MadGraph5
UFO/ALOHA

Olivier Mattelaer
FNRS
MG5: J. Alwall / M. herquet / F. Maltoni / T. Stelzer
ALOHA: P. Aquino / W. Link / F. Maltoni / T. Stelzer
UFO: C. Degrande / C. Duhr / B. Fuks / D. Grellsheid
T. Reiter
and a lot of external collaborators

MG5 Two Years AGO...

MG5 First Objectives

- ☐ Diagram Generation (tree level) ✓
- ☐ Diagram Drawing ✓
- ☐ Color Factor 95%
- ☐ Amplitude Computation ✓
- ☐ Helas Automatic Generation 75%

What's Needed from FR

- Need A Python Module for the Model
  - Discussion on this Workshop
    - particles/vertices/parameters/ couplings
- Lorentz information for creating Helas
  - (See working Group)

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Plan

- [ ] UFO
- [ ] ALOHA
- [ ] MadGraph5

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- MadGraph5

UFO: Motivations

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- Avoid multiple output model written by FR.

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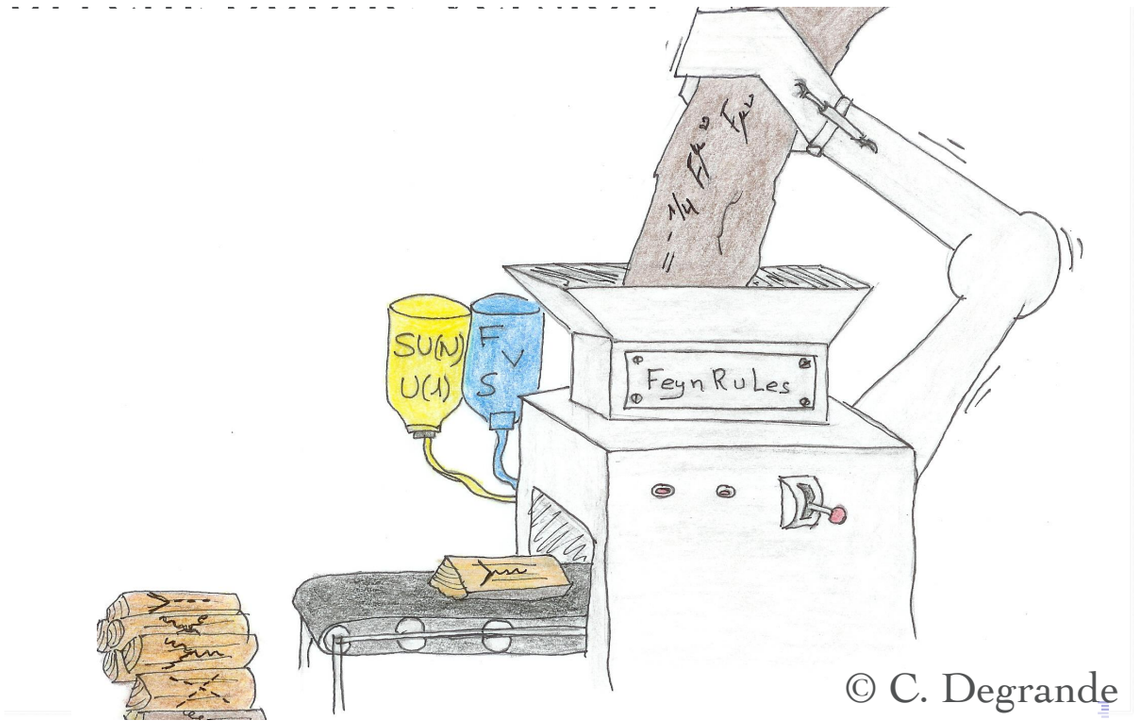

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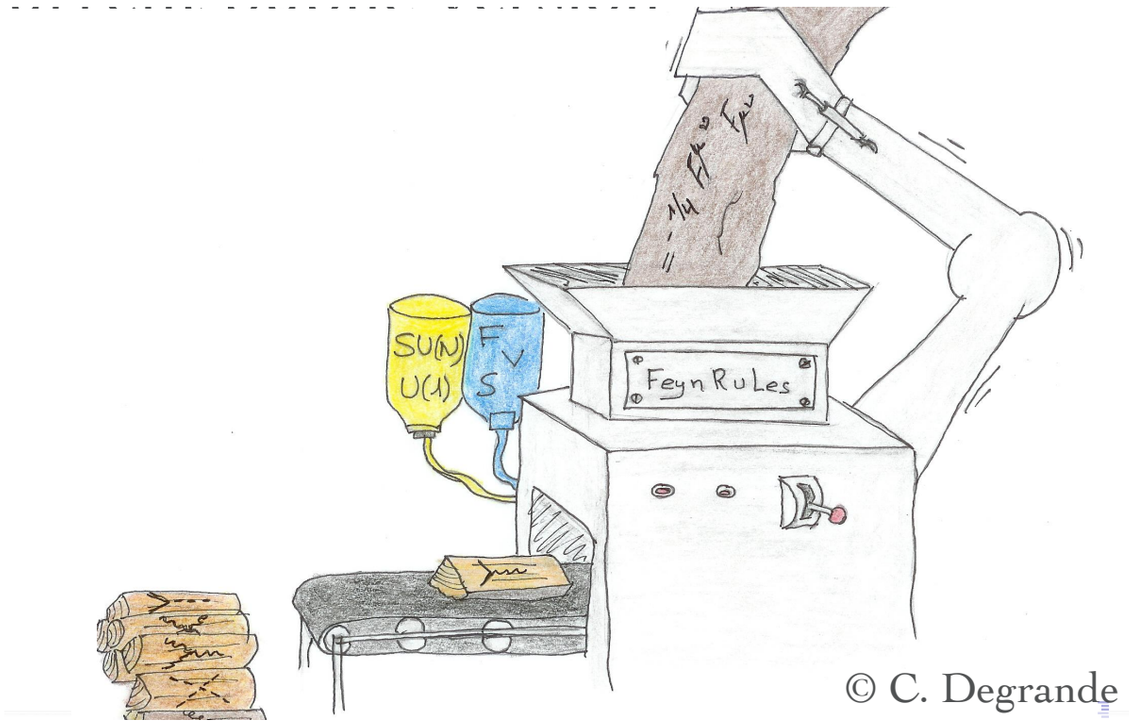

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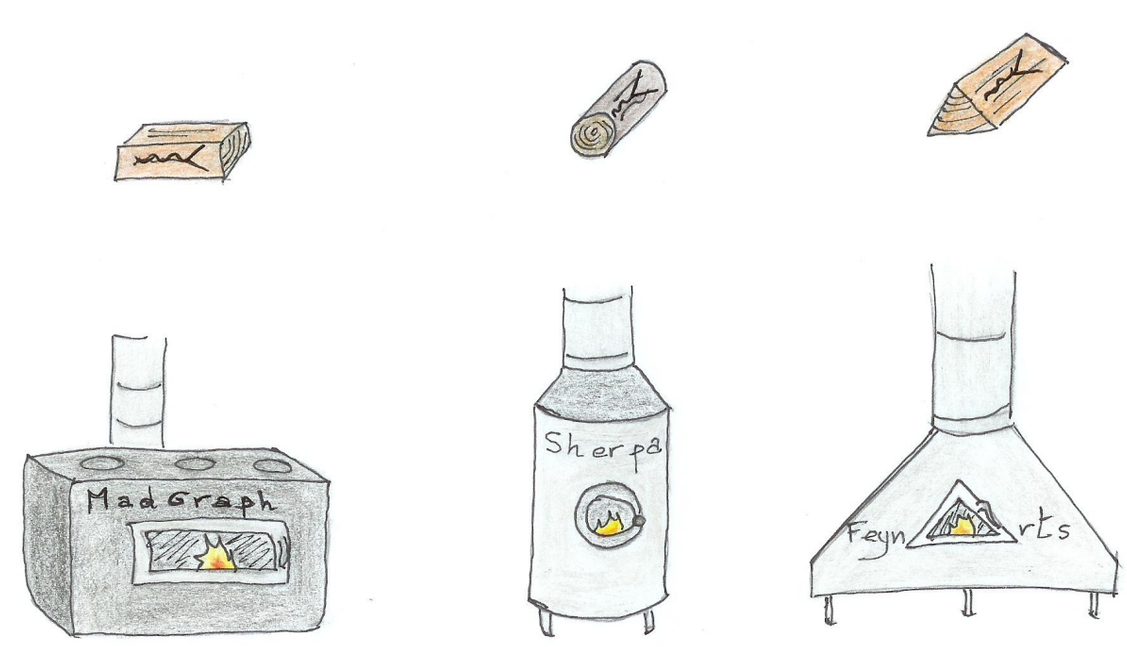

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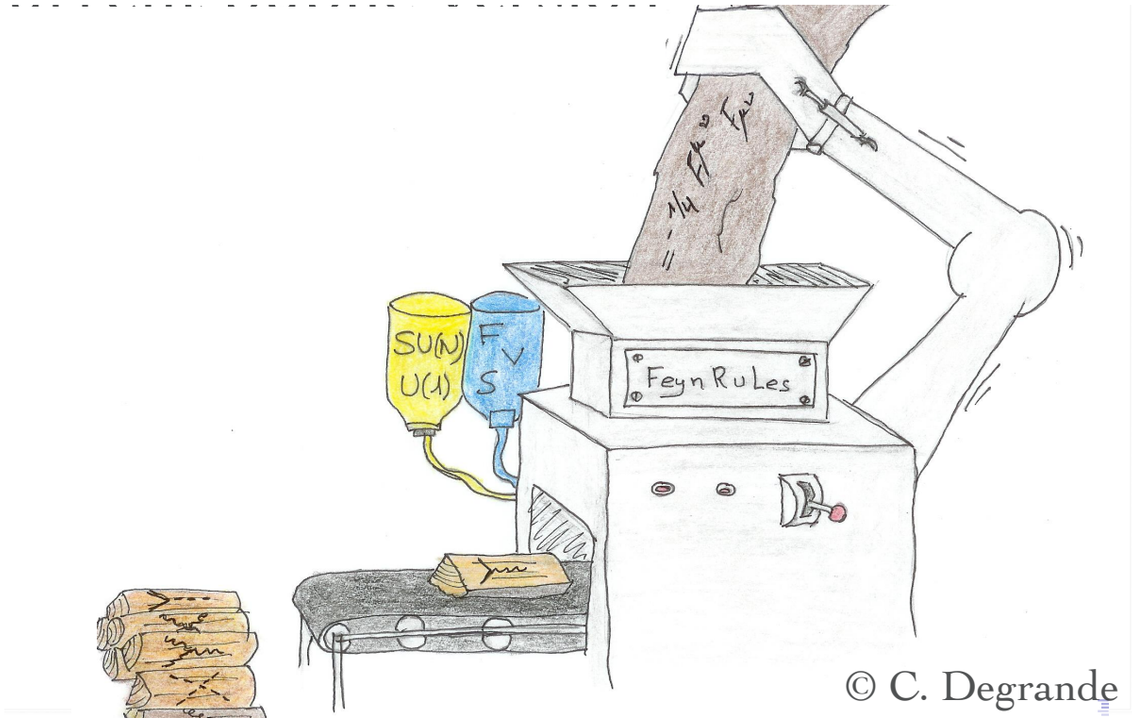

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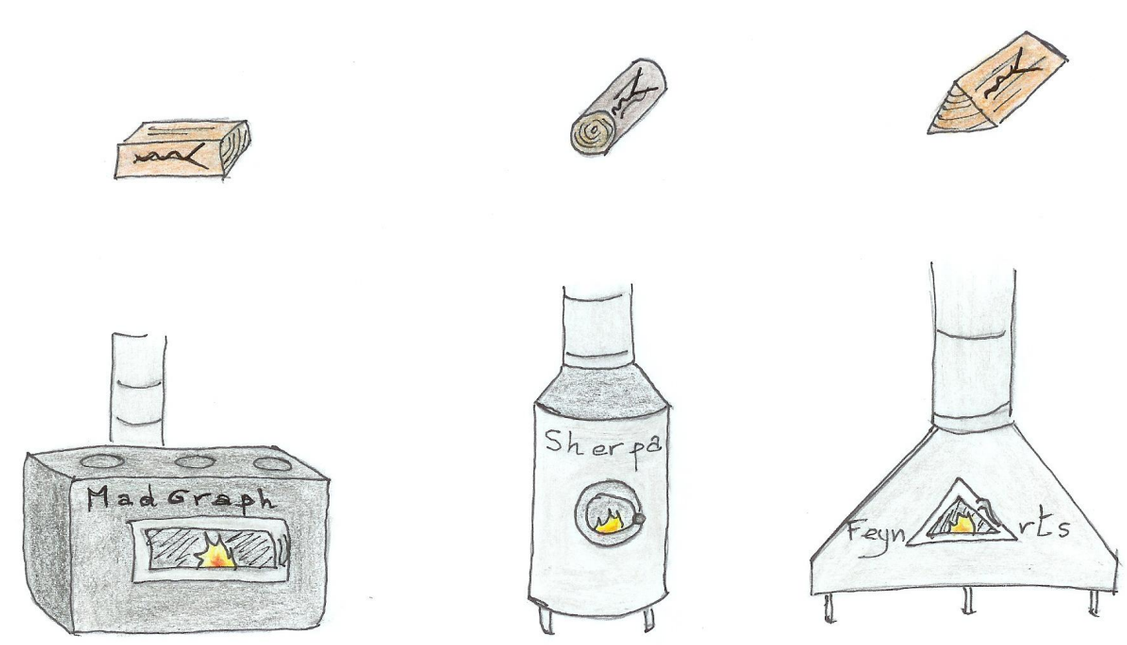

© C. Degrande

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

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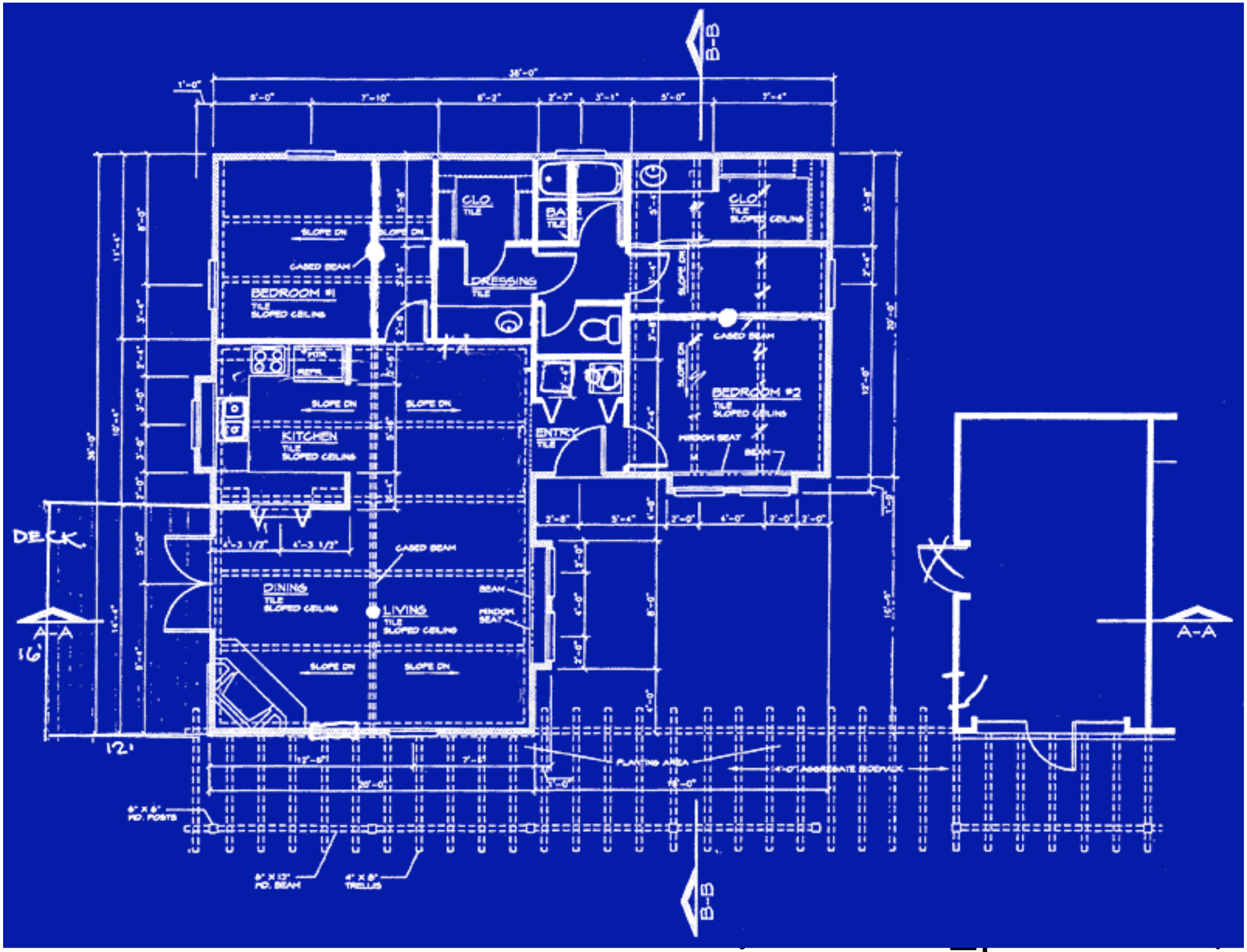
- Joint model for MG5 / GOSAM / Herwig++
- Python Object Oriented Model

FORMAT


B-B
36'-0"
BEDROOM #1
TILE
SLOPED CEILING
CLO
TILE
DRESSING
TILE
BA
TILE
CLO
TILE
SLOPED CEILING
GABED BEAM
SLOPE DN
BEDROOM #2
TILE
SLOPED CEILING
WINDOW SEAT
SEAT
ENTRY
TILE
KITCHEN
TILE
SLOPED CEILING
DINING
TILE
SLOPED CEILING
LIVING
TILE
SLOPED CEILING
BEAM
DECK
A-A
16'
12'
PLANTING AREA
14'-0" AGGREGATE BOOTJACK
6" X 6"
PO. POSTS
6" X 12"
PO. BEAM
4" X 8"
TRELLIS

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})
```

Plan

- UFO
- ALOHA
- MadGraph5

HELAS

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

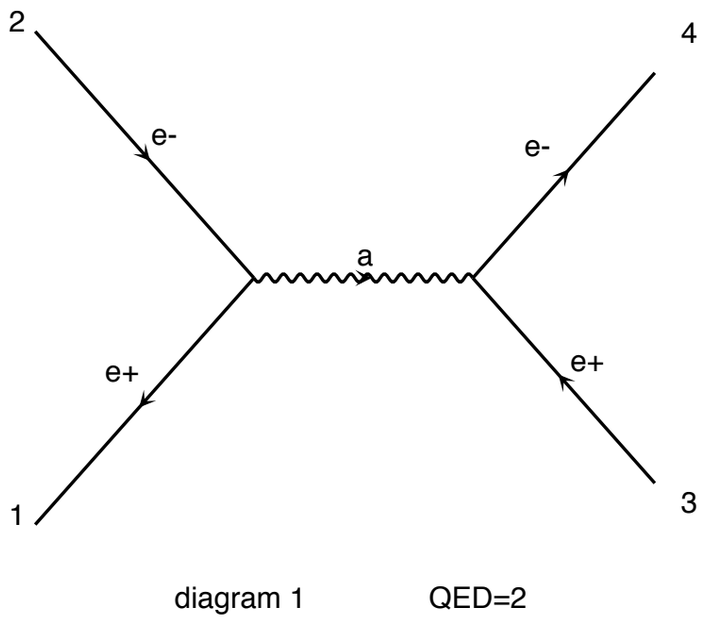


diagram 1 QED=2

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

HELAS

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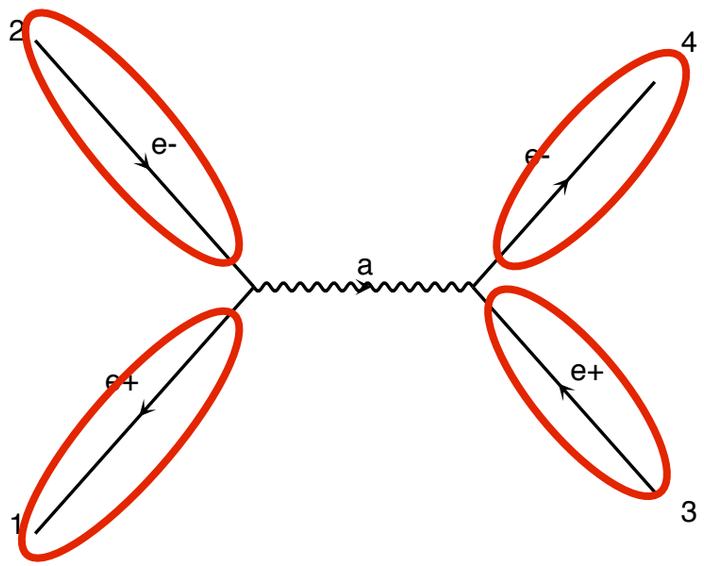

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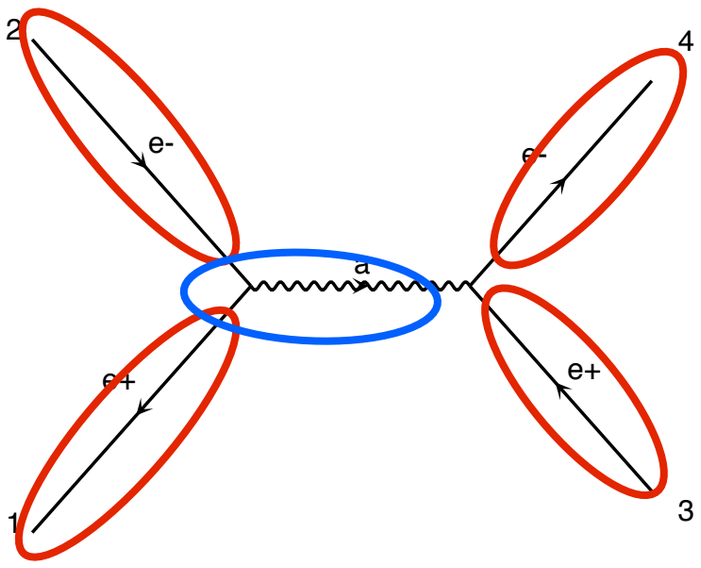
$$M = \bar{u}\gamma^{\mu}v\, P_{\mu\nu}\, \bar{u}\gamma^{\nu}v$$

→ 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 $\mathcal{M}$ for fixed helicity of external particles.



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

→ Number for a given helicity

→ Evaluate Interaction by interaction

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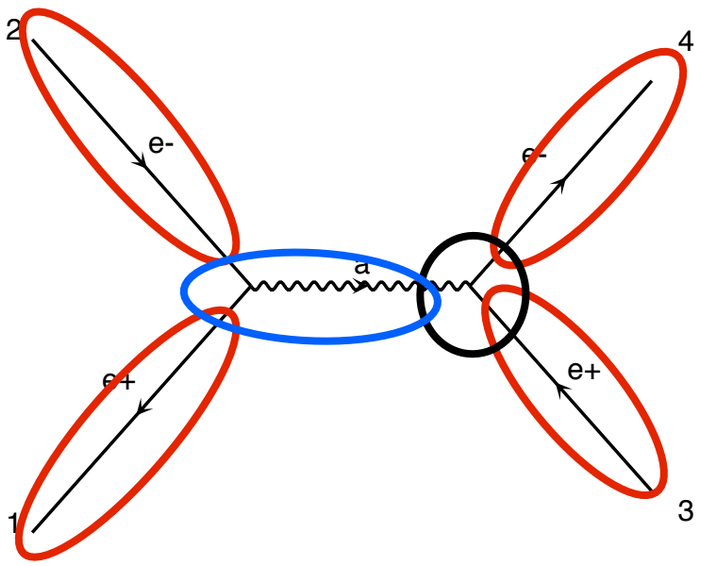
CALL OXXXXX(P(0,3),MT,NHEL(3),+1*IC(3),W(1,3))
CALL IXXXXX(P(0,4),MT,NHEL(4),-1*IC(4),W(1,4))
CALL JIOXXX(W(1,1),W(1,2),GG,ZERO,ZERO,W(1,5))
```

HELAS

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



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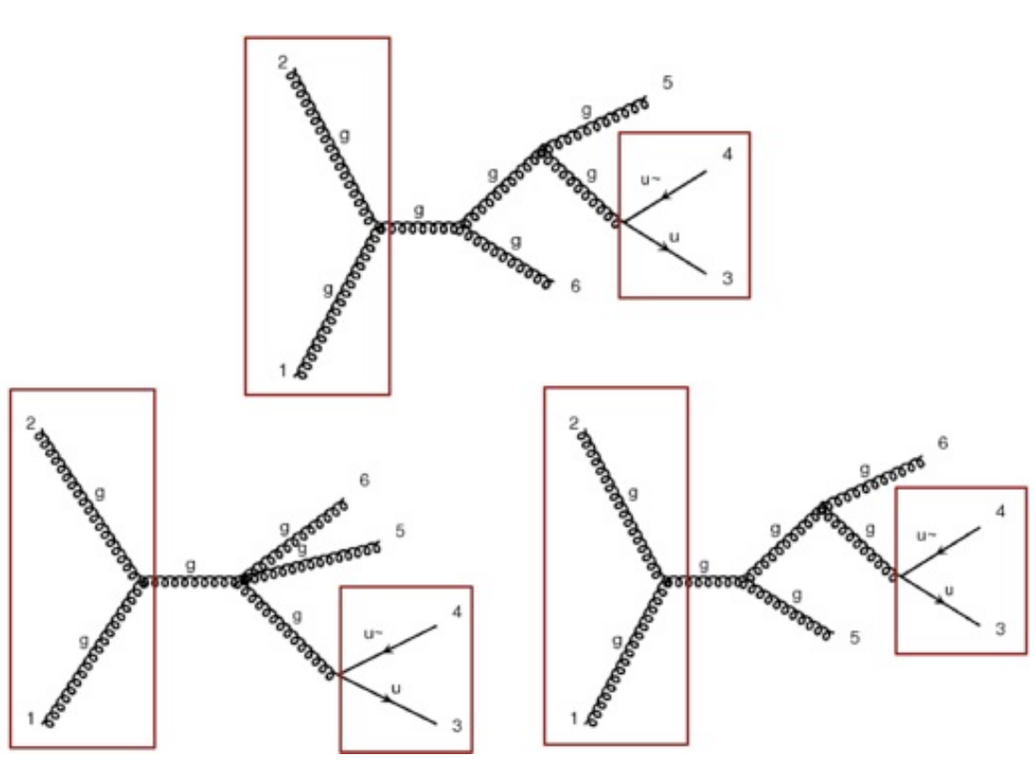
CALL IXXXXX(P(0,4),MT,NHEL(4),-1*IC(4),W(1,4))
CALL JIOXXX(W(1,1),W(1,2),GG,ZERO,ZERO,W(1,5))
CALL IOVXXX(W(1,4),W(1,3),W(1,5),GG,AMP(1))
```

HELAS

- Speed:
  - The complexity grows linearly with the number of diagram
  - recycling between diagram (so reduces the factorial growth)



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BNV Model
SLIH
Effective Field Theory
Full HEFT
Chromo-magnetic
NMSSM
Chiral Perturbation
operator
Black Holes

ALOHA

[O.M, al 1]

- Automatic Creation of HELAS routine for ANY BSM theory

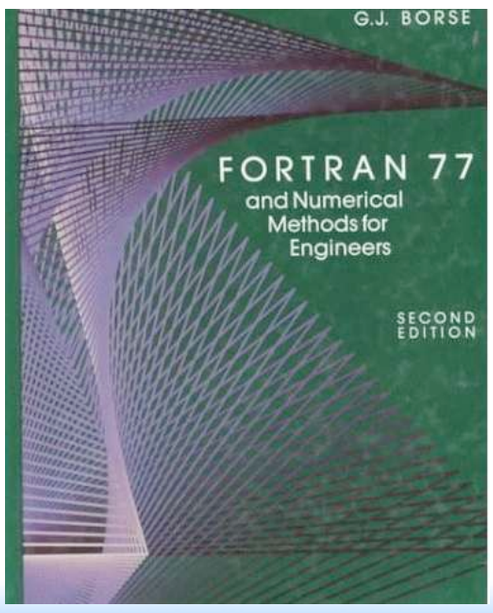
- Output
  - Fortran
  - C++
  - Python

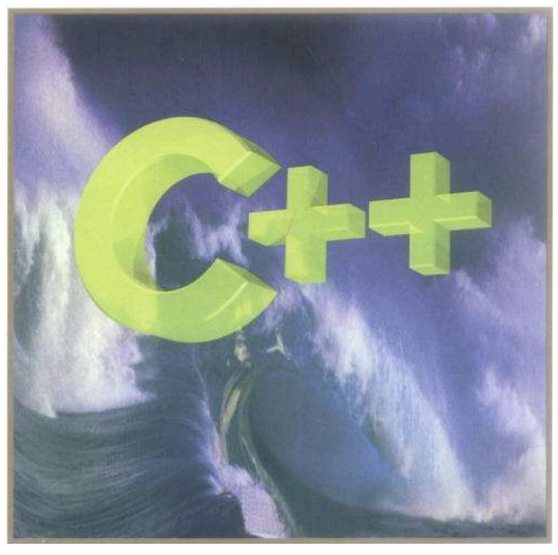
The Helas routine for BSM without the pain to write it.

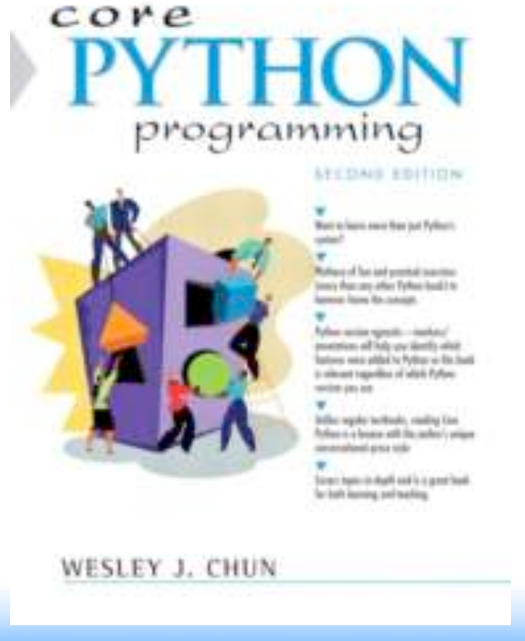
ALOHA

From: UFO To: Helicity Translate

Type text or a website address or translate a document.







ALOHA

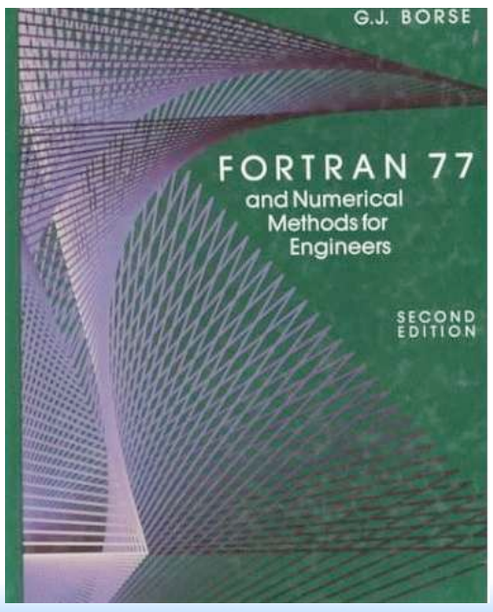
ALOHA

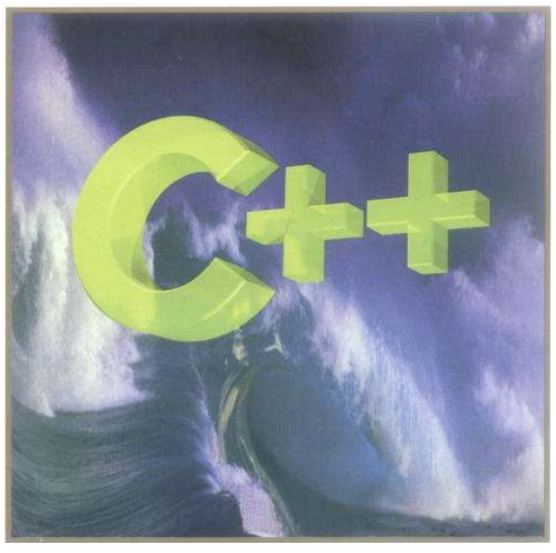
Google translate

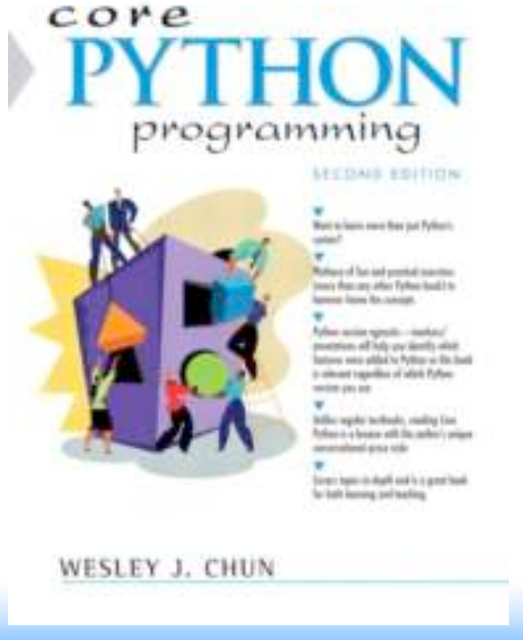
From: UFO ⇆ To: Helicity Translate

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

Type text or a website address or translate a document.







ALOHA

ALOHA

Google translate

From: UFO ⇆ To: Helicity Translate

Options:
- Standard (HELAS)
- Feynman gauge 1.5
- Complex-mass scheme 1.5
- Loop 2.0

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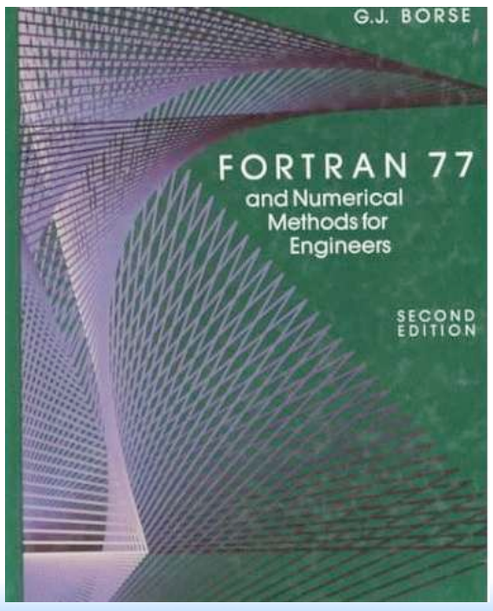

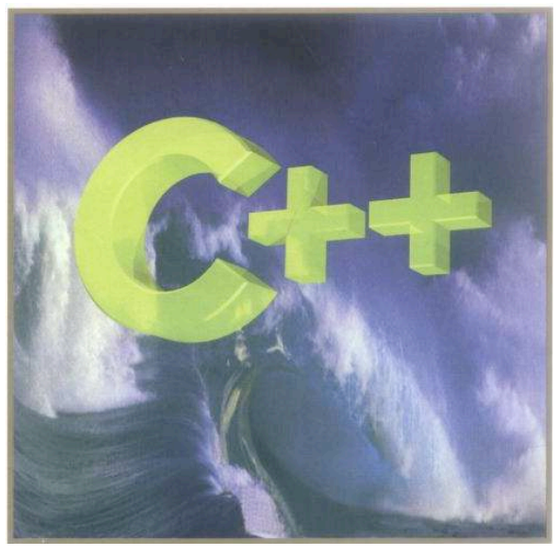

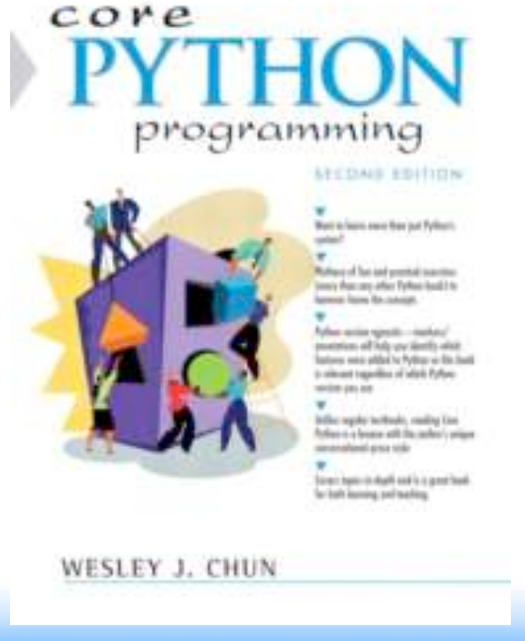

Feynman Gauge

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- UFO Model supports both Unitary gauge and Feynman gauge
- Quite trivial for ALOHA (just changing the propagator)
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- Easy for MG5 (Just have to add the goldstino)

This is trivial to implement

- Usefull to test the gauge invariance
- Might be more optimal for some processes/ energy (need to be checked)
- Will be helpfull for NLO

Complex Mass Scheme

- The presence of width BREAKS gauge and lorentz invariance

```
Gauge results:
Process                    matrix            BRS                ratio              Result
g g > b b~ e+ e- ve ve~ 1.6829262916e-20 1.1523186709e-24 6.8471131304e-05 Failed
   JAMP 0              7.3202114973e-19 4.3818201275e-23 5.9859201187e-05 Failed
   JAMP 1              8.0802219962e-20 1.0339427857e-23 1.2795970039e-04 Failed
Summary: 0/1 passed, 1/1 failed
Failed processes: g g > b b~ e+ e- ve ve~
Lorentz invariance results:
Process          Min element      Max element      Relative diff.   Result
g g > b b~ e+ e- 6.7878430489e-21 6.7885480993e-21 1.0385879728e-04 Failed
   JAMP 0        2.8968137980e-20 2.9000153627e-20 1.1039819500e-03 Failed
   JAMP 1        3.0460455373e-19 3.0461513397e-19 3.4733125877e-05 Failed
Summary: 0/1 passed, 1/1 failed
Failed processes: g g > b b~ e+ e- ve ve~
```

Complex Mass Scheme

- The presence of width BREAKS gauge and lorentz invariance
- Complex mass scheme solves this problems

$$M_c = \sqrt{M^2 - iM * W}$$

- Needs to fix also yukawa in that way and compute couplings accordingly.

Complex Mass Scheme

- The presence of width BREAKS gauge and lorentz invariance
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$$M_c = \sqrt{M^2 - iM * W}$$

```
Gauge results:
Process                  matrix           BRS                ratio              Result
g g > b b~ e+ e- ve ve~ 1.3981771141e-20 1.5230480926e-46 1.0893098430e-26 Passed
Summary: 1/1 passed, 0/1 failed
Gauge results (switching between Unitary/Feynman):
Process                  Unitary          Feynman            Relative diff.   Result
g g > b b~ e+ e- ve ve~ 3.3591262659e-16 3.3591262659e-16 6.0178031715e-15 Passed
Summary: 1/1 passed, 0/1 failed
Lorentz invariance results:
Process          Min element      Max element      Relative diff.   Result
g g > b b~ e+ e- 4.0109884021e-21 4.0109884021e-21 1.8756383941e-15 Passed
Summary: 1/1 passed, 0/1 failed
```

Plan

- ☐ UFO
- ☐ ALOHA
- ☐ MadGraph5

Plan

- ☐ UFO
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- ☐ MadGraph5

MadGraph5 Goal

- Remove ALL limitations of MadGraph4
  - speed
  - number of particles
  - type of interactions
  - modularity / flexibility of the code
  - static HELAS library

MadGraph Home Page

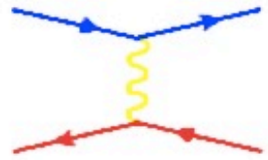
madgraph.hep.uiuc.edu

High Energy Physics Illinois

This material is based upon work supported by the National Science Foundation under Grant No. 0426272.
Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation

The MadGraph homepage

UCL UIUC Fermi
by the MG/ME Development team



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

Generate processes online using MadGraph 5

To improve our web services we request that you register. Registration is quick and free. You may register for a password by clicking here.
You can still use **MadGraph 4** here.

Code can be generated either by:

I. Fill the form:

Model: SM — Model descriptions

Input Process: — Examples/format

Example: p p > w+ j j QED=3, w+ > l+ vl

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

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

Submit

3. **MadGraph 5 : Going Beyond.**
Johan Alwall (Fermilab), Michel Herquet (NIKHEF, Amsterdam), Fabio Maltoni, Olivier Mattelaer (Louvain U., CP3), Tim Stelzer (Illinois U., Urbana). FERMILAB-PUB-11-448-T.
Jun 2011. 37 pp.
Published in **JHEP 1106 (2011) 128**
e-Print: **arXiv:1106.0522 [hep-ph]**

Speed

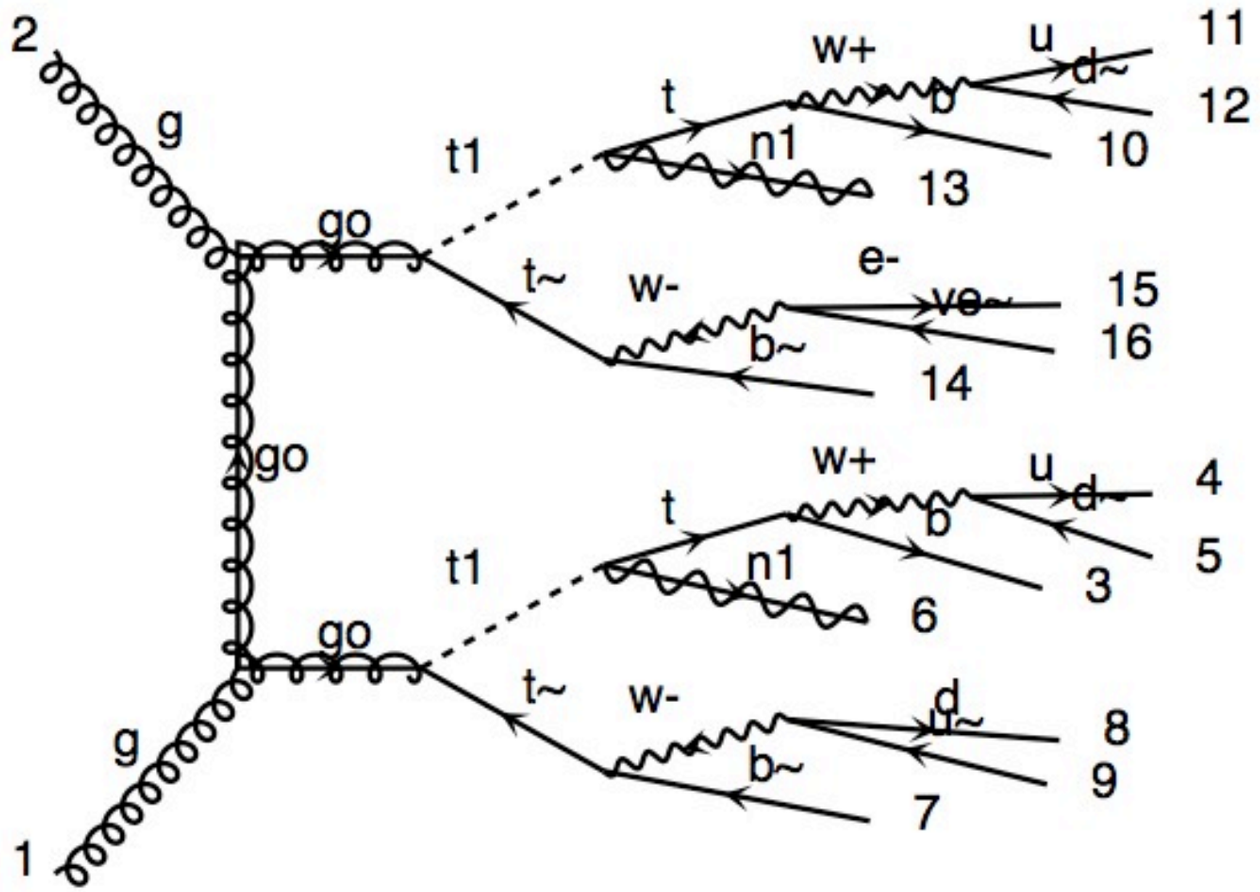
Matrix Element generation:

Process	MadGraph 4	MadGraph 5	Subprocesses	Diagrams
$pp \to jjj$	2 min	22 s	34	307
$pp \to jjl^+l^-$	23 min	26 s	108	1216
$pp \to jjje^+e^-$	60 min	132 s	141	9012
$u\bar{u} \to e^+e^-e^+e^-e^+e^-$	51 min	75 s	1	3474
$gg \to ggggg$	3 hours	5 min	1	7245
$pp \to jj(W^+ \to l^+\nu_l)$	10 min	19 s	82	304
$pp \to t\bar{t}$+full decays	6h	29 s	27	45
$pp \to \tilde{q}/\tilde{g}\,\tilde{q}/\tilde{g}$	14 min	63 s	313	475
$gg \to (\tilde{g} \to u\bar{u}\tilde{\chi}_1^0)(\tilde{g} \to u\bar{u}\tilde{\chi}_1^0)$	5 min	7 s	1	48
$pp \to (\tilde{g} \to jj\tilde{\chi}_1^0)(\tilde{g} \to jj\tilde{\chi}_1^0)$	—	30s	144	11008

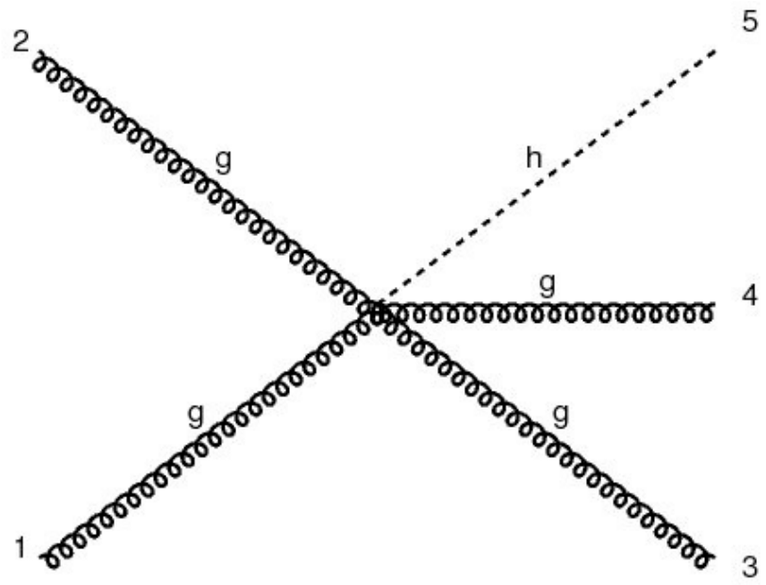
Matrix Element evaluation (Fortran):

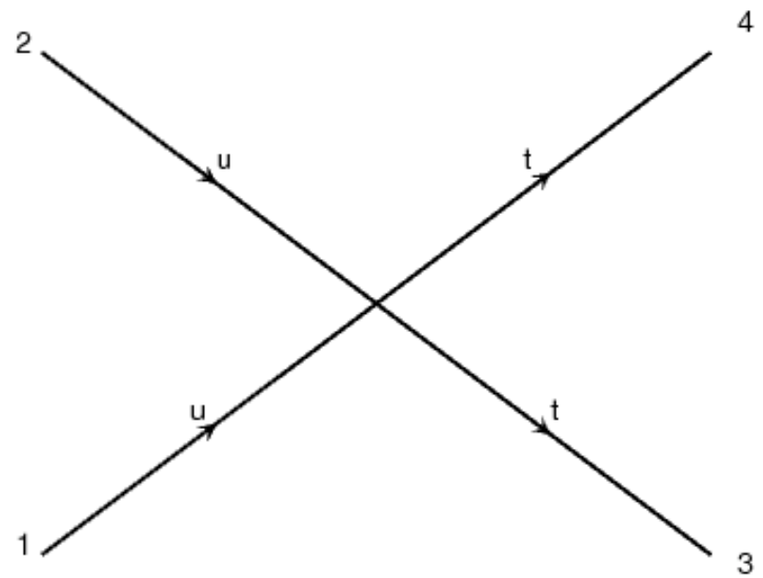
Process	Function calls		Run time	
	MG 4	MG 5	MG 4	MG 5
$u\bar{u} \to e^+e^-$	8	8	$< 6\mu$s	$< 6\mu$s
$u\bar{u} \to e^+e^-e^+e^-$	110	80	0.22 ms	0.14 ms
$u\bar{u} \to e^+e^-e^+e^-e^+e^-$	6668	3775	46.5 ms	19.0 ms
$u\bar{u} \to d\bar{d}$	6	6	$< 4\mu$s	$< 4\mu$s
$u\bar{u} \to d\bar{d}g$	16	16	27 μs	27 μs
$u\bar{u} \to d\bar{d}gg$	85	67	0.42 ms	0.31 ms
$u\bar{u} \to d\bar{d}ggg$	748	515	10.8 ms	6.75 ms
$u\bar{u} \to u\bar{u}gg$	160	116	1.24 ms	0.80 ms
$u\bar{u} \to u\bar{u}ggg$	1468	960	35.7 ms	17.2 ms
$u\bar{u} \to d\bar{d}d\bar{d}$	42	33	84 μs	83 μs
$u\bar{u} \to d\bar{d}d\bar{d}g$	310	197	1.88 ms	1.15 ms
$u\bar{u} \to d\bar{d}d\bar{d}gg$	3372	1876	141 ms	34.4 ms
$u\bar{u} \to d\bar{d}d\bar{d}d\bar{d}$	1370	753	42.5 ms	6.6 ms

number of particles



Type of Interactions





Effective Theory

multi fermion interactions

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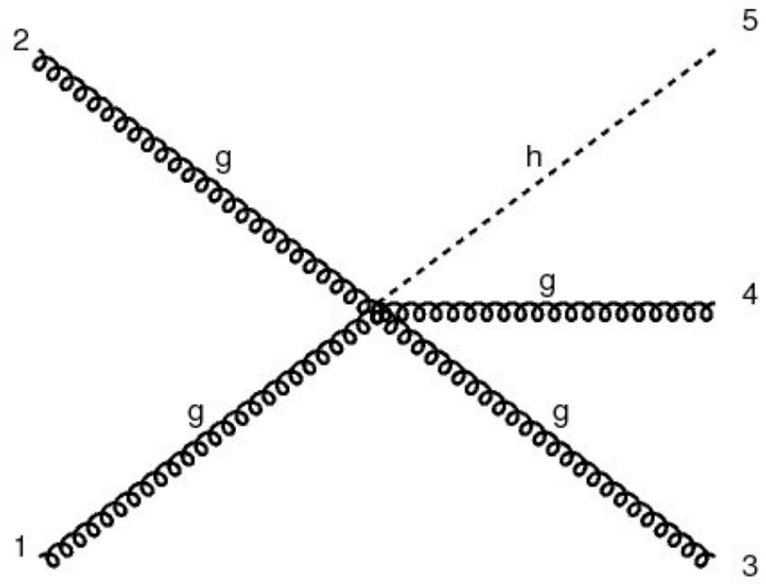

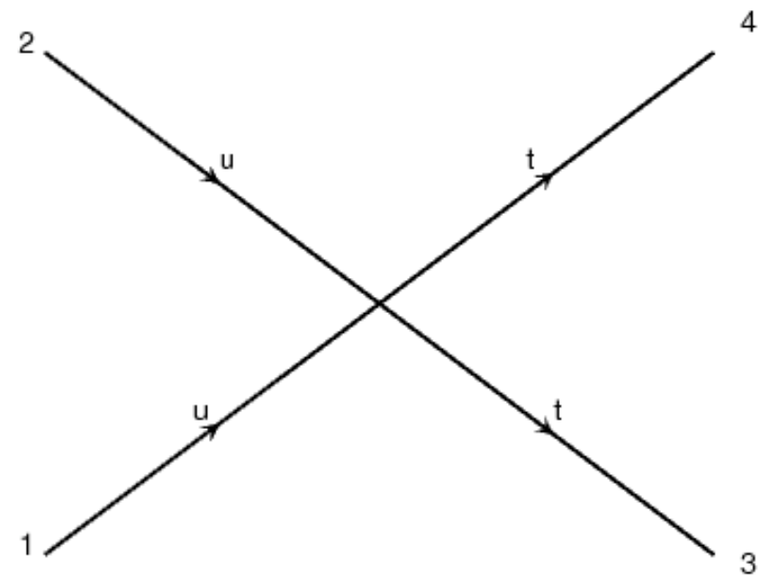

Effective Theory

multi fermion interactions

As well as new color structures (triplet/sextet)

Command Interface

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Command Interface

- Nice Interactive session

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Command Interface

- Nice Interactive session
  - Auto-completion

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Command Interface

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If You test it, you are going to like it !

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Command Interface

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- Simple command set

```
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*          W E L C O M E  to  M A D G R A P H  5            *
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```

Command Interface

- Nice Interactive session
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- Simple command set
  - import model sm
  - generate p p > e+ e-
  - output FORMAT MY_DIR
  - launch

```
************************************************************
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*           W E L C O M E  to  M A D G R A P H  5          *
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```

Output

- MadEvent (Fortran)
- Standalone (Fortran)
- Standalone(C++) ⟵ NEW
- Pythia 8 (C++) ⟵ NEW

Compact and optimise output for MadEvent

Process	Subprocess directories		Channels for survey		Directory size	
	ME 4	ME 5	ME 4	ME 5	ME 4	ME 5
$pp \to W^+j$	6	2	12	4	79 MB	35 MB
$pp \to W^+jj$	41	4	138	29	438 MB	64 MB
$pp \to W^+jjj$	73	5	1164	184	842 MB	110 MB
$pp \to W^+jjjj$	296	7	15029	1327	3.8 GB	352 MB
$pp \to l^+l^-j$	12	2	48	8	149 MB	44 MB
$pp \to l^+l^-jj$	54	4	586	58	612 MB	83 MB
$pp \to l^+l^-jjj$	86	5	5408	368	1.2 GB	151 MB
$pp \to l^+l^-jjjj$	235	7	63114	2500	5.3 GB	662MB
$pp \to t\bar{t}$	3	2	5	4	49 MB	39 MB
$pp \to t\bar{t}j$	7	3	45	25	97 MB	56 MB
$pp \to t\bar{t}jj$	22	5	417	188	274 MB	98 MB
$pp \to t\bar{t}jjj$	34	6	3816	1300	620 MB	209 MB

MadGraph5 Goal

- Remove ALL limitations of MadGraph4
  - speed
  - number of particles
  - type of interactions
  - modularity / flexibility of the code

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- Remove ALL limitations of MadGraph4
  - speed
  - number of particles
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So we succeed the initial goal

After the initial Goal?

After the initial Goal?

After the initial Goal?

Current 1.4.3

1.4.0

After the initial Goal?

Current 1.4.3

1.4.0

Not possible to detail everything

What's new

What's new

- Improve Phase-space integration

What's new

- Improve Phase-space integration
- automatic order restriction for any model

```
mg5>display coupling_order
 QCD : weight = 1
 QED : weight = 2
```

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- automatic order restriction for any model

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 QCD : weight = 1
 QED : weight = 2
mg5>generate p p > w- > b b~ e+ ve j j
INFO: Checking for minimal orders which gives processes.
INFO: Please specify coupling orders to bypass this step.
INFO: Trying coupling order WEIGHTED=8
INFO: Trying coupling order WEIGHTED=9
INFO: Trying coupling order WEIGHTED=10
INFO: Trying process: g g > w- > b b~ e+ ve d u~ WEIGHTED=10
INFO: Process has 63 diagrams
```

If no coupling order specify: take minimal weight

What's new

- Improve Phase-space integration
- automatic order restriction for any model

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QED=4, QCD=2

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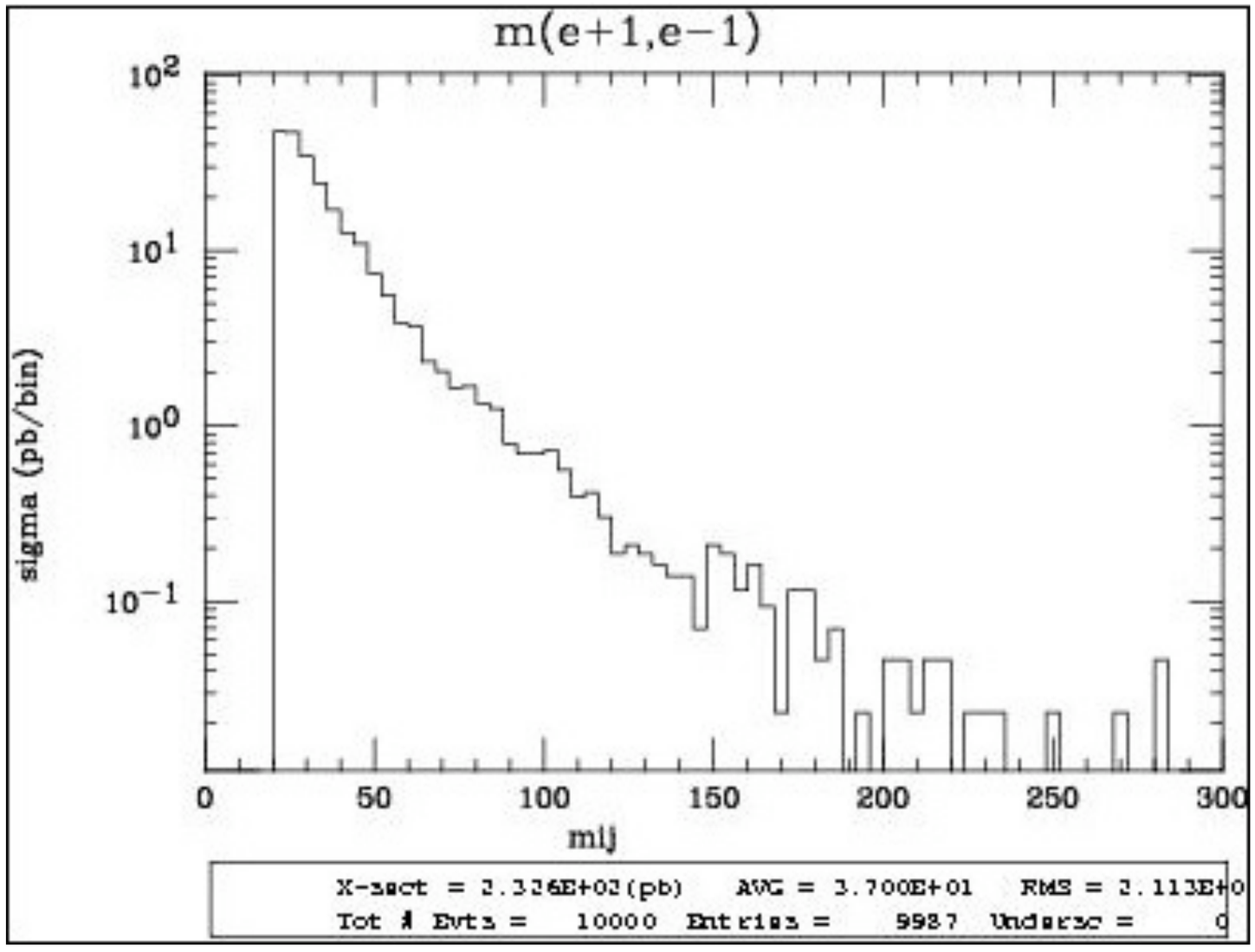
- Possibility to compute partial width (and BR)
- Improving the gridpack
- add a cut forbidding on-shell particles but allowing off-sheel contribution ($)

$ explanation

```
p p > e+ e- $$ z
```



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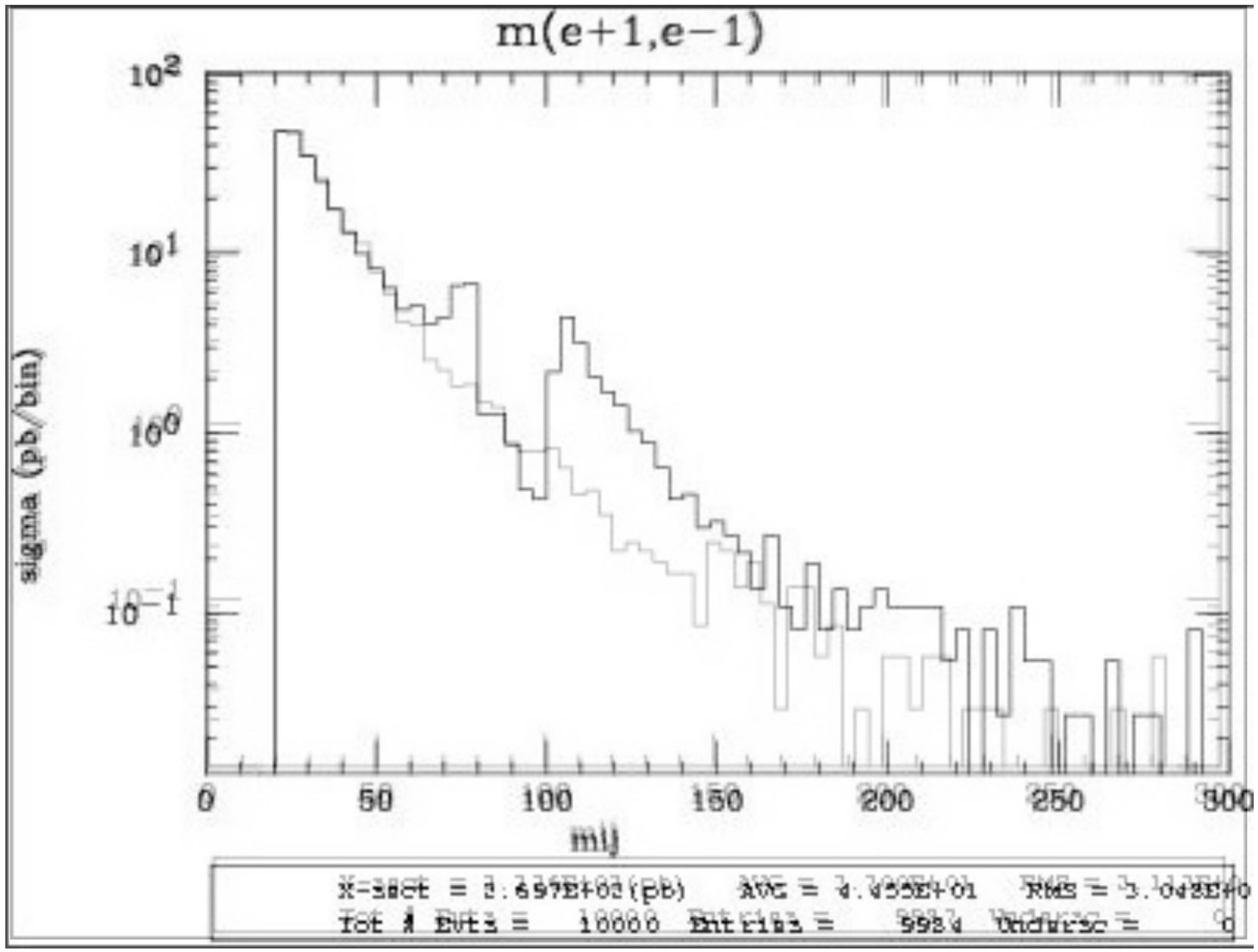
p p > e+ e- $ Z

BW cutt =5 (small for the example)



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Z- onshell veto

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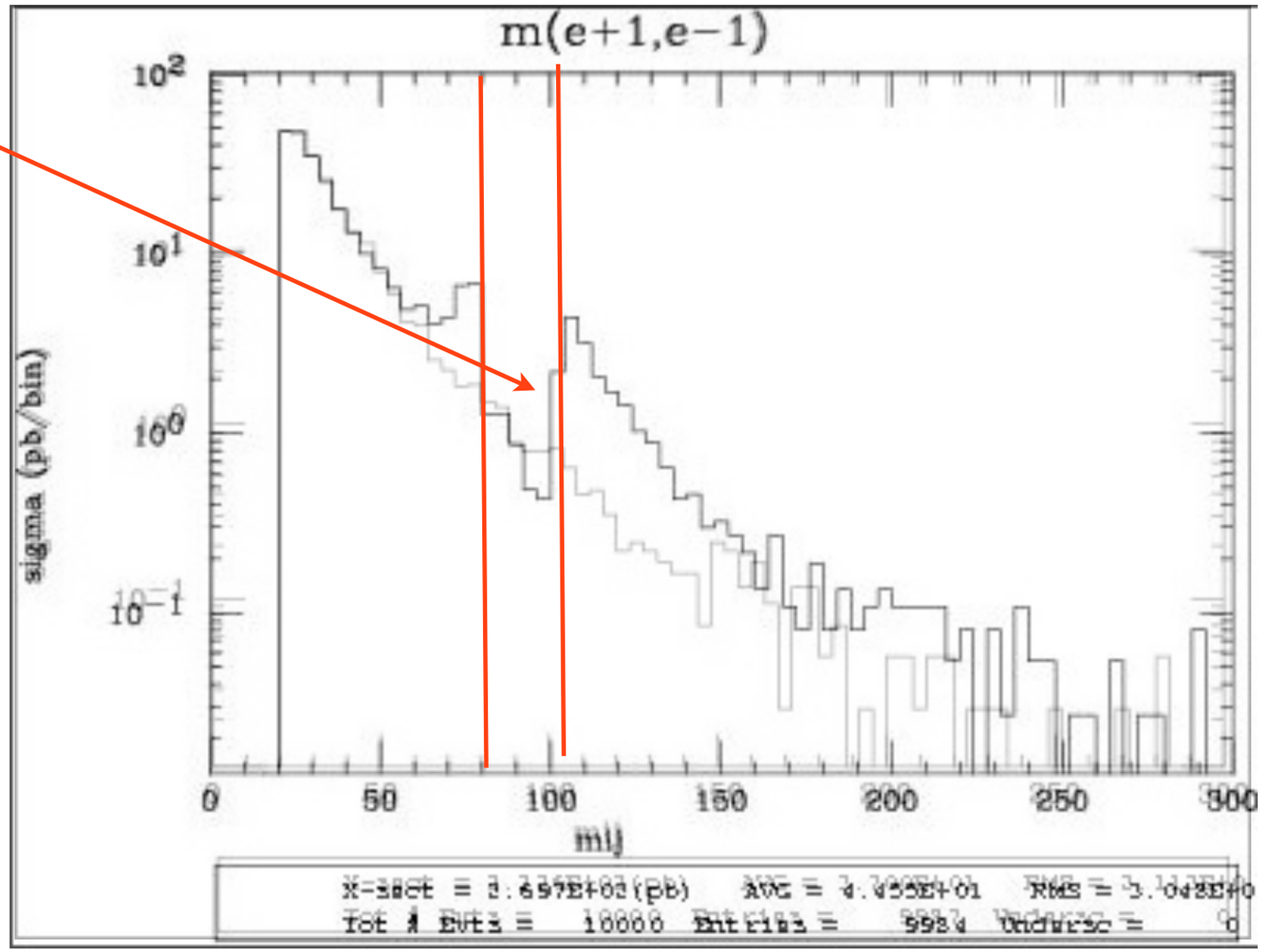

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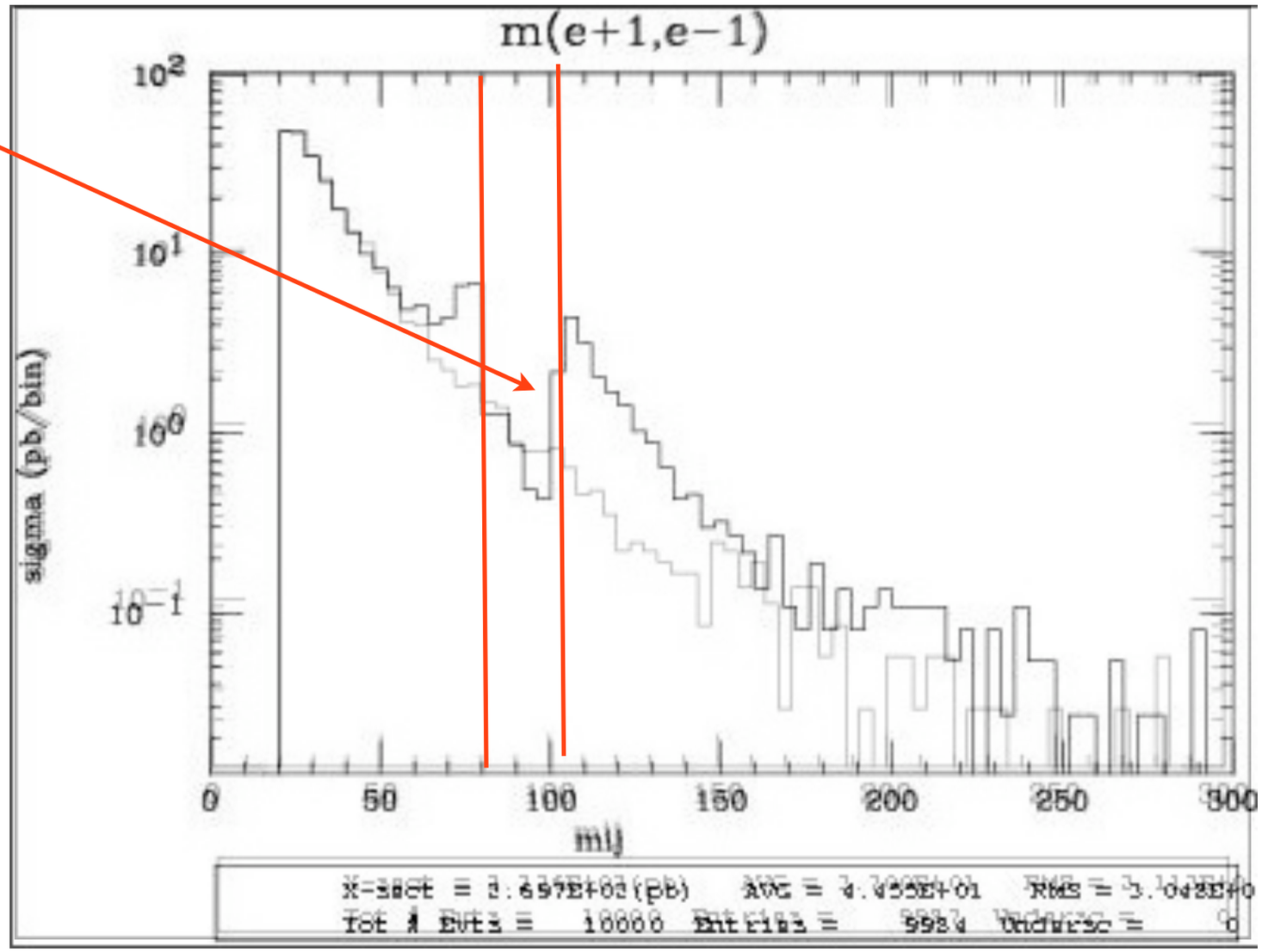

Offshell Z interference is BG

And After...

And After…

- Inclusion of new output
  - MadDarkMatter
  - MadWeight
  - …

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  - MadDarkMatter
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  - ...
- MadLoop / aMC@NLO

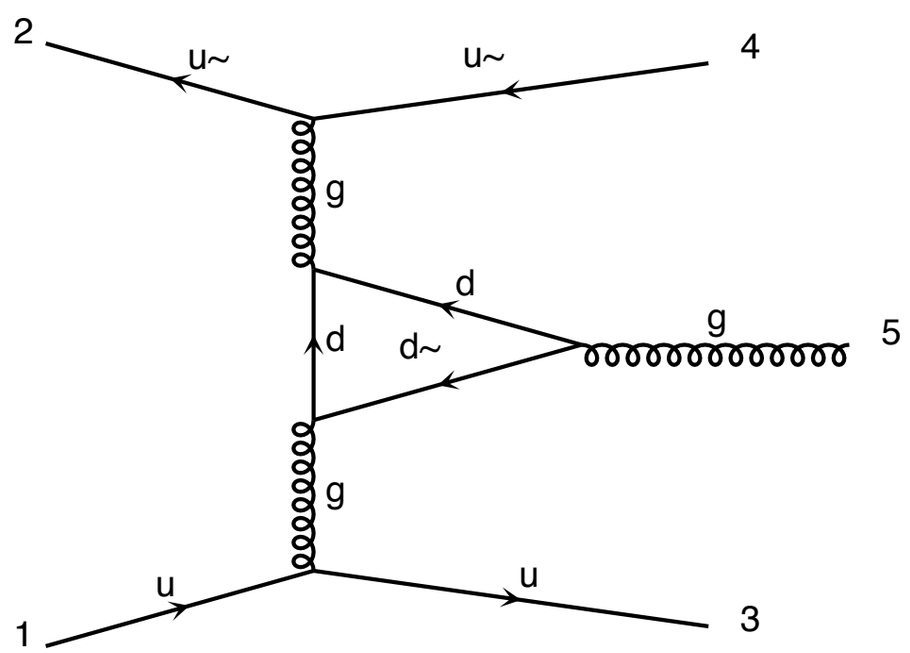

diagram 19 QCD=5

And After...

- Inclusion of new output
  - MadDarkMatter
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  - ...
- MadLoop / aMC@NLO
- usermod for UFO model
- MadAnalysis5

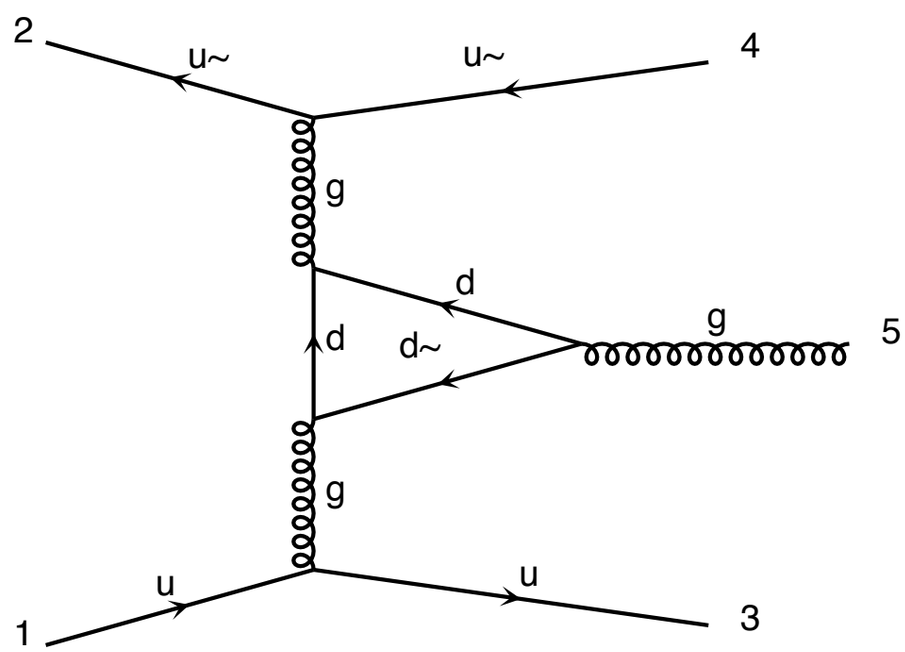

diagram 19 QCD=5

And After...

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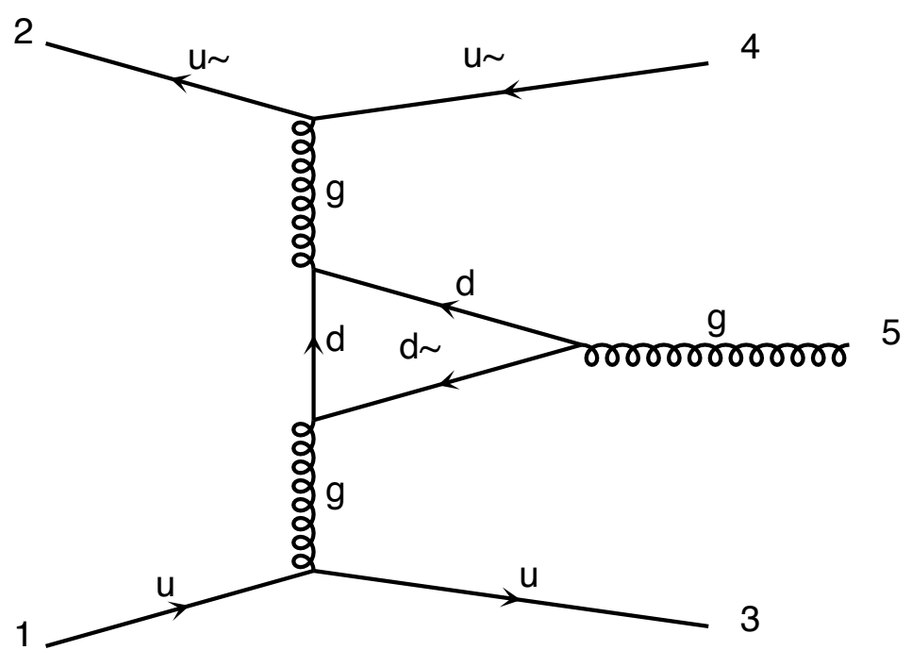
- color ordered amplitude



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- recursion relations

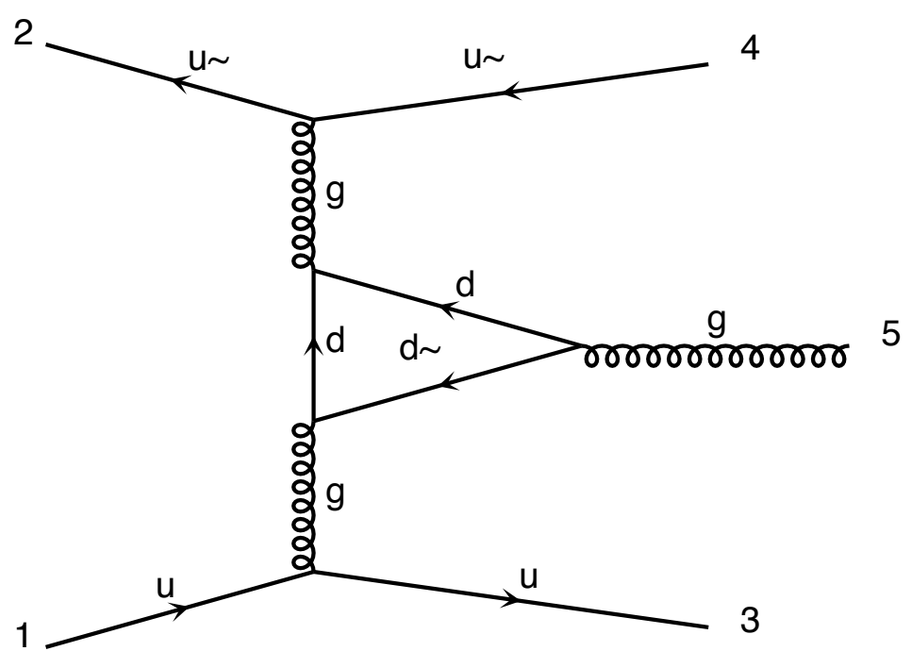

diagram 19 QCD=5

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  - ...
- MadLoop / aMC@NLO
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- MadAnalysis5
- color ordered amplitude
- recursion relations
- computing the widths

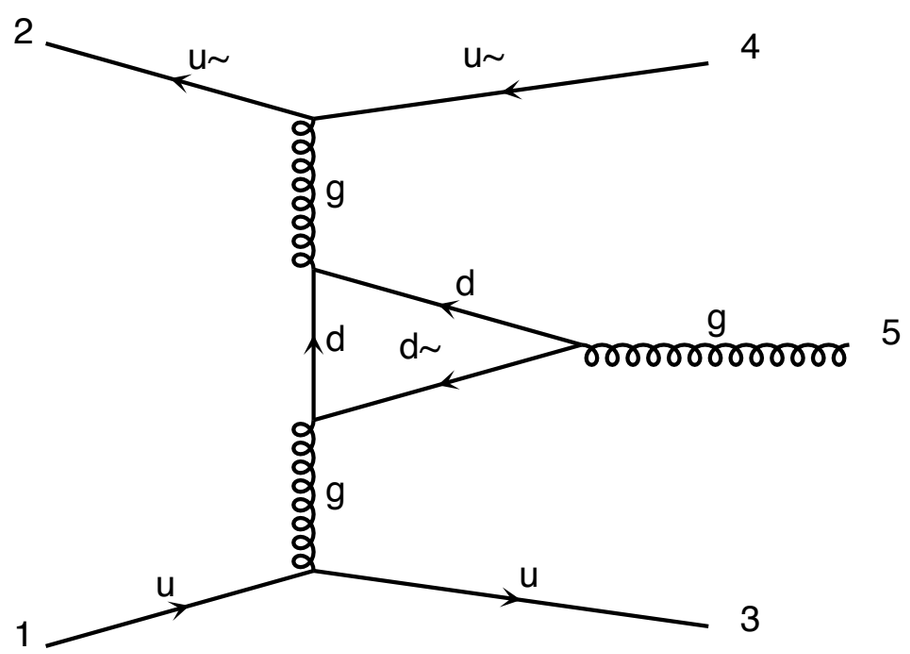

diagram 19 QCD=5

Computing the widths

- mg5> compute_widths Z
  - First evaluate 2>2 and 2>3 contribution
  - Compute ONLY the relevant contribution
  - Write the new param_card.dat

What we need from FR

We are VERY happy

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- 4 fermion operator
- Unitary Operator
- spin 3/2
- Automatic width for 2>2?

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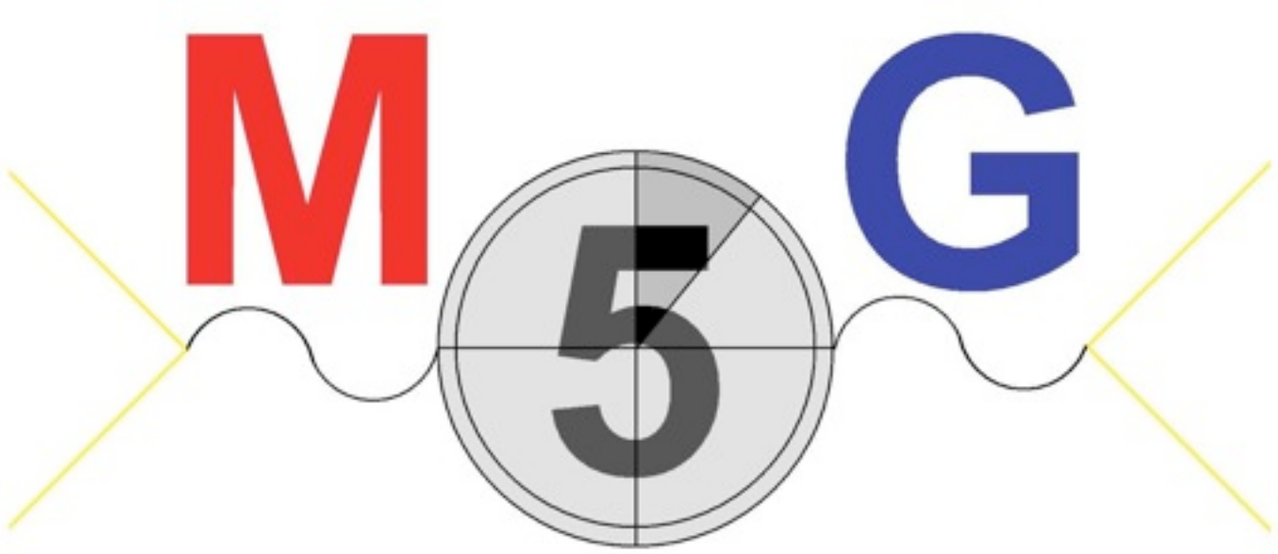
- 4 fermion operator
- Unitary Operator
- spin 3/2
- Automatic width for 2>2?

And off course NLO

Details in Valentin/Rik's talk

Conclusion



MadGraph 5 is working

We have include a lot of features

A lot of improvments are ongoing

https://launchpad.net/madgraph5