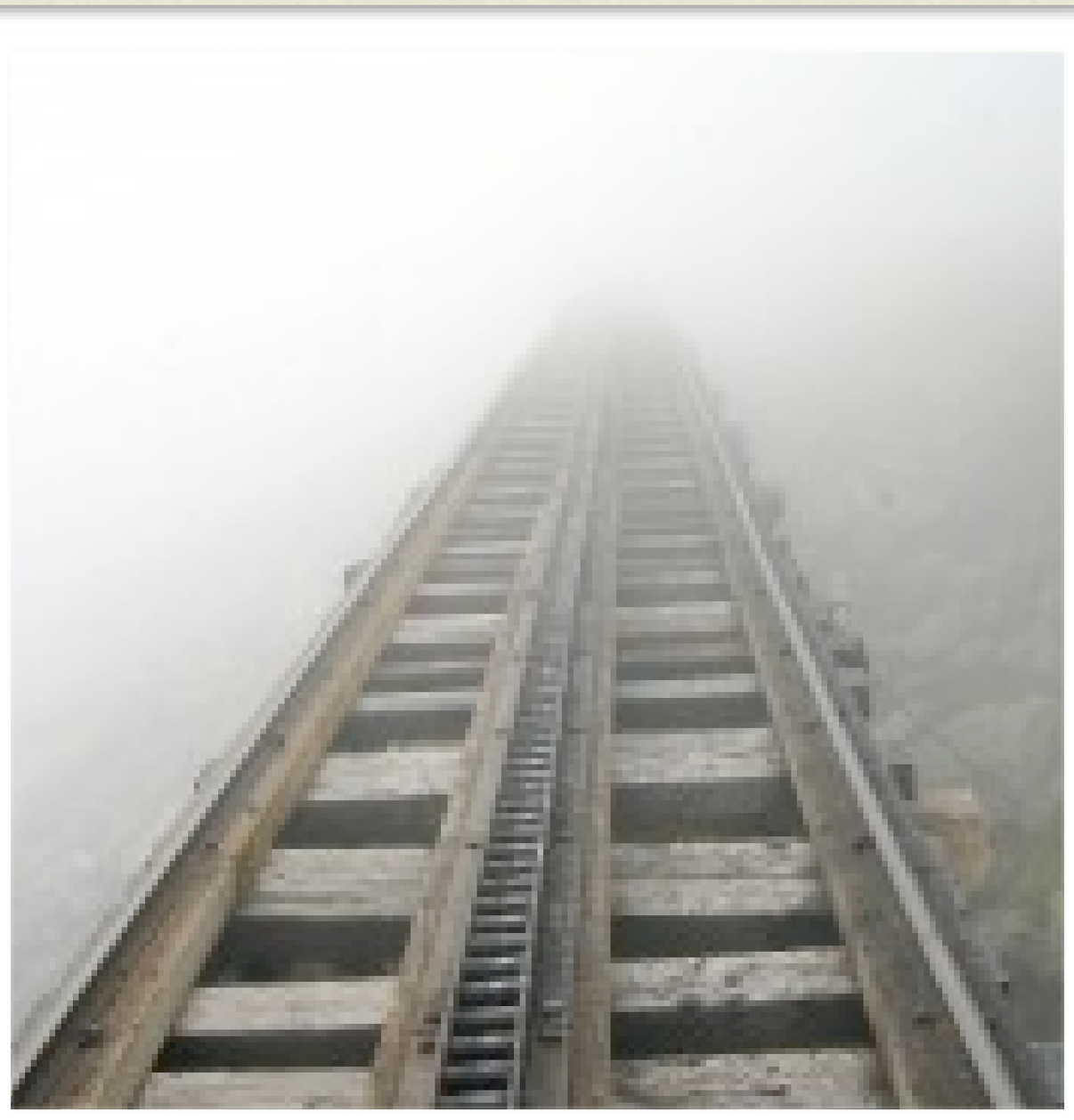
CP3 Lunch: 19/05/10

WHAT WE WILL NEED FOR THE LHC?



WHAT WE WILL NEED FOR THE LHC?

NLO

Exp-TH communication

Very exotic models

Multi-jet samples

Effective theories

Exotic models

Decay chains

Matrix Elements

Advanced analysis techniques

Real corrections

Decay Packages

Merging ME/PS

Cluster/Grid computing

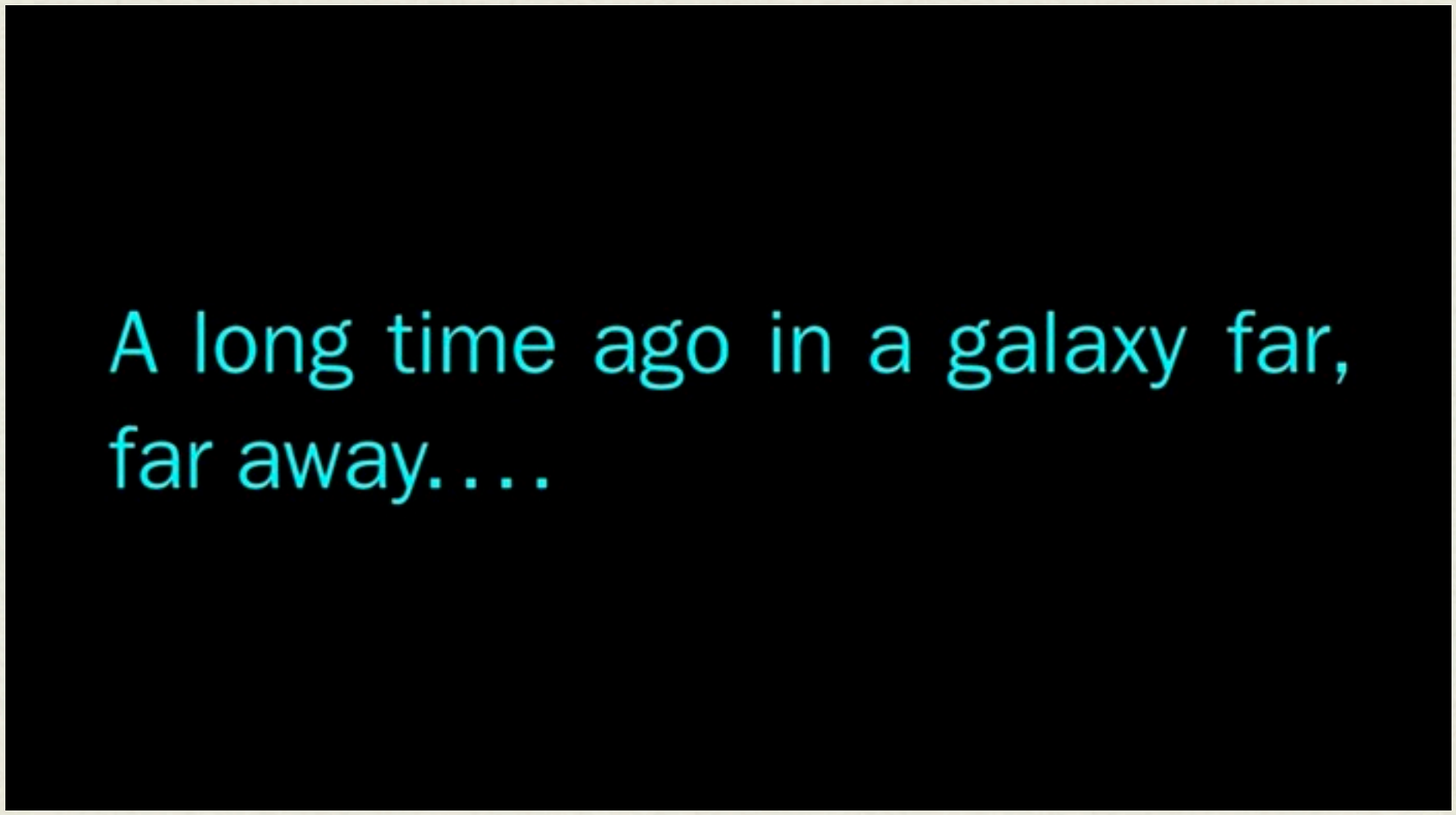
User friendliness

Testing/robustness

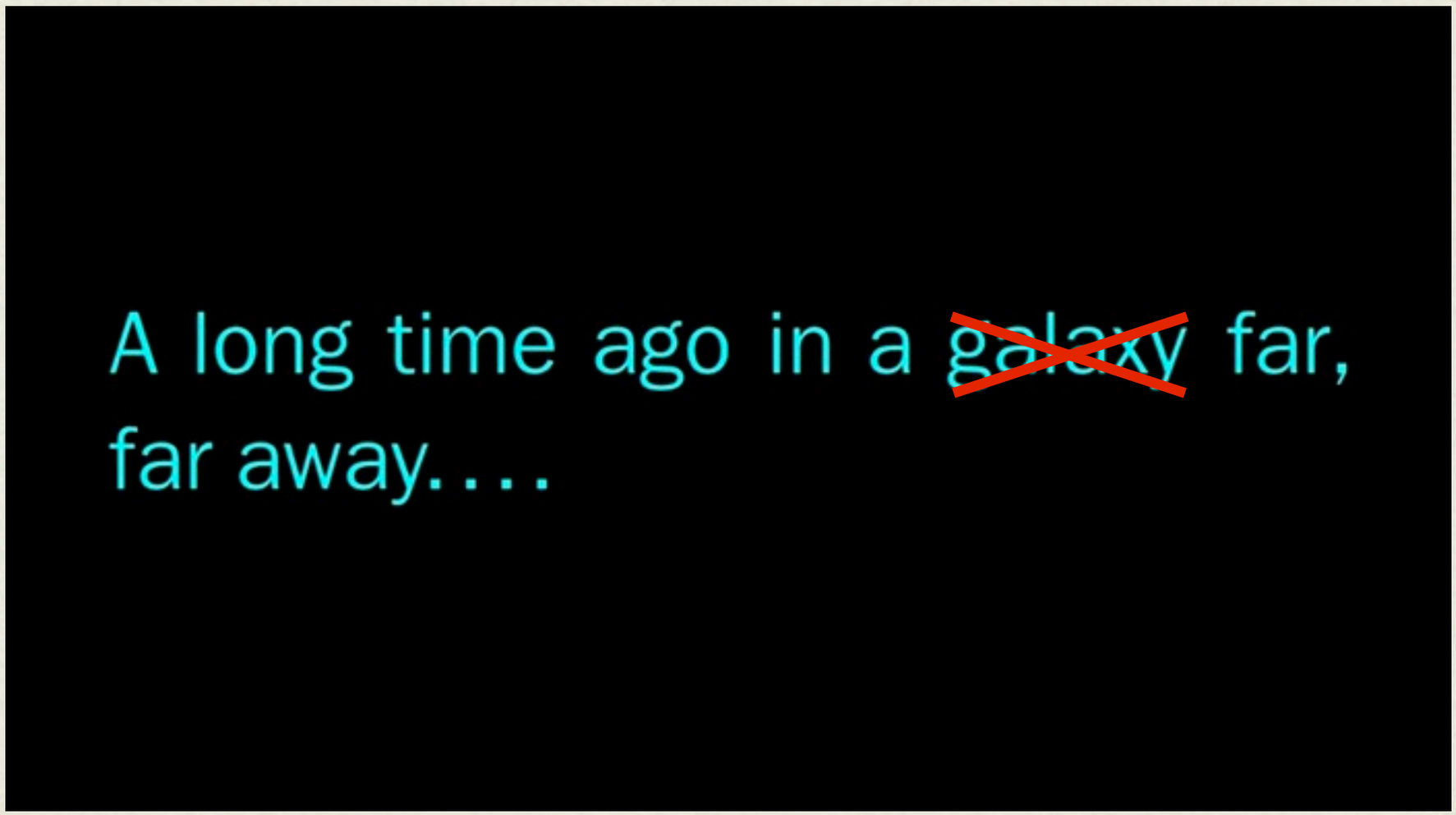
MADGRAPH/MADEVENT4

- One of the most widely used matrix element event generator
  - Specify any process using simple syntax
  - More than 1500 users (CMS/ATLAS/DO/CDF/...)

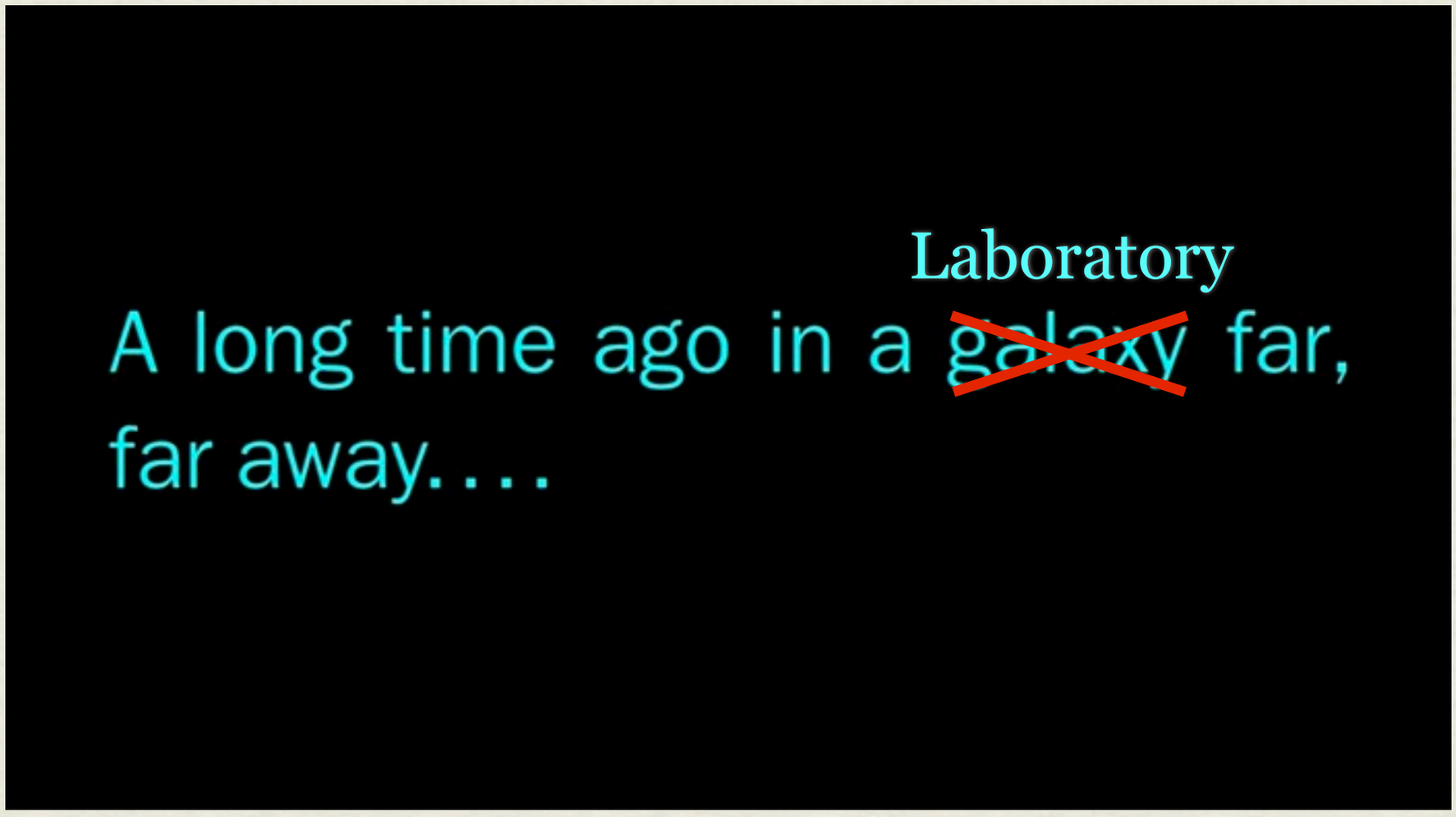
MADGRAPH/MADEVENT4



MADGRAPH/MADEVENT4



MADGRAPH/MADEVENT4



MADGRAPH/MADEVENT4

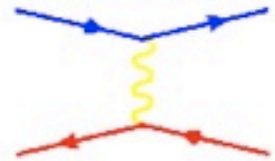
- One of the most widely used matrix element event generator
  - Specify any process using simple syntax
  - More than 1500 users (CMS/ATLAS/DO/CDF/...)
- Originally written by T. Sletzer in 1994
- Phase Space Integrator/Event Generator MadEvent in 2002. (F. Maltoni & T. Sletzer)
- MadGraph v4 in 2006

MADGRAPH/MADEVENT4

MadGraph Version 4

UCL UIUC Fermi

by the MG/ME Development team



Generate Process | Register | Tools | My Database | Cluster Status | Downloads (needs registration) | Wiki/Docs | Admin

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Code can be generated either by:

I. Fill the form:

Model: SM — Model descriptions

Input Process: — Examples

Max QCD Order: 99

Max QED Order: 99

p and j definitions: p=j=d u s c d~ u~ s~ c~ g

sum over leptons: l+ = e+, mu+ ; l- = e-, mu- ; vl = ve, vm ; vl~ = ve~, vm~

Submit

MADGRAPH 4 CHECKLIST

Leading order matrix element generation	≤ 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 A MADGRAPH 5

- First version of the core code from 1994
- Written in fortran 77
  - Fixed array size
  - Limited (no) Libraries
  - No pointer/ No recursion
  - Complicated file output
  - No Object Oriented (not modular)
  - Difficult to extend
  - But intrinsically very fast

MADGRAPH 5

- Development starts in September 2009 at MadGraph 2009
- Modular Program Structure
  - Diagram Generation/ Color Algebra / Helas Object / diagram drawing / IO libraries
- Modern Programming Technique
  - Complete test suite including extensive module/function testing
  - “Extreme Programming”

MADGRAPH 5

MadGraph Version 4

UCL UIUC Fermi

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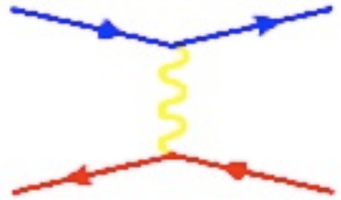
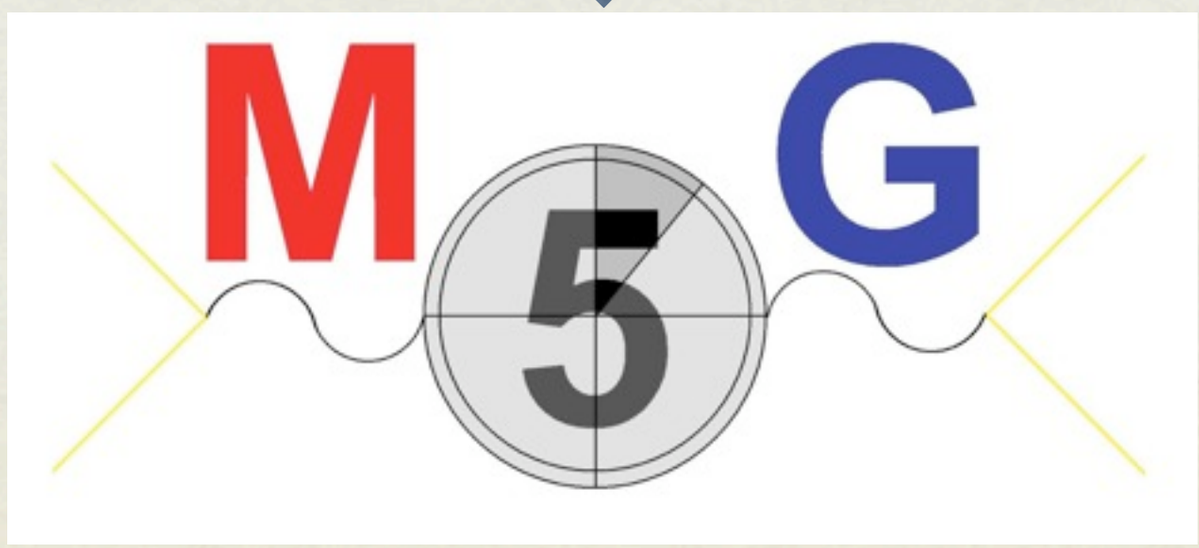


python™



WHY PYTHON?

- (Very) High Level (object oriented, functional programming, multi-heritage, ...)
- Easy to learn, to write, to read and to maintain.
  - Example: the memory is automatically cleaned
- Easily Available on all computers, no compilation required
- Slow but fast library (90% of the computation)
- 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 Multiprocess (keep track of discarded process crossing)
- Generic and smart new color calculation library
- faster and generic diagram drawing
- Very efficient decay chain package
- 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 0.4.0 available since last week
Beta 0.4.1 available today (MG5 on the web)

- Full Matrix Element generation for any v4 model
- Complete Majorana treatment
- Full decay chain generation
- Complete MadGraph StandAlone / Madevent Output
- Secure mode in order to run on the web
- Extensively tested against MG4 (SM + MSSM)

SPEED BENCHMARK

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 BENCHMARK

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	
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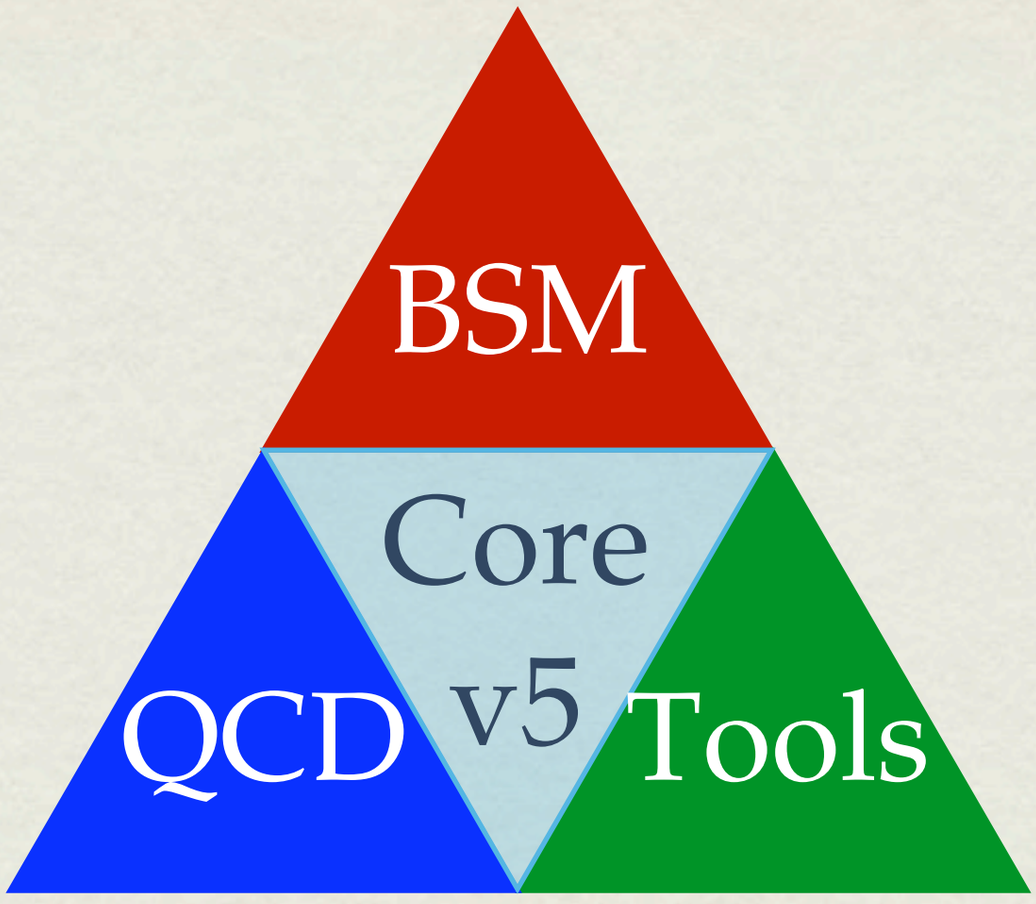
pp > jjj e+e-	40 min	16 min	p, j=u/u~/c/c~/d/d~/s/s~b/b~/g	141	9012	
uu~>e+e-e+e-e+e-	772 s (12:52 min)	175 s (2:55 min)		1	3474	
uu~ > e+e-e+e-e+e-	8 s (46:28 min)	1049 s (17:29 min)		1	7245	MG5: 898 wavefunctions
pp > jj (W+ > l+vl)	146 s (2:26 min)	70 s (1:10 min)	p, j=u/u~/c/c~/d/d~/s/s~/g l+=e+/mu+/ta+, vl=ve/vm/vt	82	304	
pp > 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	
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>jjx^0)(go>jjx^0)	>> 1 year	9 min	p, j=u/u~/c/c~/d/d~/s/s~/g	144	11008	

MG4: 3194 wfs
MG5: 301 wfs

~ 2.5 times faster evaluation for produced matrix elements

DEVELOPMENT DIRECTIONS



BSM : UFO

UFO = Universal Feynrules Output

- New FeynRules (python) output including color and lorentz structures. Output for golem-herwig-MG5 [Duhr et al]

- Automatic Helas Amplitude Generation for any new model (including effective theory) [P. de Aquino, W. Link, OM]
  - Output for fortran/C++
  - reproduces the SM and spin2

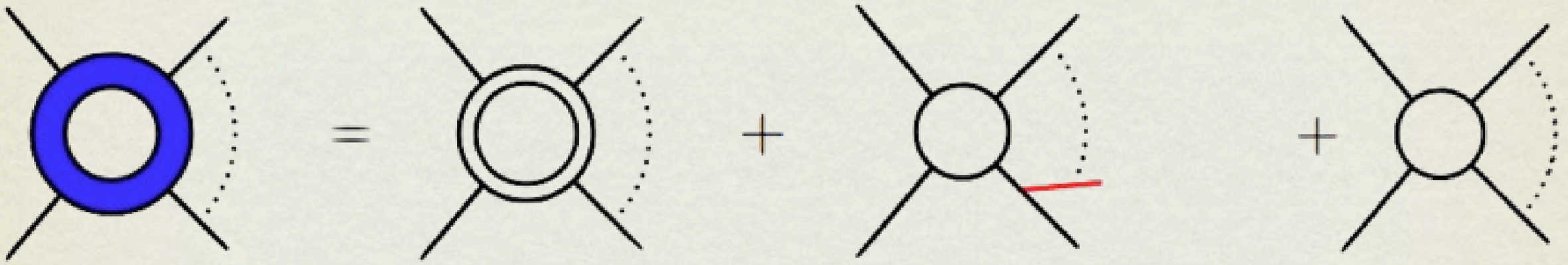
From Lagrangian to event generation in ANY model

MULTIJETS

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

MADGRAPH NLO

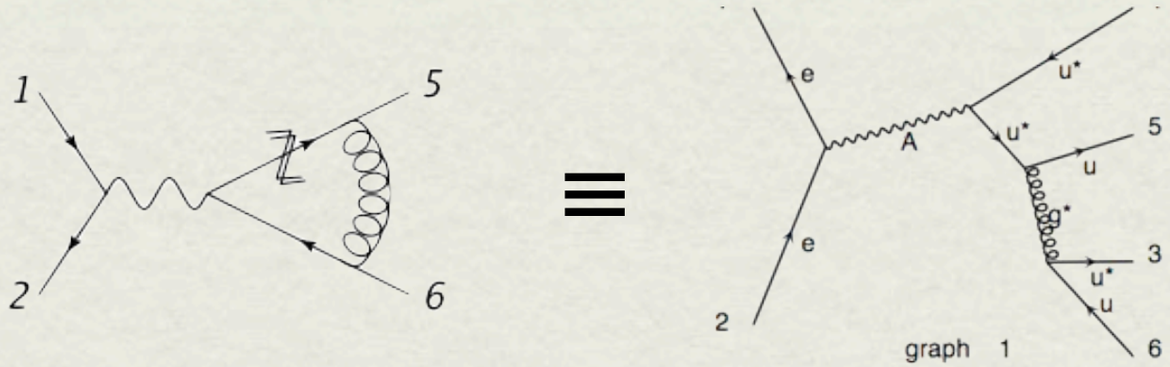
NLO Virtual Real Born



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

NLO: VIRTUALS

- Use MG to generate n+2 amplitudes to build NLO result (CutTools Technique) [V. Hirschi, R. Pittau, M. V. Garzielli, R. Frederix]



- Rely on external Tools (BlackHat, Golem, ...)
  - less generic
  - more possibilities for optimization

NLO: REAL

[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 FOR NLO

- MADGRAPH 5 will significantly simplify the development for both real and virtual contributions
  - Clear structure -> easy to extract what is needed
  - Modular -> easy to extend to add new features
  - Flexible -> output not limited to fortran

V4 V5

	Sept 09	Dec 09	Mar 10	June 10	Sept 10	Dec 10
MG	MadGraph v4					
	Development v5			Release core MG v5		
ME	MadEvent v4					
				Start dvlpt. ME v5		
BSM	FeynRules interface v4 + USRMOD2					
	Dvlpt. FR interf v5 + autom. HELAS			Generic MG5		
NLO V	Dvlpt. CutTools		Physics results v4			
			Dvlpt. CutTools v5	Physics res. v5		
NLO R	Dvl. MadFKS		Physics results MadFKS + stable MadDipole			
				Dvl.MadFKS v5		
Tools	MadWeight, MadOnia, etc. released and stable for ME v4					
				Move to ME v5		

CONCLUSION

- MG/ME v4 is a mature, well established and stable code with many features for BSM and QCD physics and numerous peripheral tools

- MG5 is available with important and unprecedented improvements in all directions.

- Still many new features to come in the near future

- A tutorial of MG5 will be given in a few minuts