MadGraph 5

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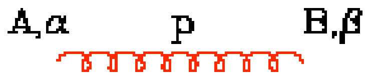
Aims for these lectures

- Get you acquainted with the concepts and techniques used in event generation
- Give you hands-on experience with matrix element generation, event generation and analysis
- Answer as many of your questions as I can (so please ask questions!)

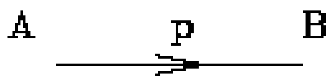
Topic of this lecture

- How to compute the matrix element
  - ➡ HELAS / ALOHA
- Features of MG5
- Life demonstration
- MadSpin ?

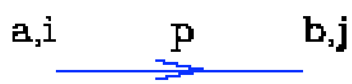
The Matrix Element



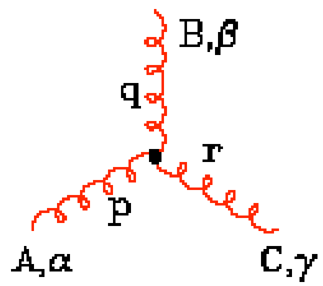
$$\delta^{AB}\left[-g^{\alpha\beta}+(1-\lambda)\frac{p^{\alpha}p^{\beta}}{p^{2}+i\epsilon}\right]\frac{i}{p^{2}+i\epsilon}$$



$$\delta^{AB}\frac{i}{(p^{2}+i\epsilon)}$$

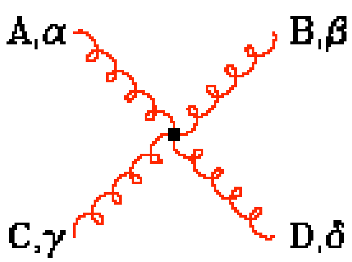


$$\delta^{ab}\frac{i}{(\not{p}-m+i\epsilon)_{ji}}$$

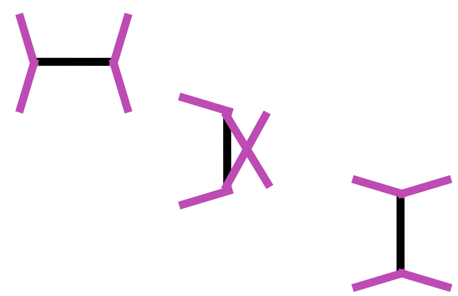


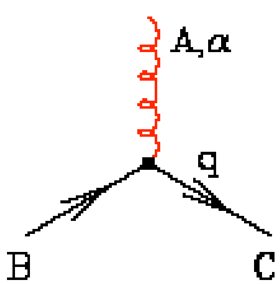
$$-g\ f^{ABC}[(p-q)^{\gamma}g^{\alpha\beta}+(q-r)^{\alpha}g^{\beta\gamma}+(r-p)^{\beta}g^{\gamma\alpha}]$$

(all momenta incoming)

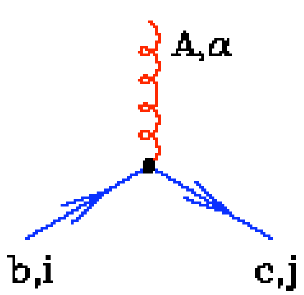


$$-ig^{2}\ f^{XAC}f^{XBD}\ [g^{\alpha\beta}g^{\gamma\delta}-g^{\alpha\delta}g^{\beta\gamma}]$$
$$-ig^{2}\ f^{XAD}f^{XBC}\ [g^{\alpha\beta}g^{\gamma\delta}-g^{\alpha\gamma}g^{\beta\delta}]$$
$$-ig^{2}\ f^{XAB}f^{XCD}\ [g^{\alpha\gamma}g^{\beta\delta}-g^{\alpha\delta}g^{\beta\gamma}]$$



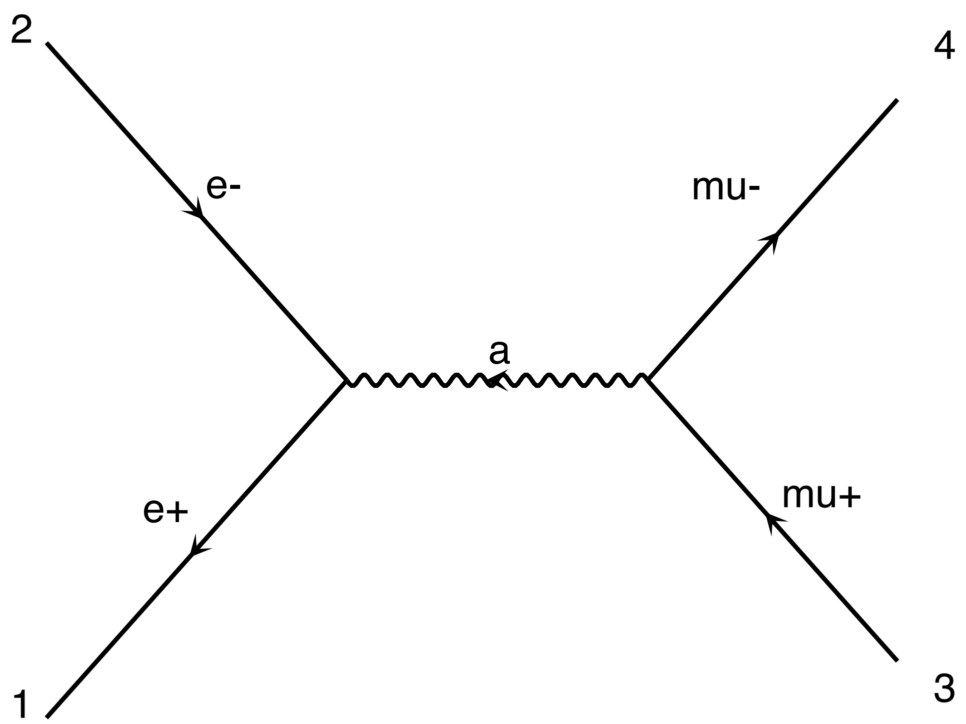


$$g\ f^{ABC}q^{\alpha}$$

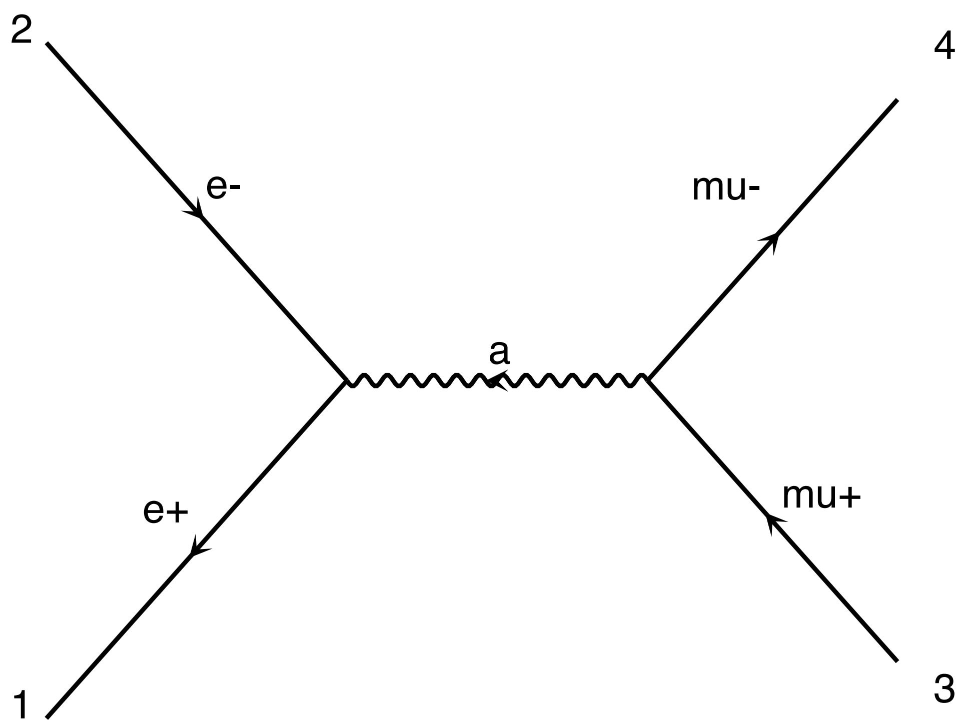


$$-ig\ (t^{A})_{cb}\ (\gamma^{\alpha})_{ji}$$

Evaluate a square Matrix Element

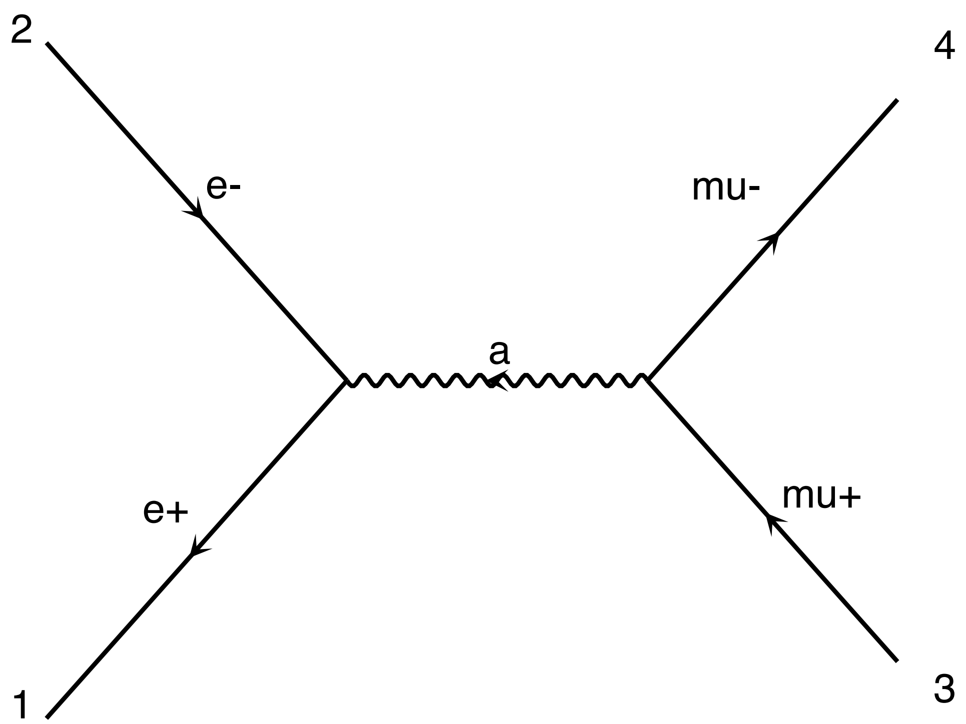


Evaluate a square Matrix Element



$$\mathcal{M} = e^2 (\bar{u}\gamma^\mu v) \frac{g_{\mu\nu}}{q^2} (\bar{u}\gamma^\nu v)$$

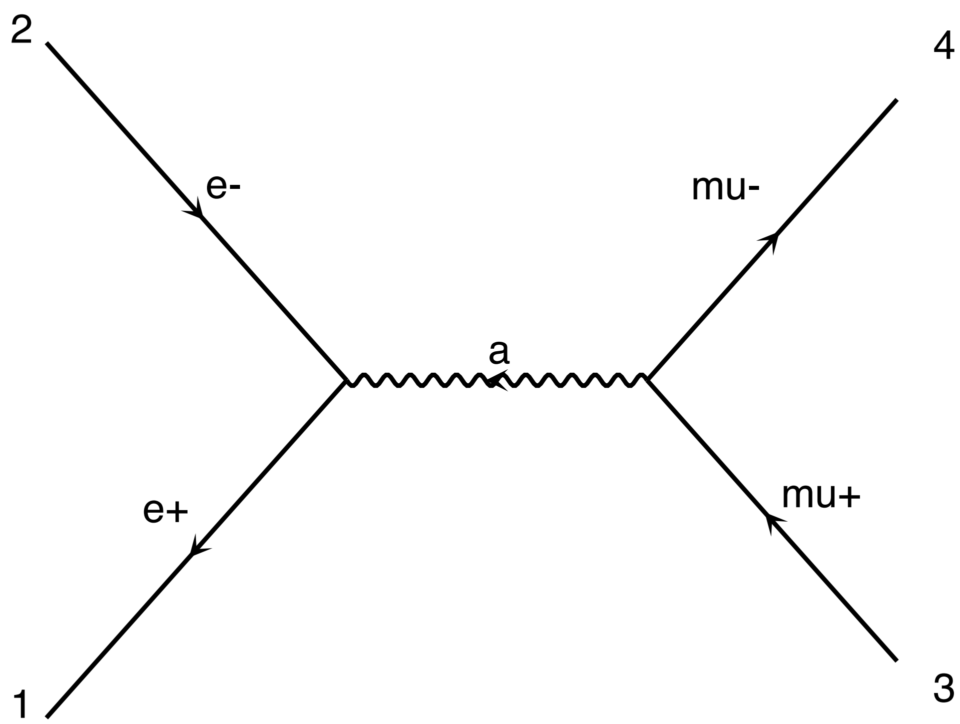
Evaluate a square Matrix Element



$$\mathcal{M} = e^2 (\bar{u}\gamma^\mu v) \frac{g_{\mu\nu}}{q^2} (\bar{u}\gamma^\nu v)$$

$$\frac{1}{4}\sum_{pol} |\mathcal{M}|^2 = \frac{1}{4}\sum_{pol} \mathcal{M}^* \mathcal{M}$$

Evaluate a square Matrix Element



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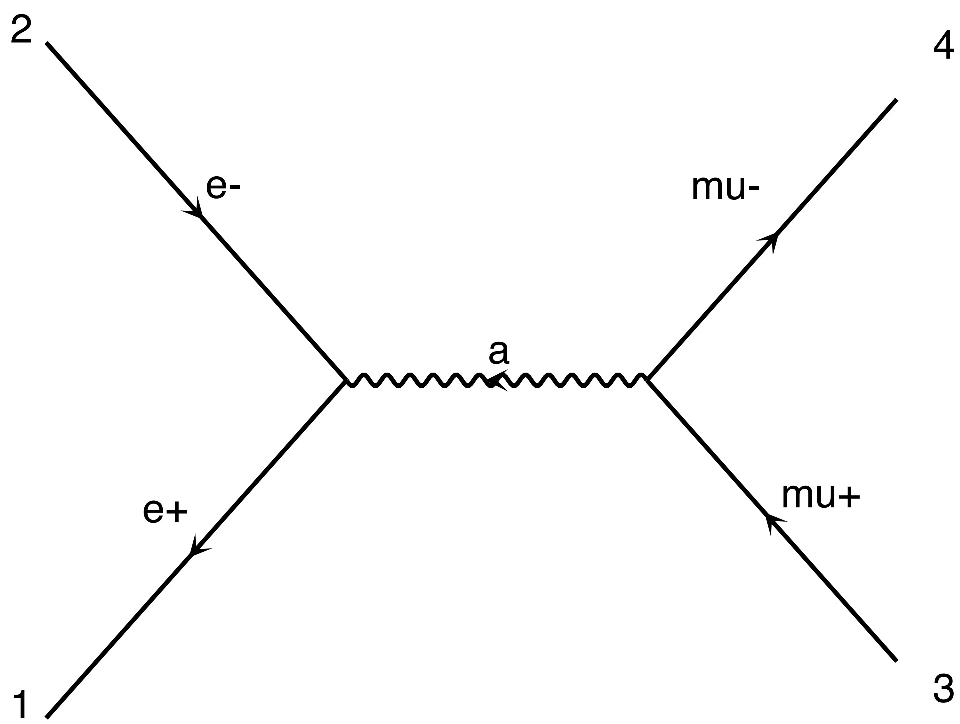
$$\sum_{pol} \bar{u}u = \not{p} + m$$

Evaluate a square Matrix Element



$$\mathcal{M} = e^2 (\bar{u}\gamma^\mu v) \frac{g_{\mu\nu}}{q^2} (\bar{u}\gamma^\nu v)$$

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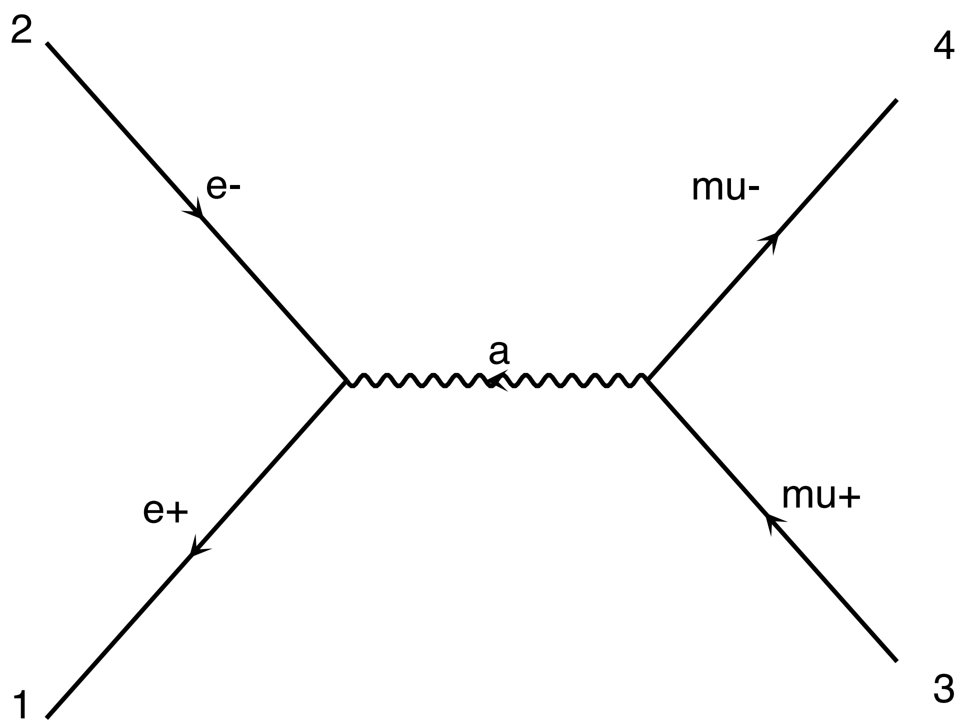
$$\sum_{pol} \bar{u}u = \not{p} + m$$

$$\rightarrow \frac{e^4}{4q^4} Tr[\not{p}_1 \gamma^\mu \not{p}_2 \gamma^\nu] Tr[\not{p}_3 \gamma_\mu \not{p}_4 \gamma_\nu]$$

Evaluate a square Matrix Element



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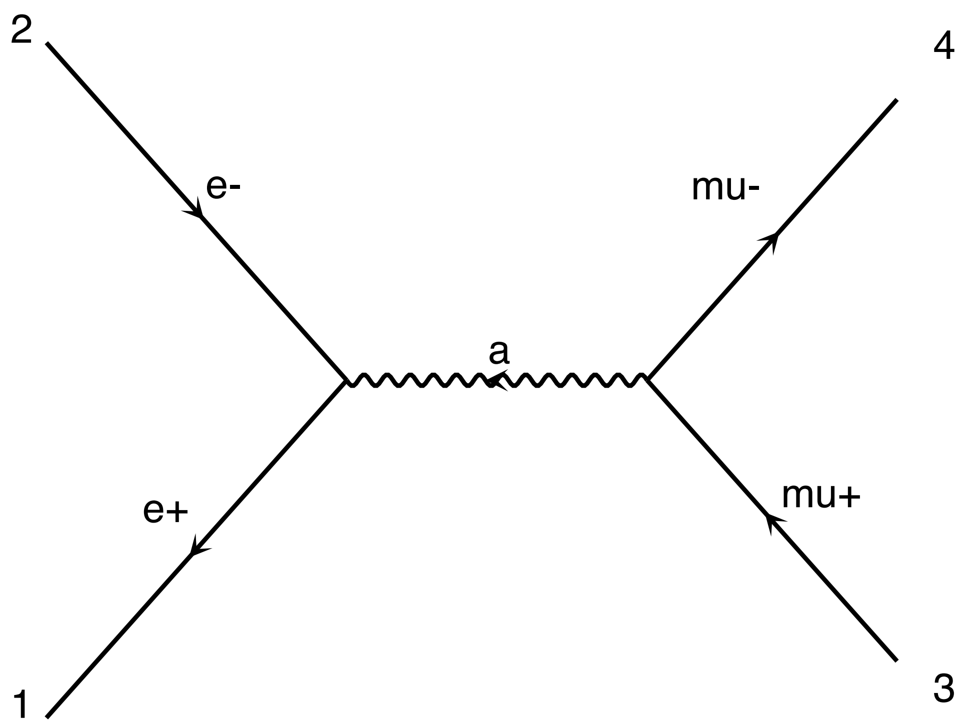
Very Efficient !!!

Evaluate a square Matrix Element



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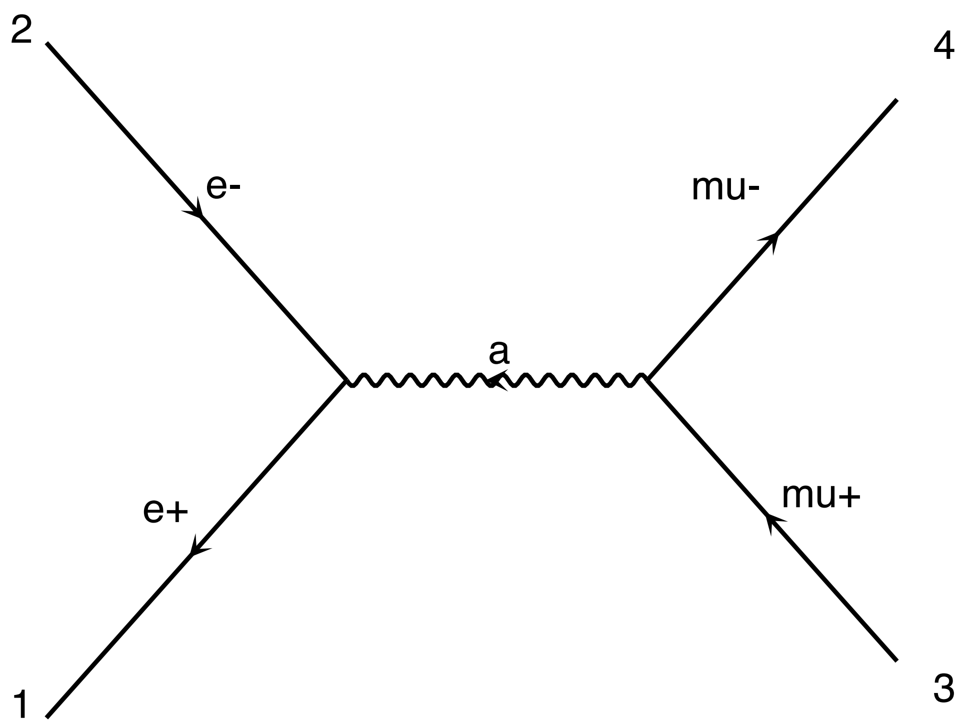
Very Efficient !!!

But The number of term raises as N^2

Evaluate a square Matrix Element



$$\mathcal{M} = e^2 (\bar{u}\gamma^\mu v) \frac{g_{\mu\nu}}{q^2} (\bar{u}\gamma^\nu v)$$

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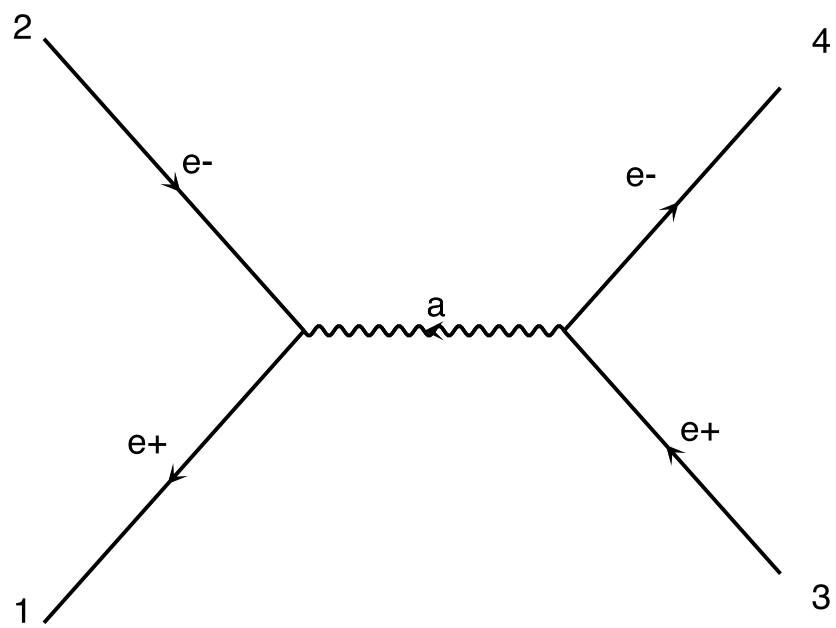
Very Efficient !!!

But The number of term raises as N^2

Only for 2>2 and 2>3

- Idea: Evaluate $\mathcal{M}$ for fixed helicity of external particles
    - ➡ Multiply $\mathcal{M}$ with $\mathcal{M}^*$ -> $|\mathcal{M}|$^2
    - ➡ Loop on Helicity and sum the results



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

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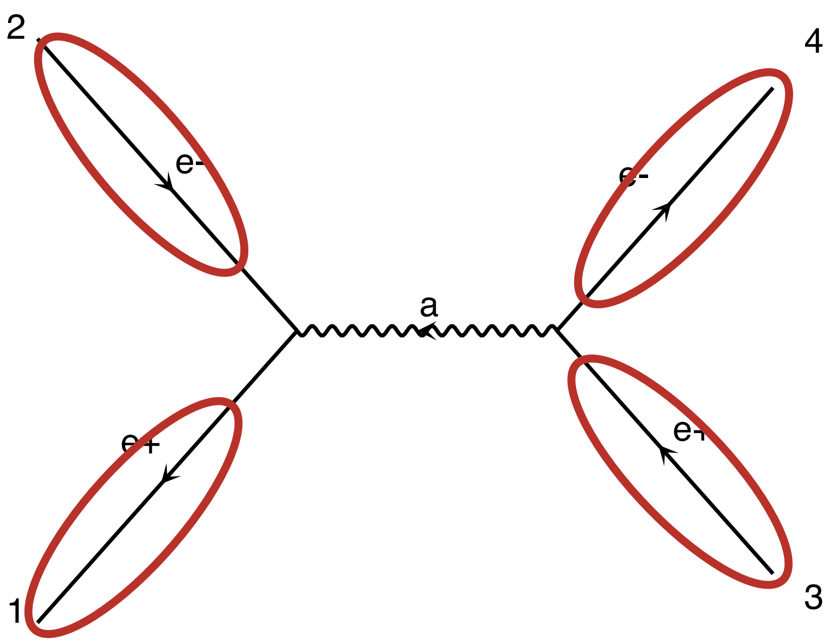

$$\mathcal{M} = \bar{u}\gamma^\mu v P_{\mu\nu} \bar{u}\gamma^\nu v$$

Numbers for given helicity and momenta

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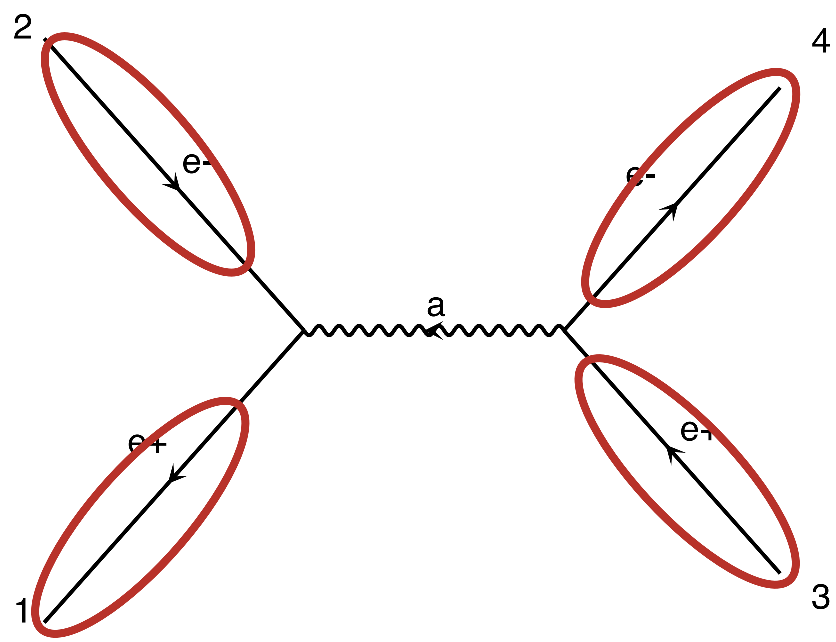

$$\mathcal{M} = \bar{u}\gamma^{\mu} v P_{\mu\nu} \bar{u}\gamma^{\nu} v$$

Numbers for given helicity and momenta

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

- Idea: Evaluate $\mathcal{M}$ for fixed helicity of external particles
  - ➡ Multiply $\mathcal{M}$ with $\mathcal{M}^*$ -> $|\mathcal{M}|$^2
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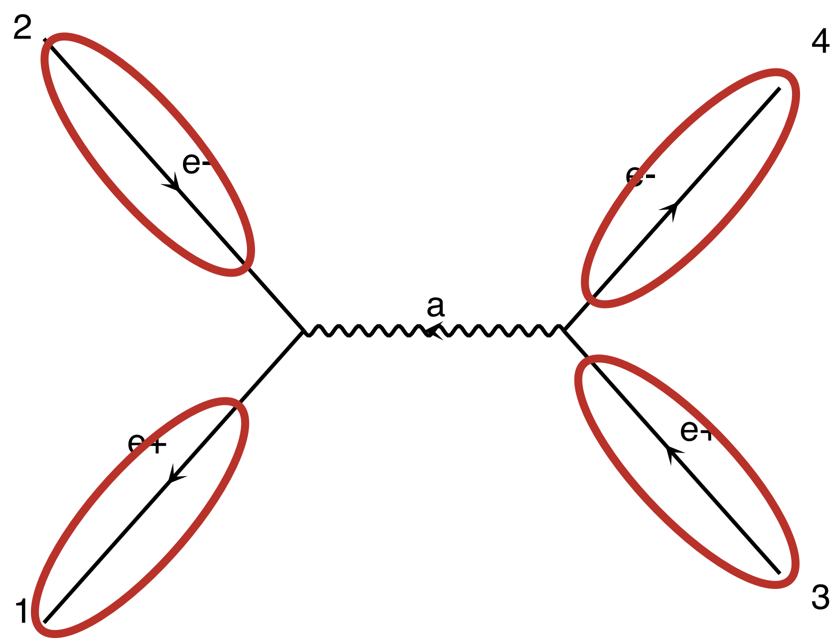

$$\mathcal{M} = \bar{u}\gamma^\mu v P_{\mu\nu} \bar{u}\gamma^\nu v$$

Numbers for given helicity and momenta

```
CALL OXXXXX(P(0,1),ZERO,NHEL(1),-1*IC(1),W(1,1))
```

Input: momenta, mass, helicity

Ouput: Wavefunction (given by an analytical formula)

- Idea: Evaluate $\mathcal{M}$ for fixed helicity of external particles
  - ➡ Multiply $\mathcal{M}$ with $\mathcal{M}^*$ -> $|\mathcal{M}|$^2
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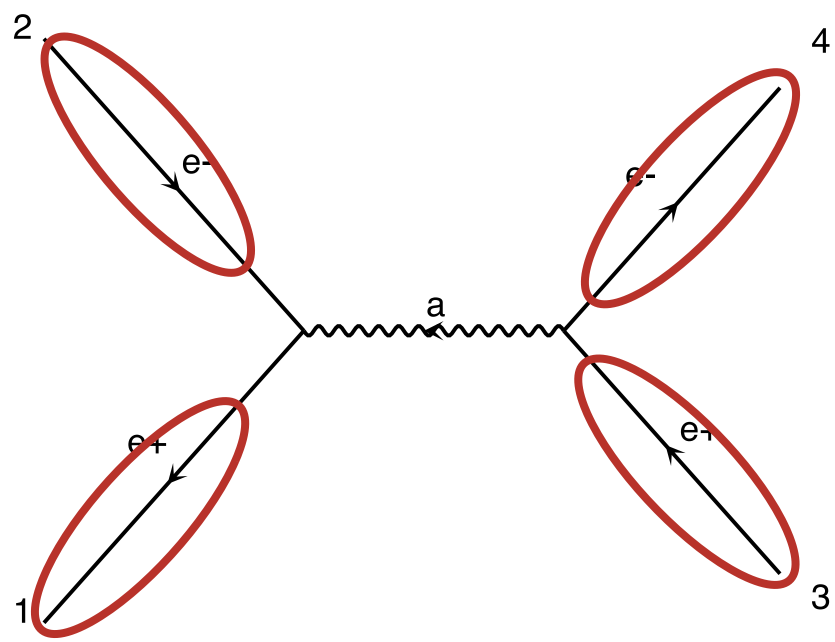

$$\mathcal{M} = \bar{u}\gamma^\mu v P_{\mu\nu} \bar{u}\gamma^\nu v$$

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

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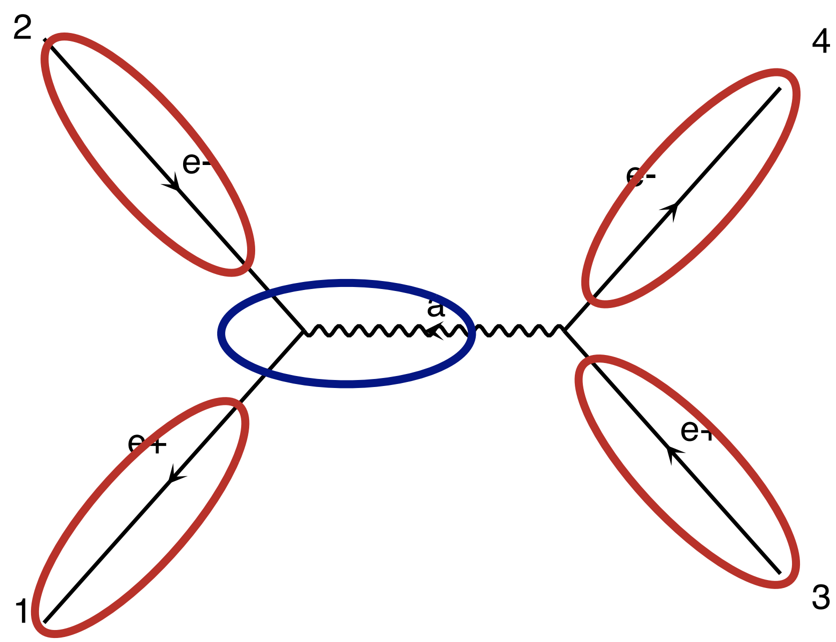

$$\mathcal{M} = \bar{u}\gamma^{\mu}v P_{\mu\nu}\bar{u}\gamma^{\nu}v$$

Numbers for given helicity and momenta

Calculate propagator wavefunctions

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

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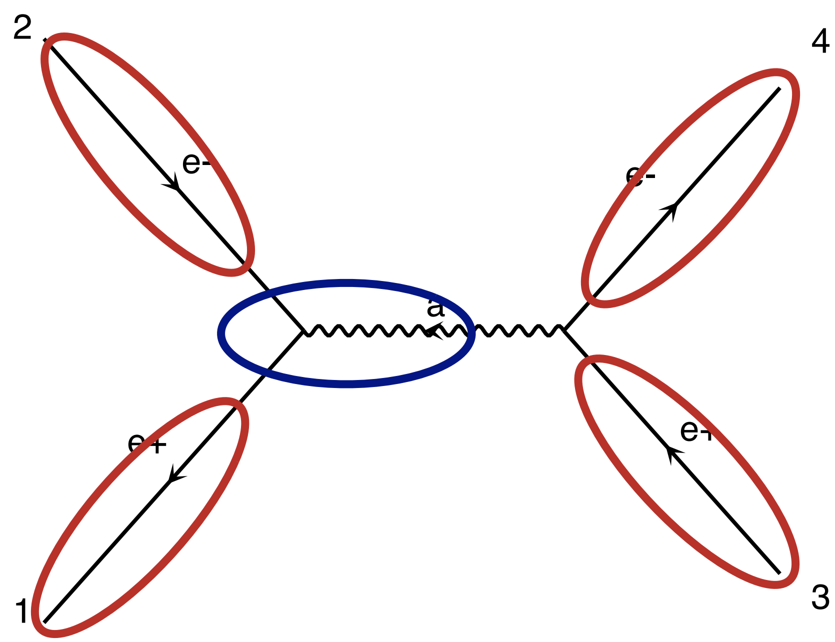

$$\mathcal{M} = \bar{u}\gamma^{\mu} v P_{\mu\nu} \bar{u}\gamma^{\nu} v$$

Numbers for given helicity and momenta

Calculate propagator wavefunctions

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

Input: Wavefunctions, mass, width, coupling

```
CALL JIOXXX(W(1,2),W(1,1),GAL,ZERO,ZERO,W(1,5))
```

Ouput: Wavefunction (given by an analytical formula)

- Idea: Evaluate $\mathcal{M}$ for fixed helicity of external particles
  - ➡ Multiply $\mathcal{M}$ with $\mathcal{M}^*$ -> $|\mathcal{M}|$^2
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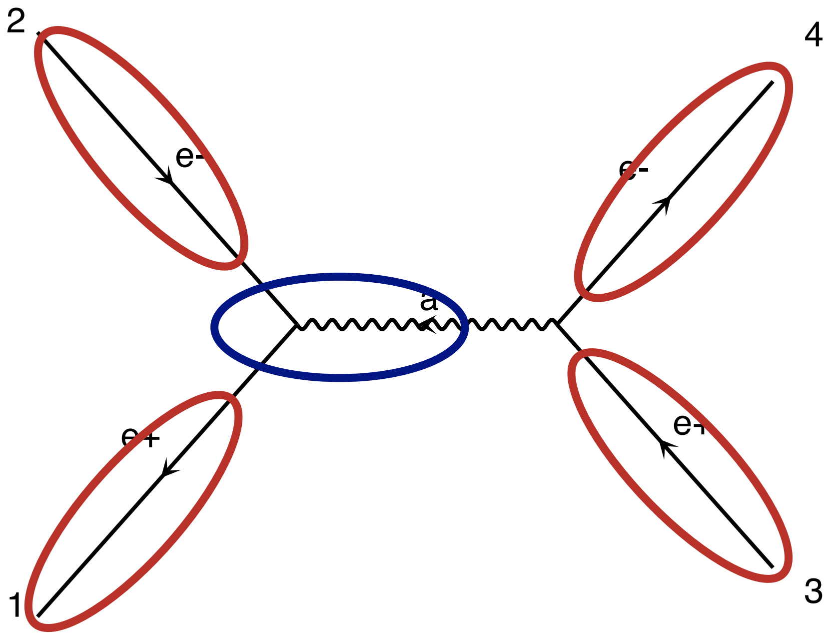

$$\mathcal{M} = \bar{u}\gamma^\mu v P_{\mu\nu} \bar{u}\gamma^\nu v$$

Numbers for given helicity and momenta

Calculate propagator wavefunctions

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

- Idea: Evaluate $\mathcal{M}$ for fixed helicity of external particles
  - ➡ Multiply $\mathcal{M}$ with $\mathcal{M}^*$ -> $|\mathcal{M}|$^2
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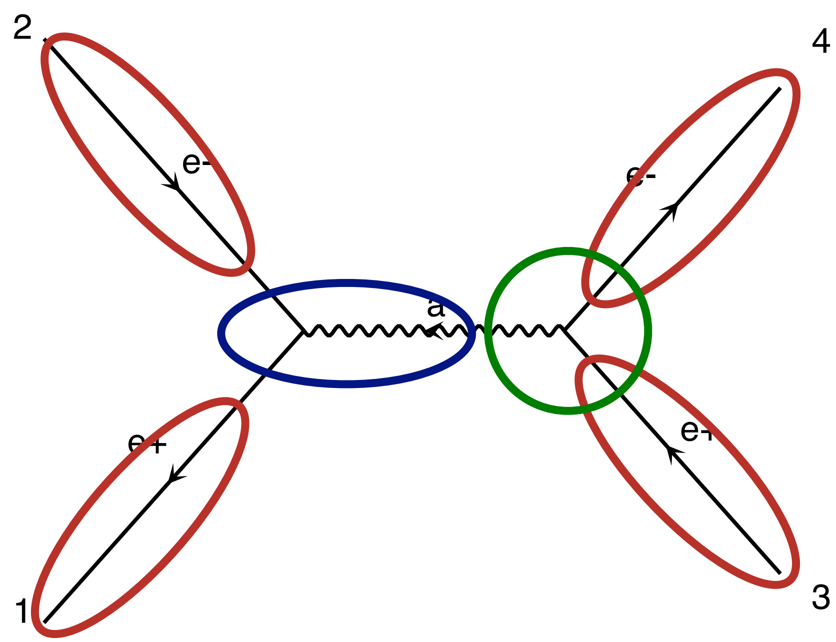

$$\mathcal{M} = \bar{u}\gamma^{\mu} v P_{\mu\nu} \bar{u}\gamma^{\nu} v$$

Numbers for given helicity and momenta

Calculate propagator wavefunctions

Finally evaluate amplitude (c-number)

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

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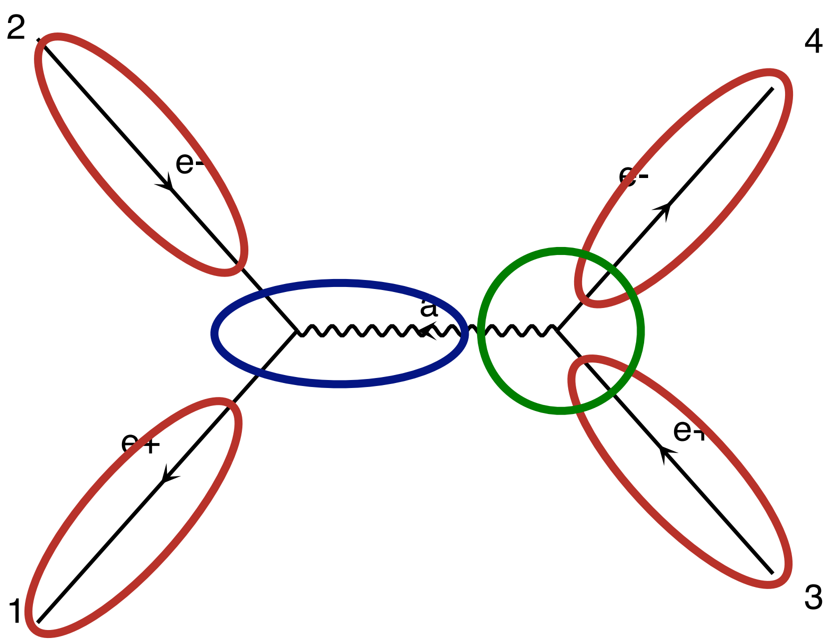

$$\mathcal{M} = \bar{u}\gamma^{\mu} v P_{\mu\nu} \bar{u}\gamma^{\nu} v$$

Numbers for given helicity and momenta

Calculate propagator wavefunctions

Finally evaluate amplitude (c-number)

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

Input: Wavefunctions, coupling

```
CALL IOVXXX(W(1,3),W(1,4),W(1,5),GAL,AMP(1))
```

Ouput: Amplitude

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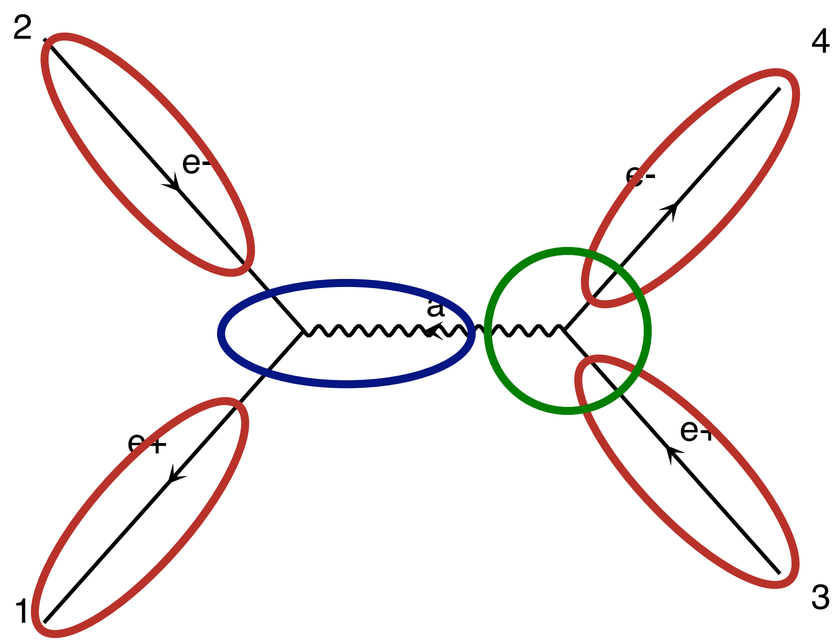

$$\mathcal{M} = \bar{u}\gamma^{\mu} v P_{\mu\nu} \bar{u}\gamma^{\nu} v$$

Numbers for given helicity and momenta

Calculate propagator wavefunctions

Finally evaluate amplitude (c-number)

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

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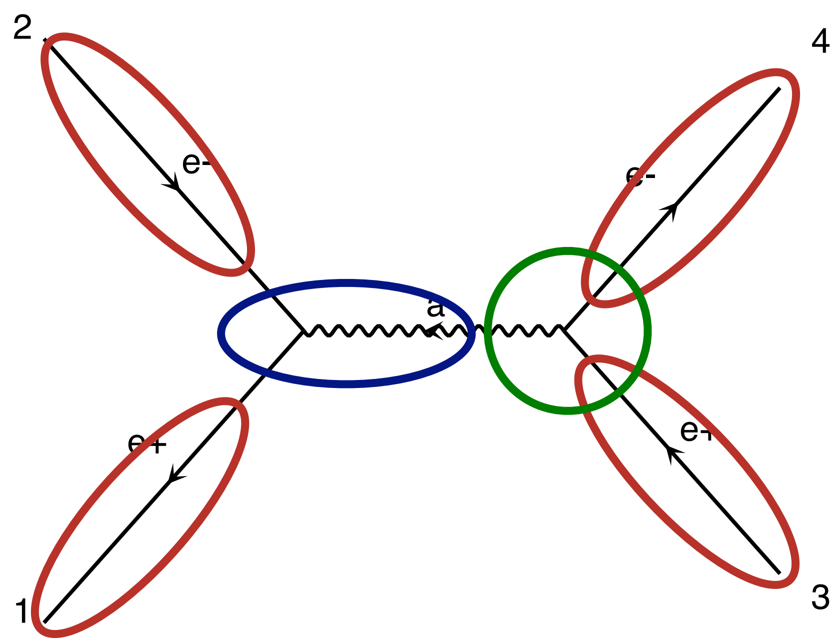


$$\mathcal{M} = \bar{u}\gamma^{\mu} v P_{\mu\nu} \bar{u}\gamma^{\nu} v$$

Numbers for given helicity and momenta

Calculate propagator wavefunctions

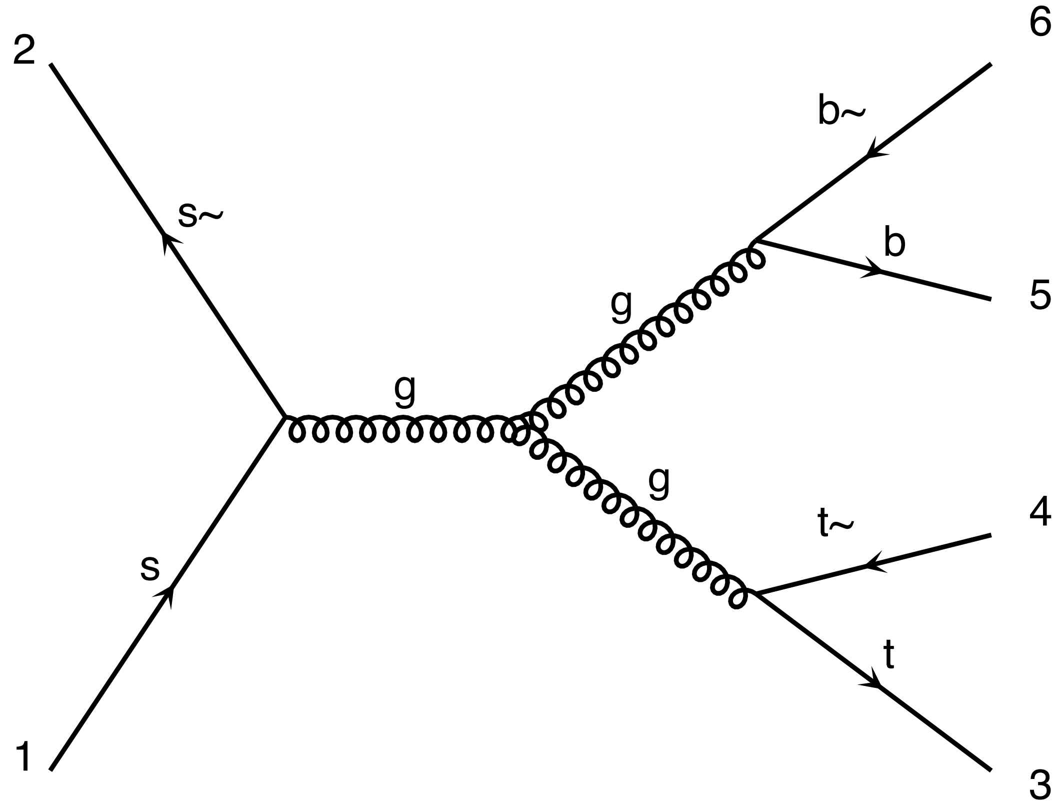
Finally evaluate amplitude (c-number)

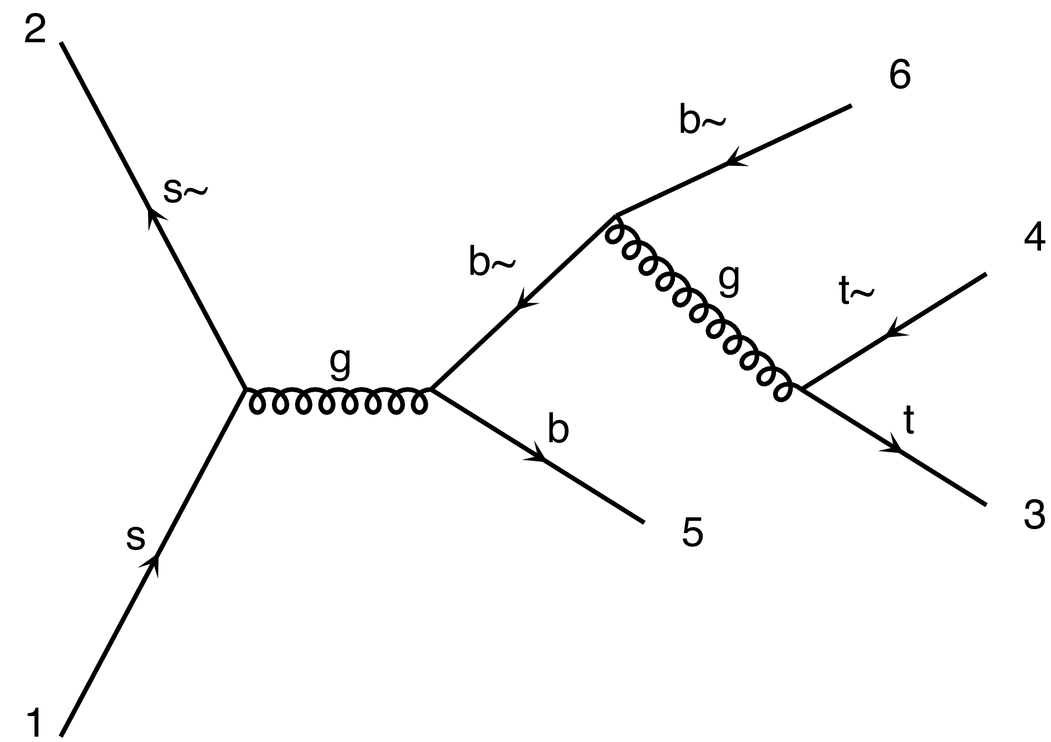
Helicity amplitude calls written by MadGraph

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

Real case

Known



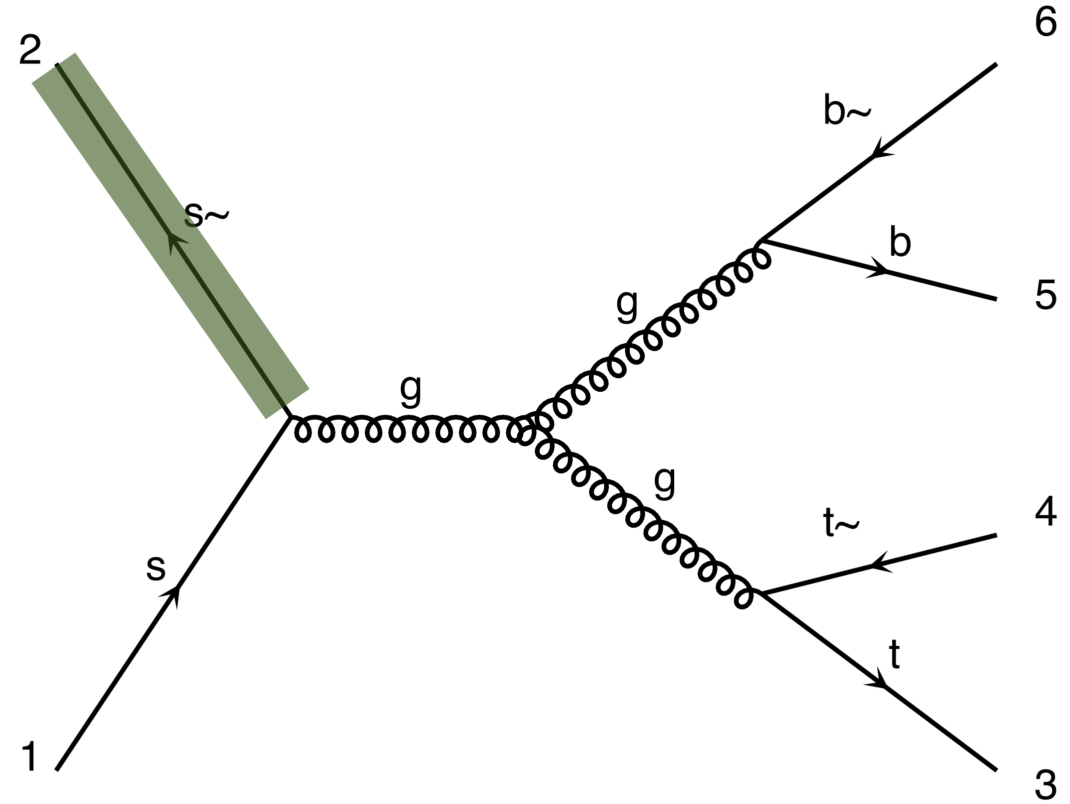


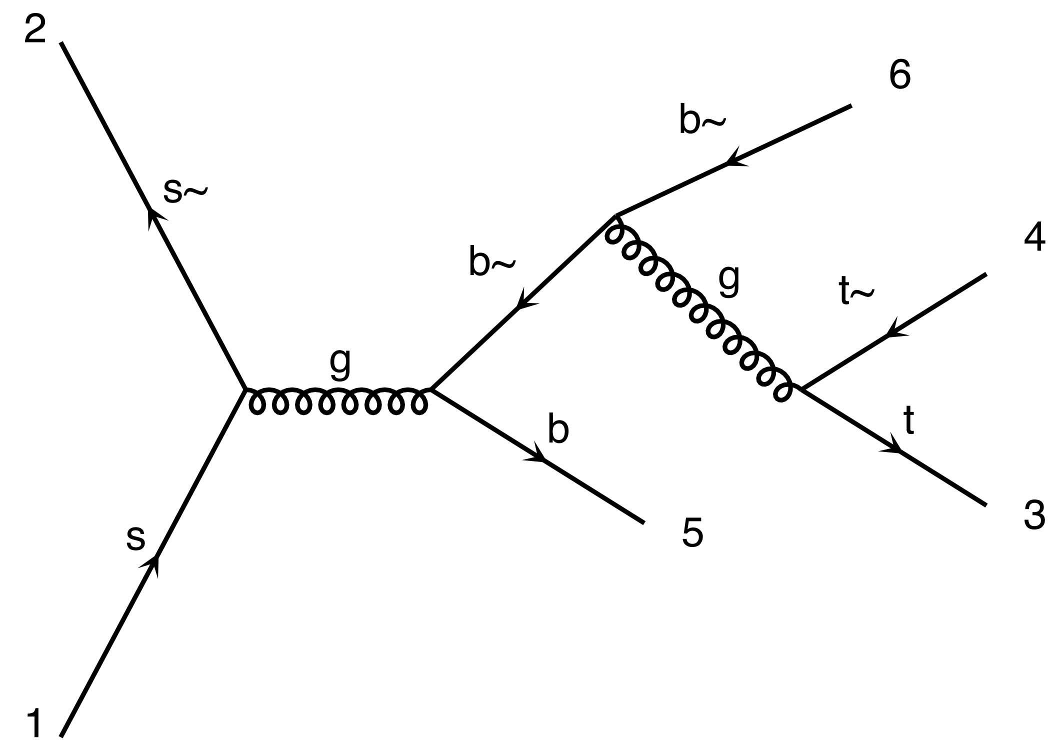
Number of routines: 0

Number of routines:0

Number of routines for both: 0

Real case



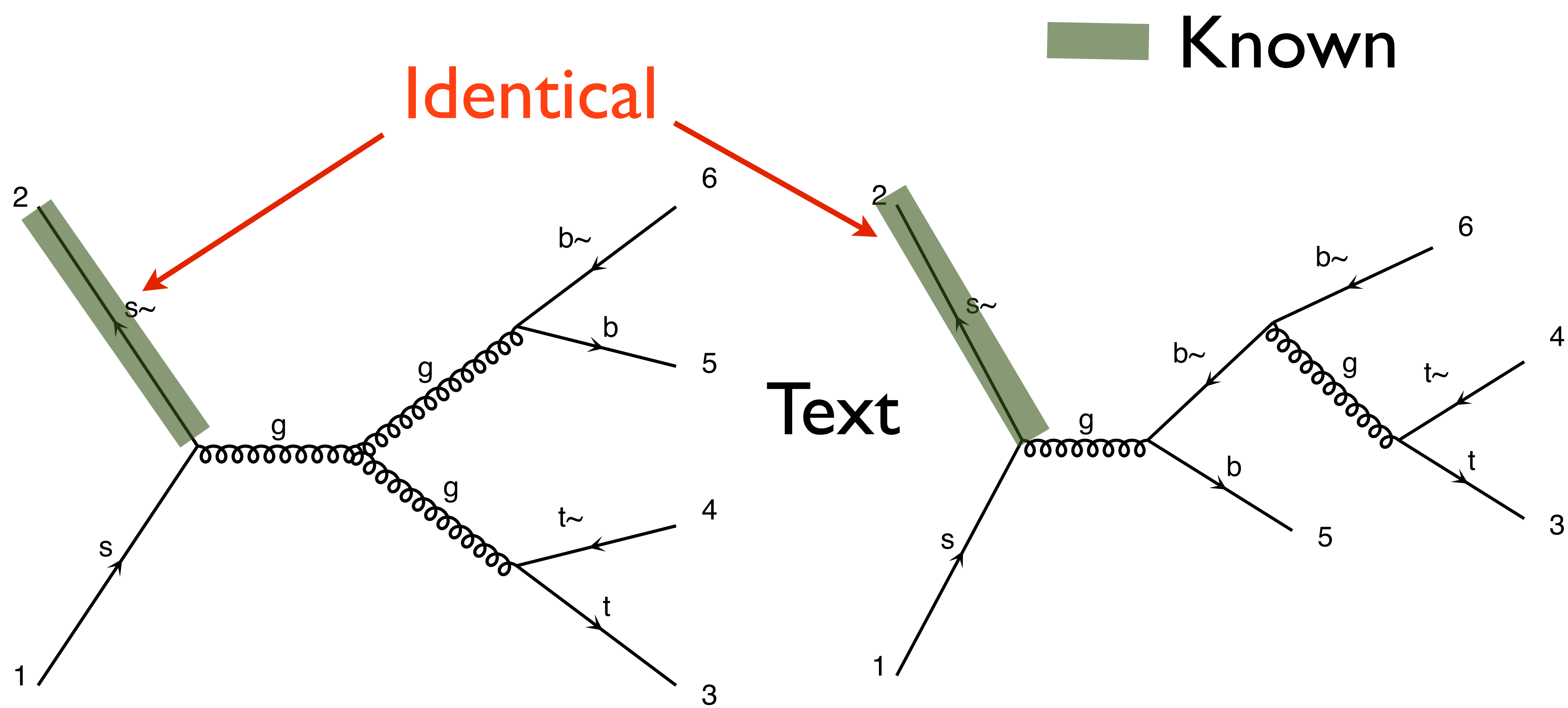


Number of routines:1

Number of routines:0

Number of routines for both: 1

Real case

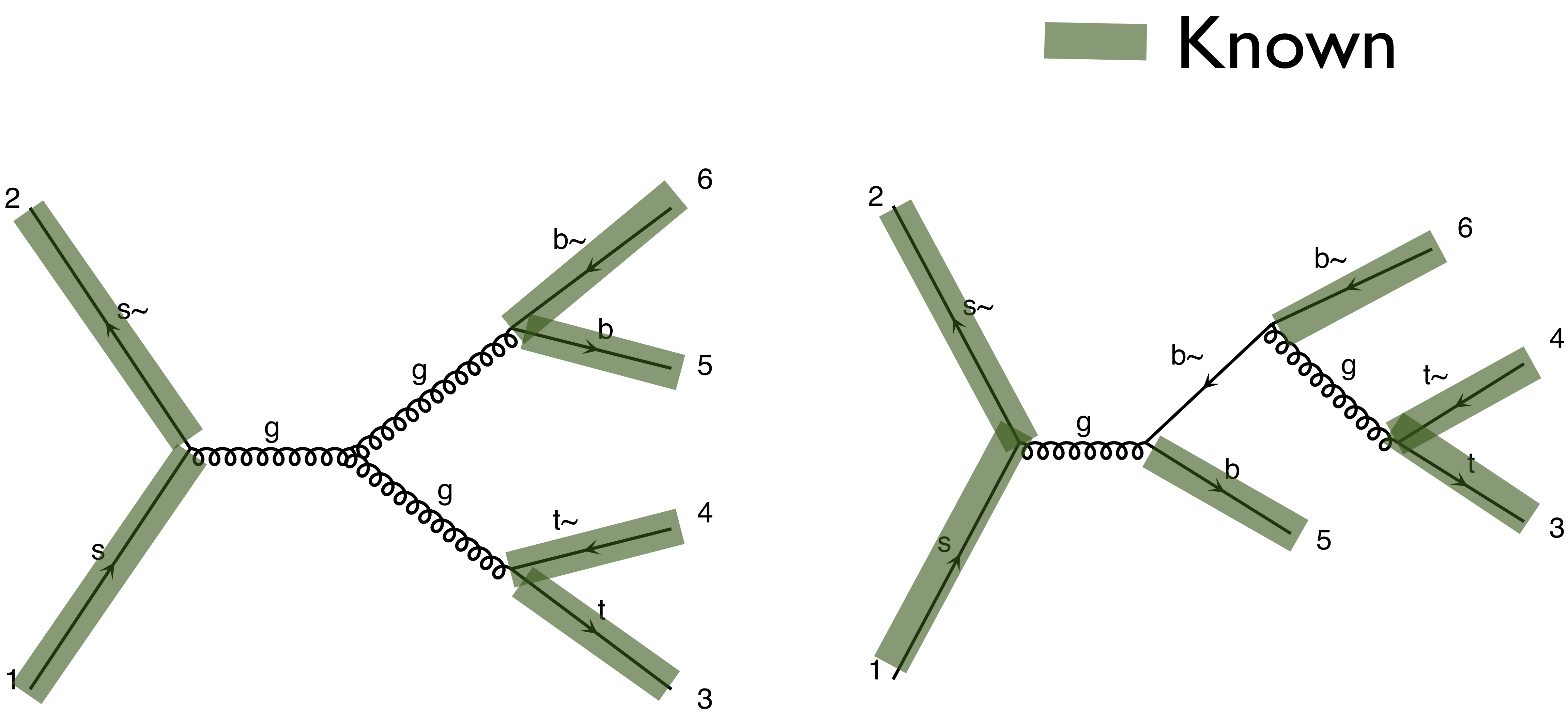


Number of routines: I

Number of routines: I

Number of routines for both: I

Real case



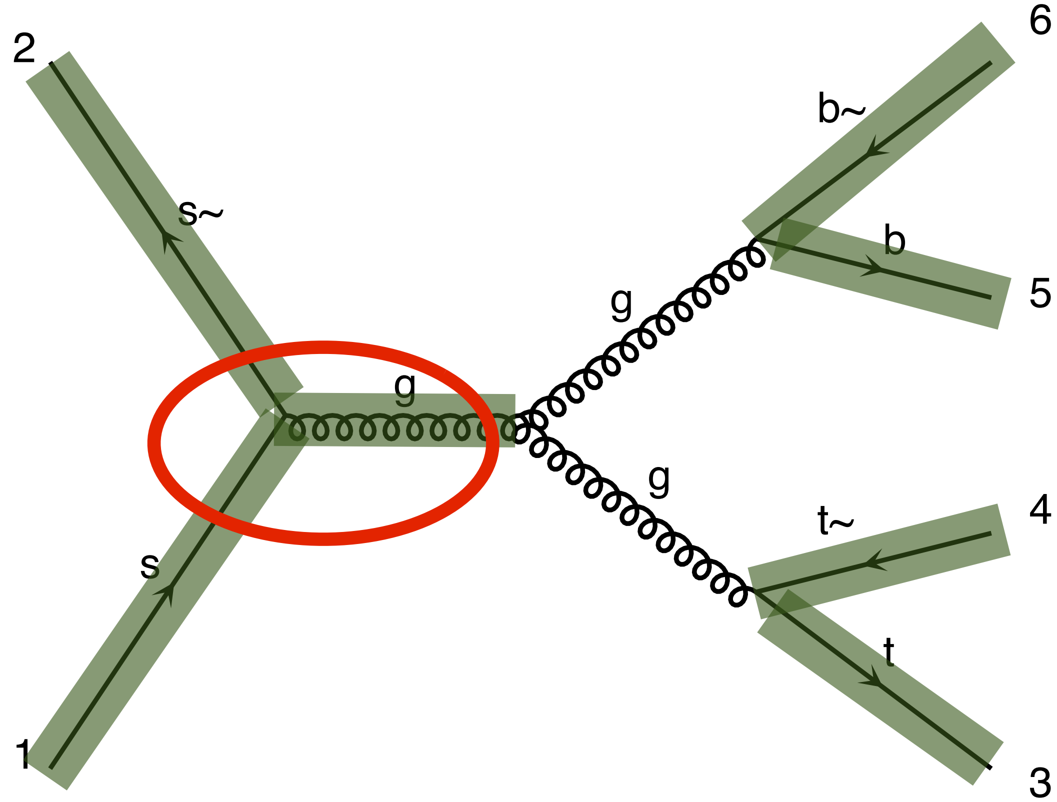
Number of routines: 6

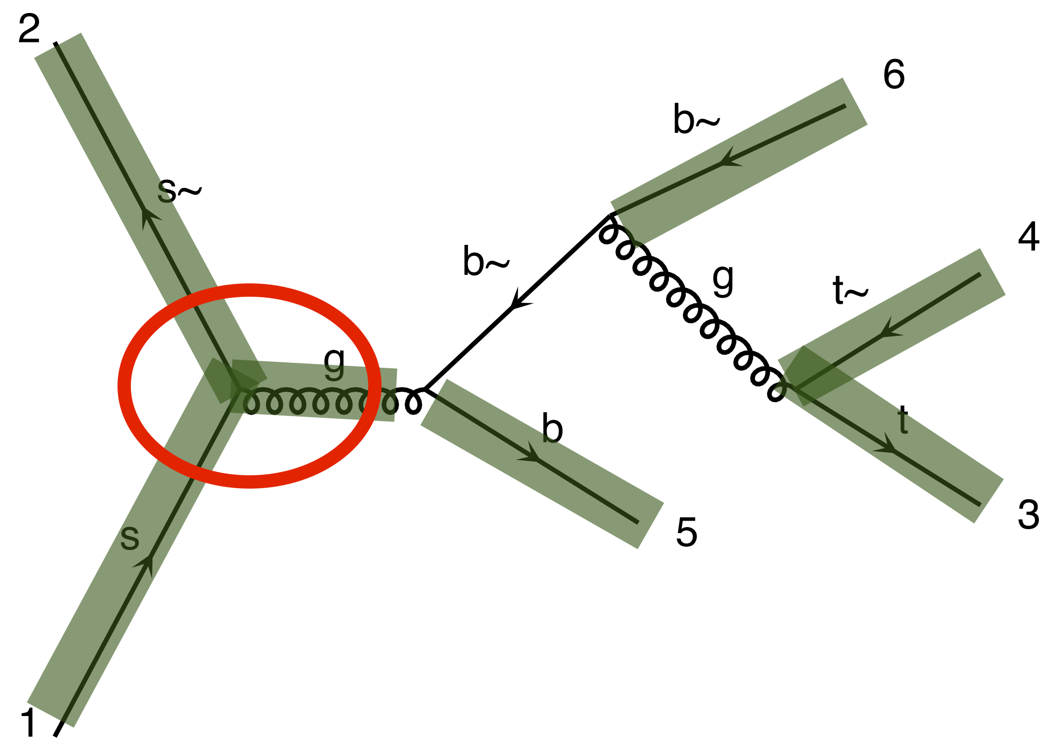
Number of routines: 6

Number of routines for both: 6

Real case

Known



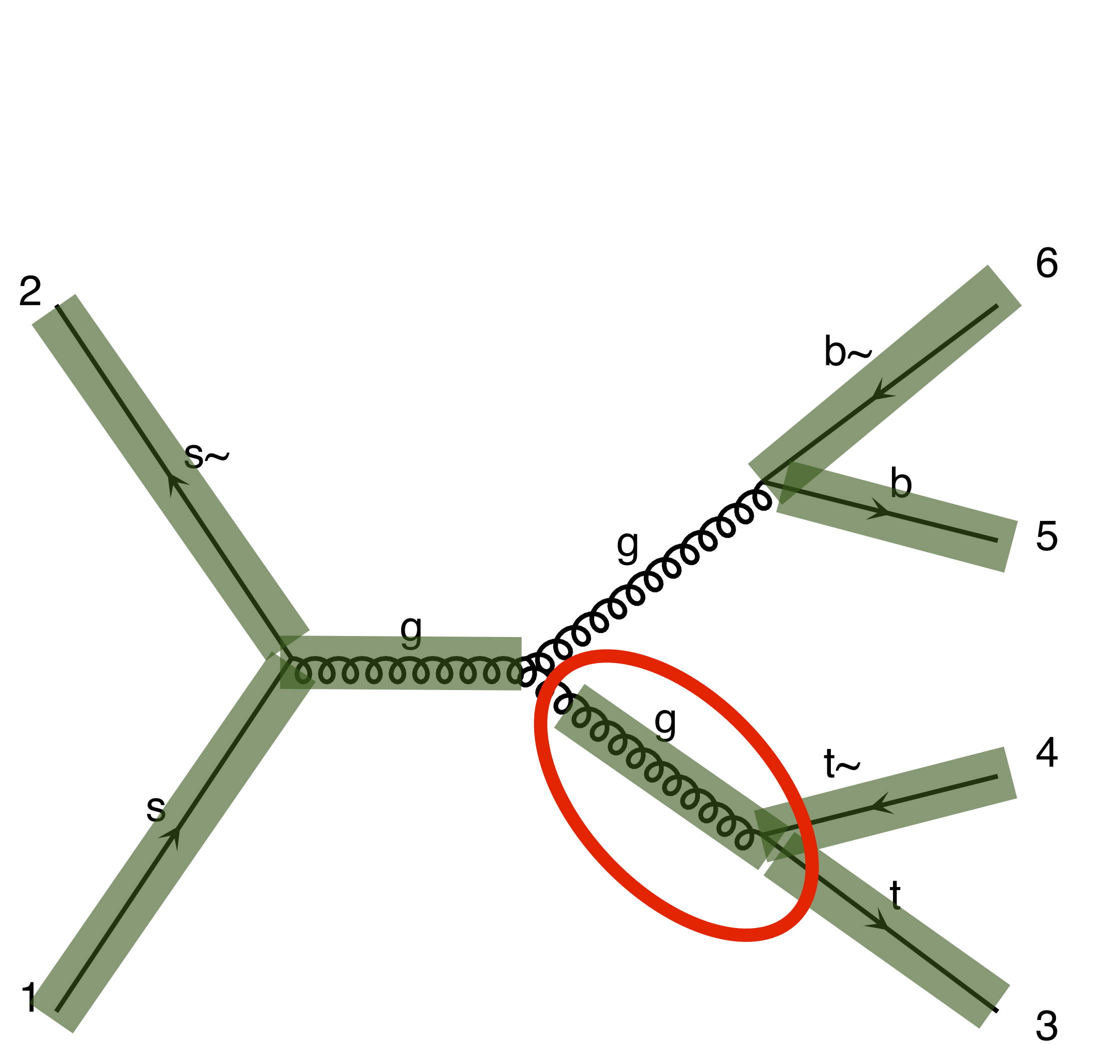


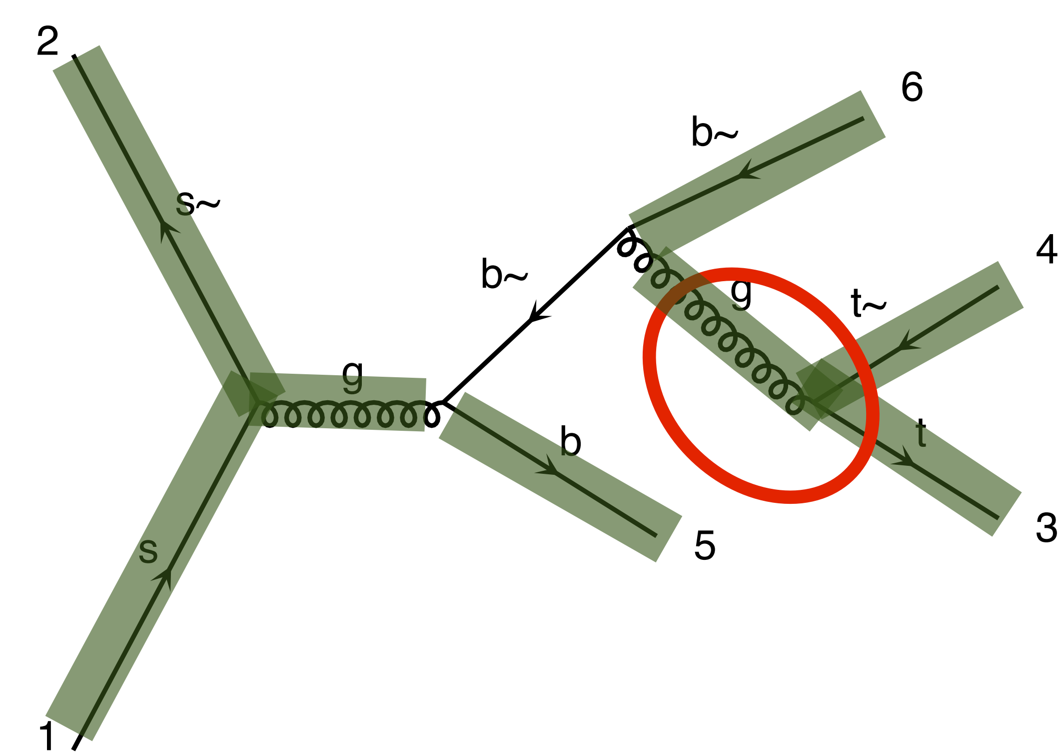
Number of routines: 7

Number of routines: 7

Number of routines for both: 7

Real case





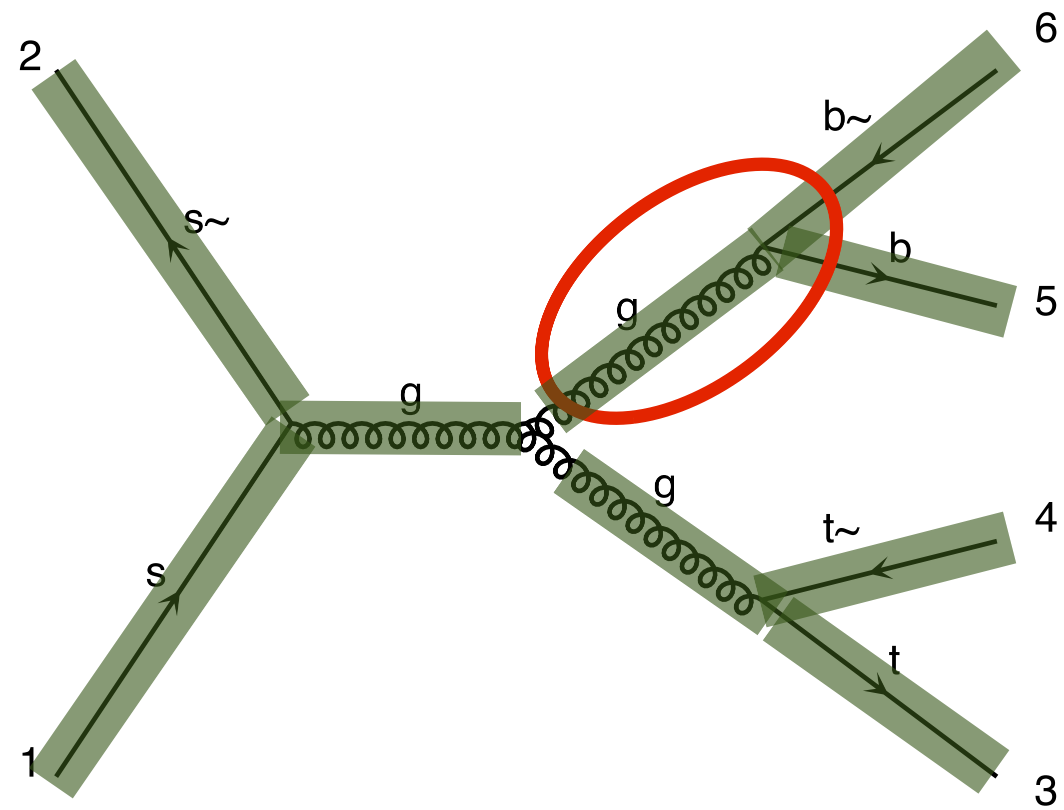
Number of routines: 8

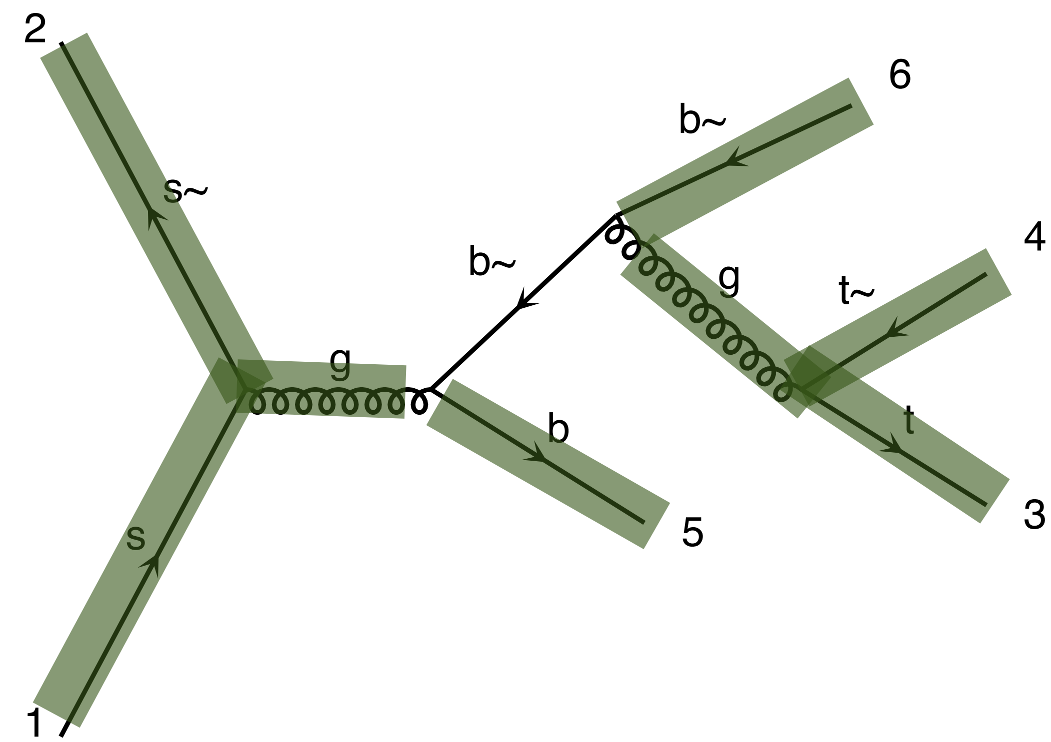
Number of routines: 8

Number of routines for both: 8

Real case

Known



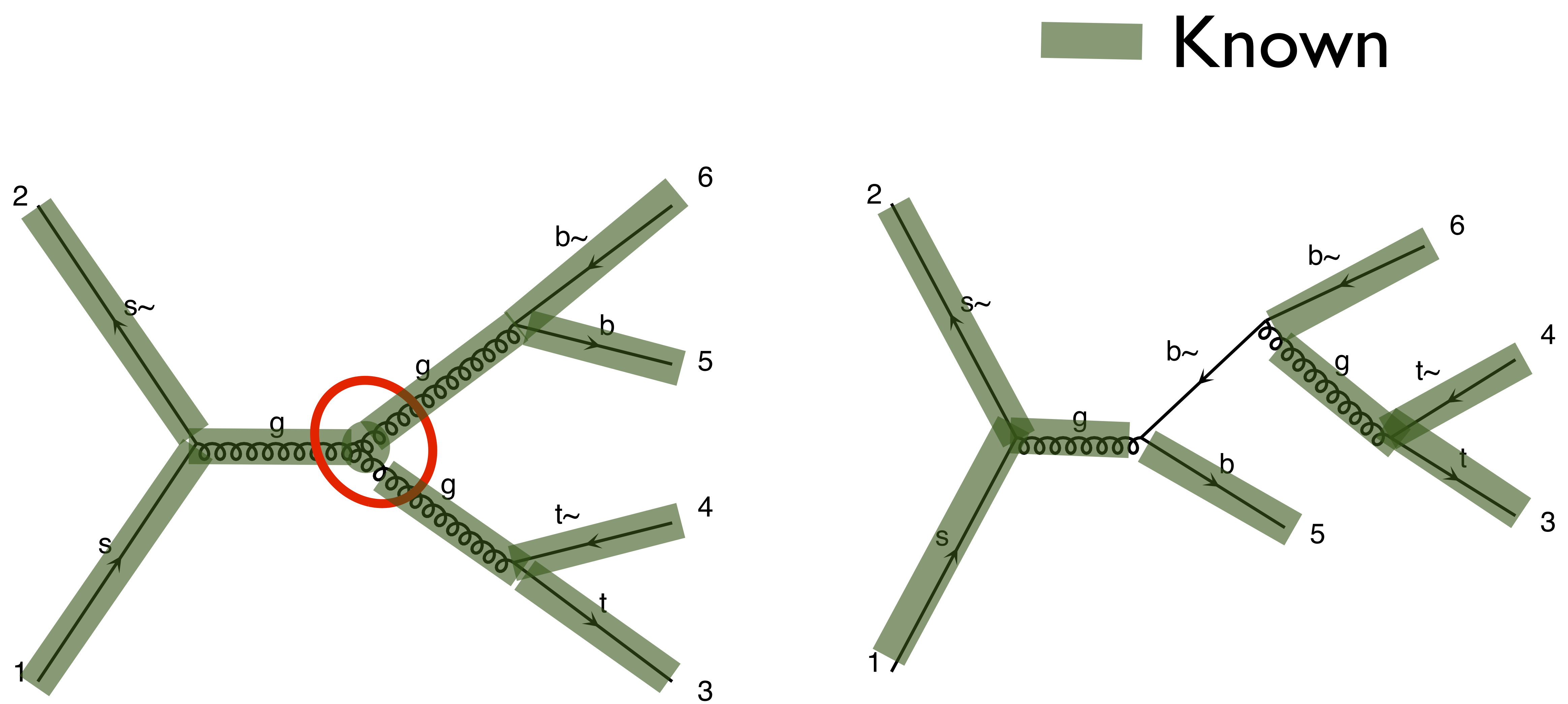


Number of routines: 9

Number of routines: 8

Number of routines for both: 9

Real case



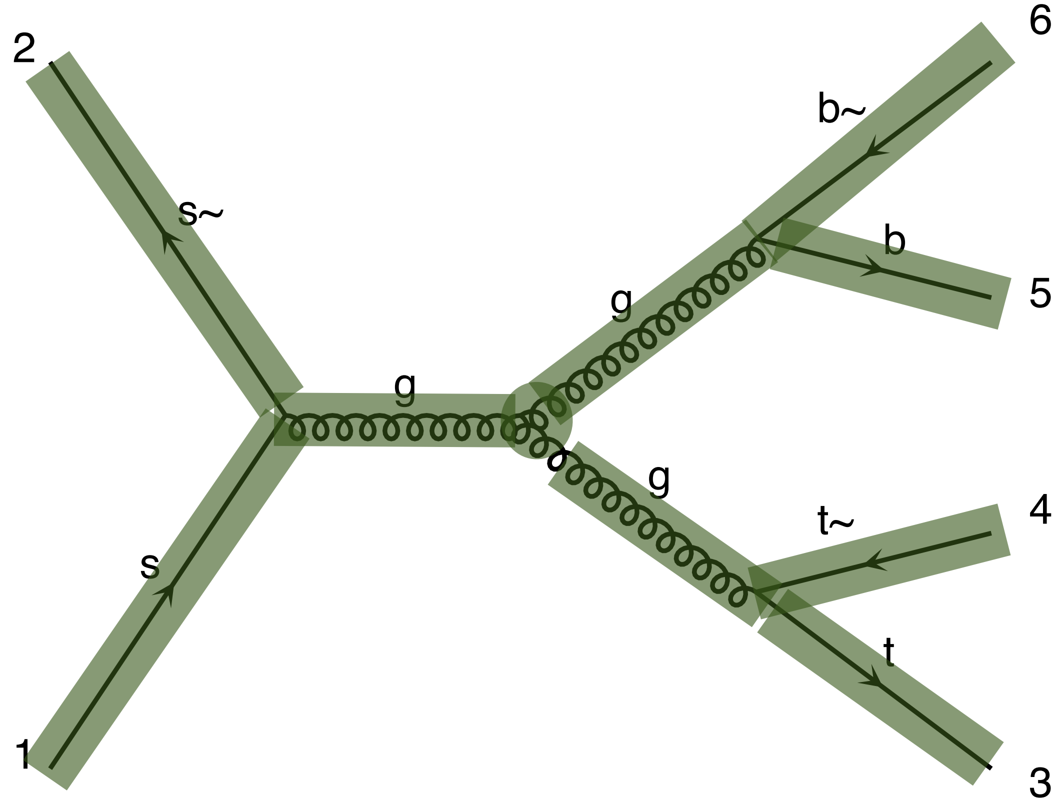
Number of routines: 10

Number of routines: 8

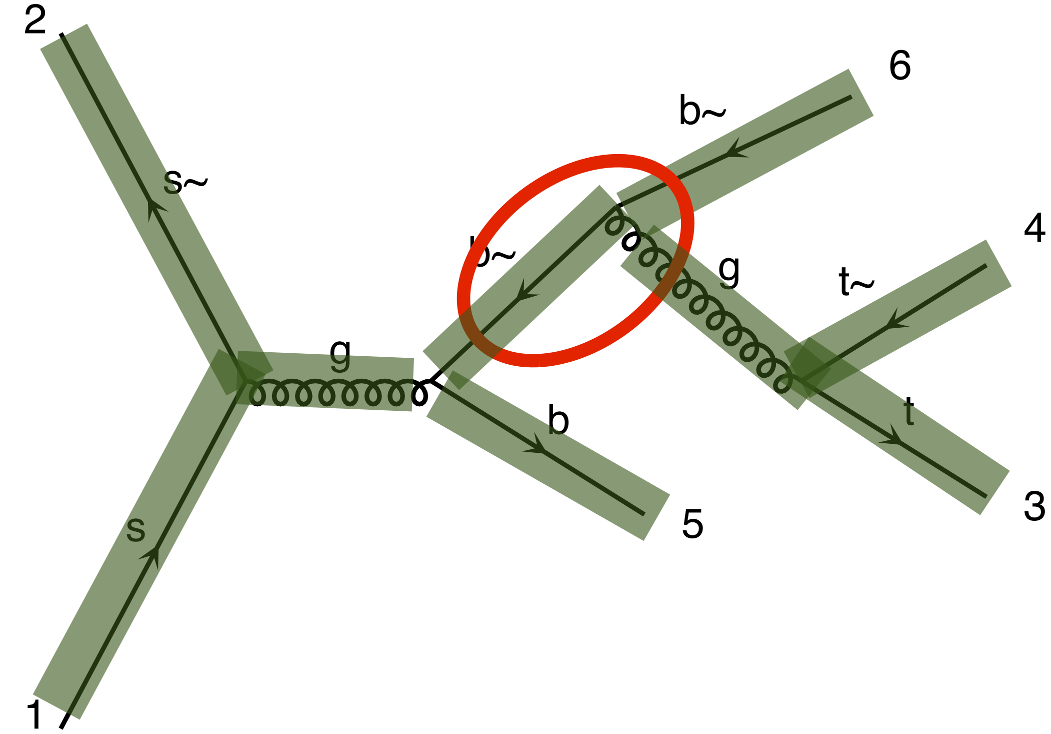
Number of routines for both: 10

Real case

Known



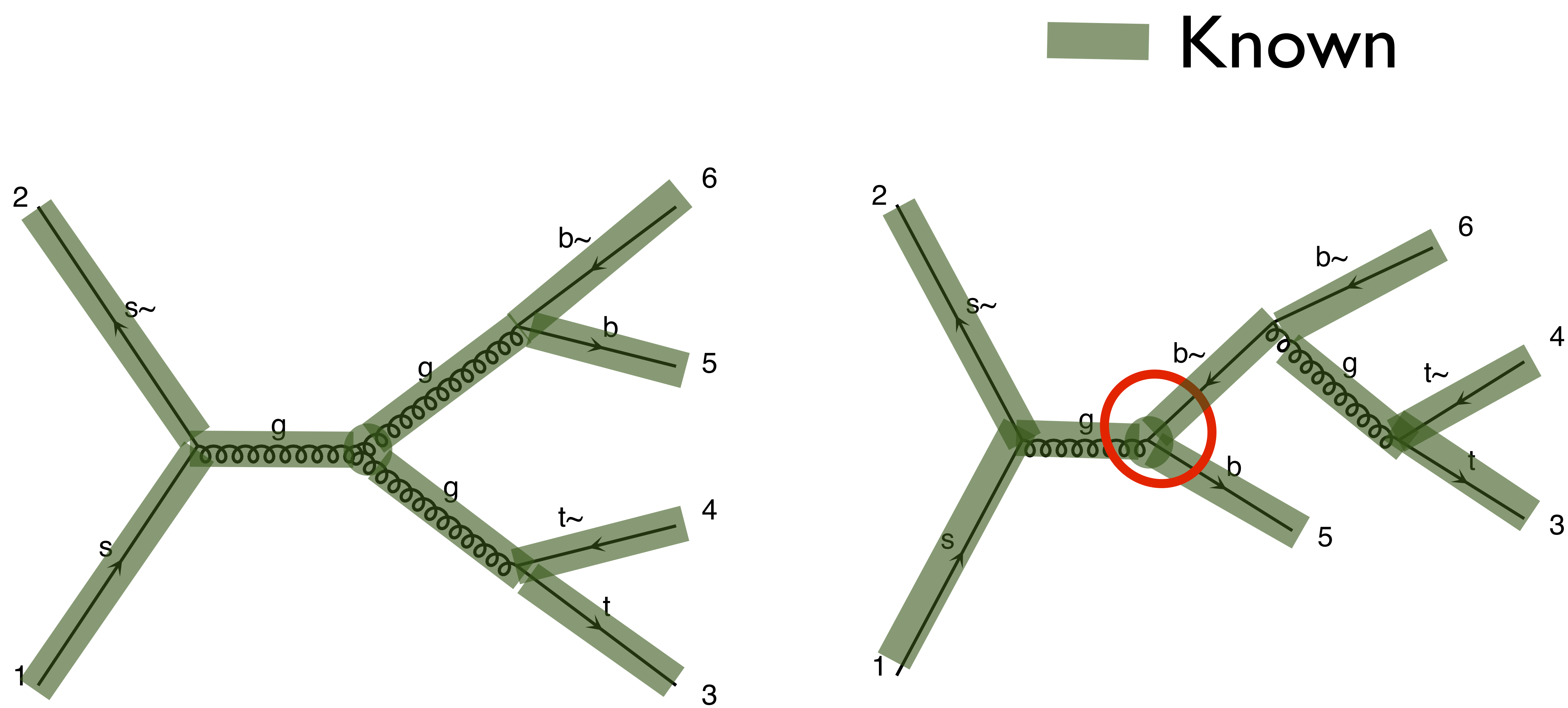
Number of routines:10



Number of routines: 9

Number of routines for both: 11

Real case



Number of routines:10

Number of routines: 10

Number of routines for both: 12

Basics: Helicity amplitudes

- Thanks to new diagram generation algorithm, wf recycling much more efficient in MG5 than MG4

Process	Amplitudes	Wavefunctions		Run time		no recycling
		MG 4	MG 5	MG 4	MG 5	
$u\bar{u} \to e^+e^-$	2	6	6	$< 6\mu s$	$< 6\mu s$	
$u\bar{u} \to e^+e^-e^+e^-$	48	62	32	0.22 ms	0.14 ms	
$u\bar{u} \to e^+e^-e^+e^-e^+e^-$	3474	3194	301	46.5 ms	19.0 ms	300k
$u\bar{u} \to d\bar{d}$	1	5	5	$< 4\mu s$	$< 4\mu s$	
$u\bar{u} \to d\bar{d}g$	5	11	11	27 μs	27 μs	
$u\bar{u} \to d\bar{d}gg$	38	47	29	0.42 ms	0.31 ms	
$u\bar{u} \to d\bar{d}ggg$	393	355	122	10.8 ms	6.75 ms	
$u\bar{u} \to u\bar{u}gg$	76	84	40	1.24 ms	0.80 ms	
$u\bar{u} \to u\bar{u}ggg$	786	682	174	35.7 ms	17.2 ms	
$u\bar{u} \to d\bar{d}d\bar{d}$	14	28	19	84 μs	83 μs	
$u\bar{u} \to d\bar{d}d\bar{d}g$	132	178	65	1.88 ms	1.15 ms	
$u\bar{u} \to d\bar{d}d\bar{d}gg$	1590	1782	286	141 ms	34.4 ms	
$u\bar{u} \to d\bar{d}d\bar{d}d\bar{d}$	612	758	141	42.5 ms	6.6 ms	5500

Time for matrix element evaluation on a Sony Vaio TZ laptop

HELAS

HELAS

- Original HELicity Amplitude Subroutine library

[Murayama, Watanabe, Hagiwara]

HELAS

- Original HELicity Amplitude Subroutine library
  [Murayama, Watanabe, Hagiwara]

- One routine by Lorentz structure
  - ➡ MSSM [cho, al] hep-ph/0601063 (2006)
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Chiral Perturbation

BNV Model

SLIH

Effective Field Theory

NMSSM

Chromo-magnetic operator

Full HEFT

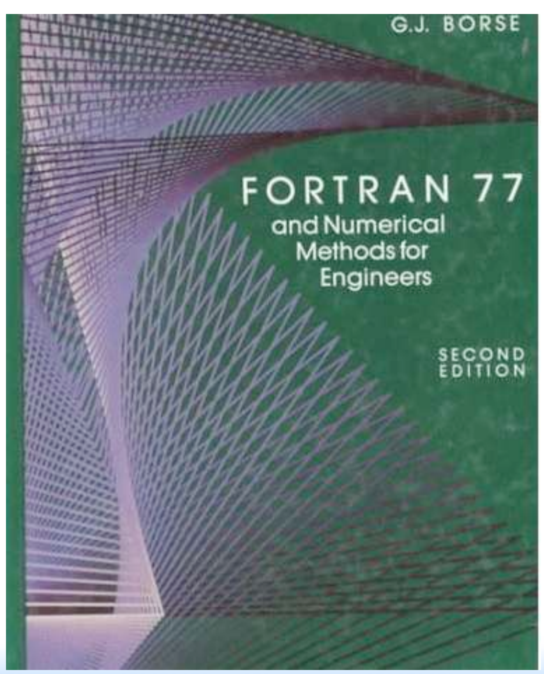
Black Holes

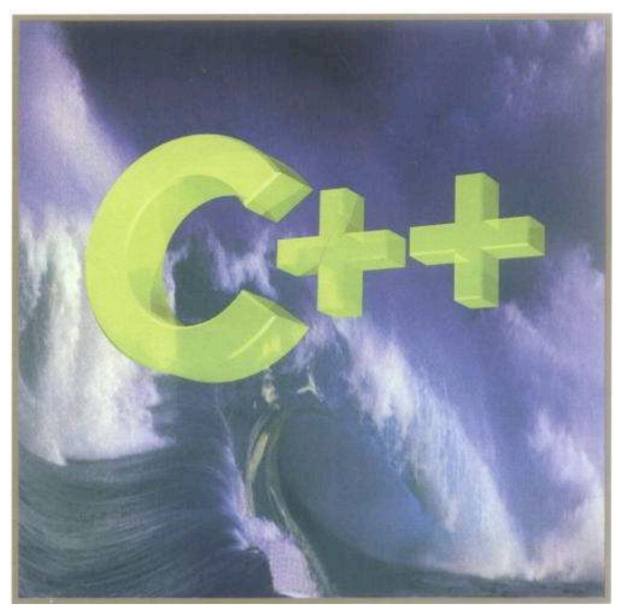
ALOHA

ALOHA
~~Google~~ translate

From: UFO To: Helicity Translate

Type text or a website address or translate a document.



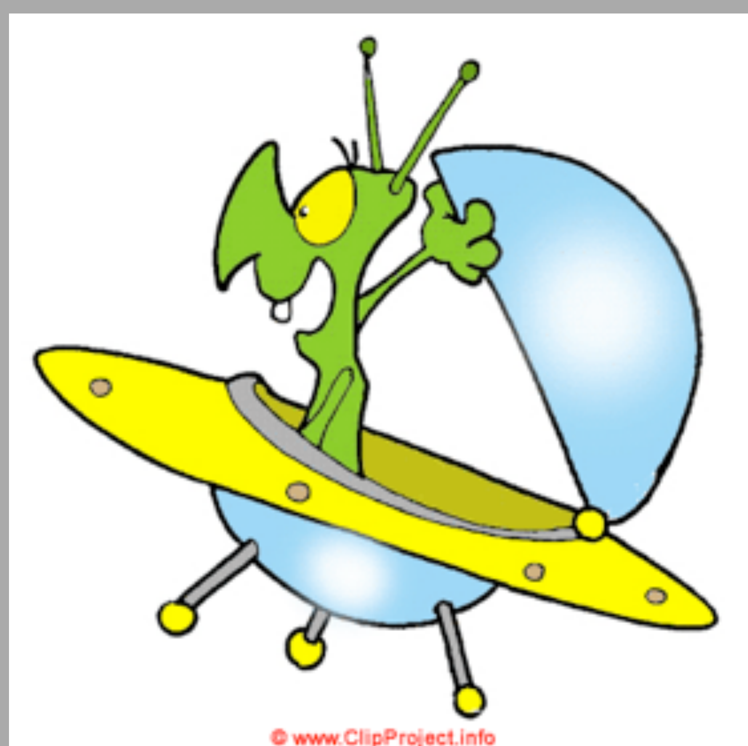


ALOHA

ALOHA
~~Google~~ translate

From: UFO ⇆ To: Helicity [Translate]

Type te



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

[Degrande, Duhr, Fuks, Grellscheid, OM, Reiter:108.2040]

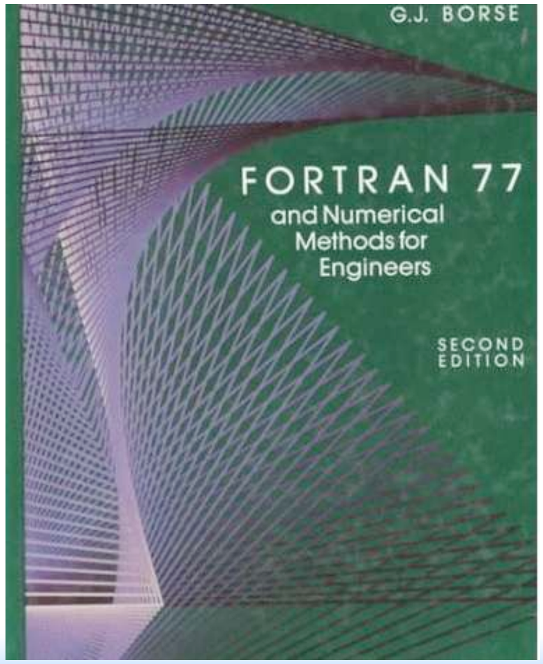
WESLEY J. CHUN

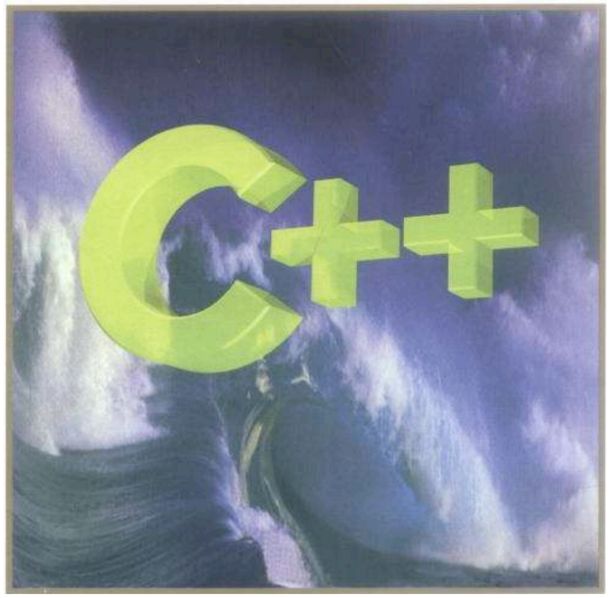
ALOHA

ALOHA ~~Google~~ translate

From: UFO To: Helicity Translate

Type text or a website address or translate a document.

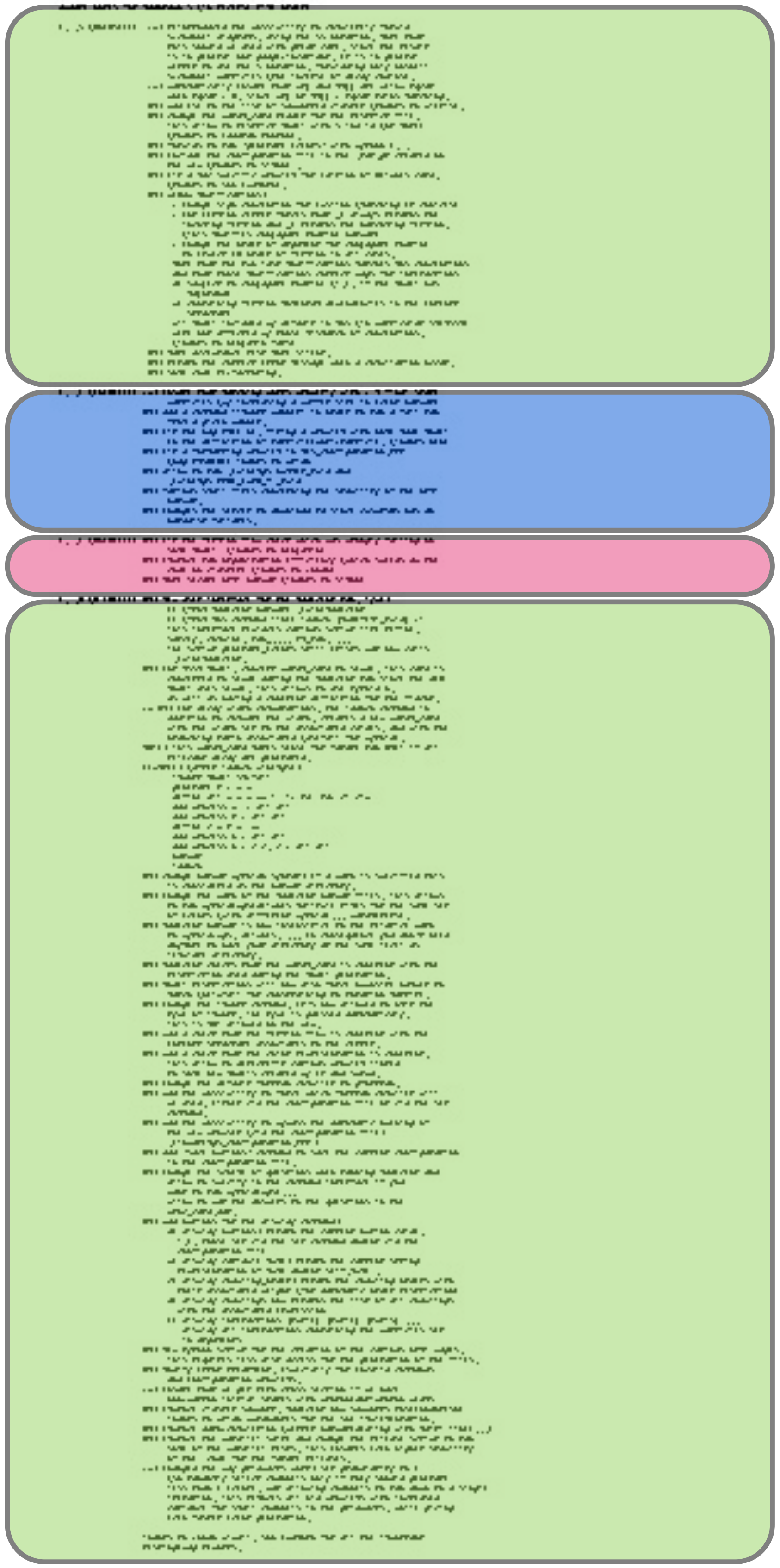




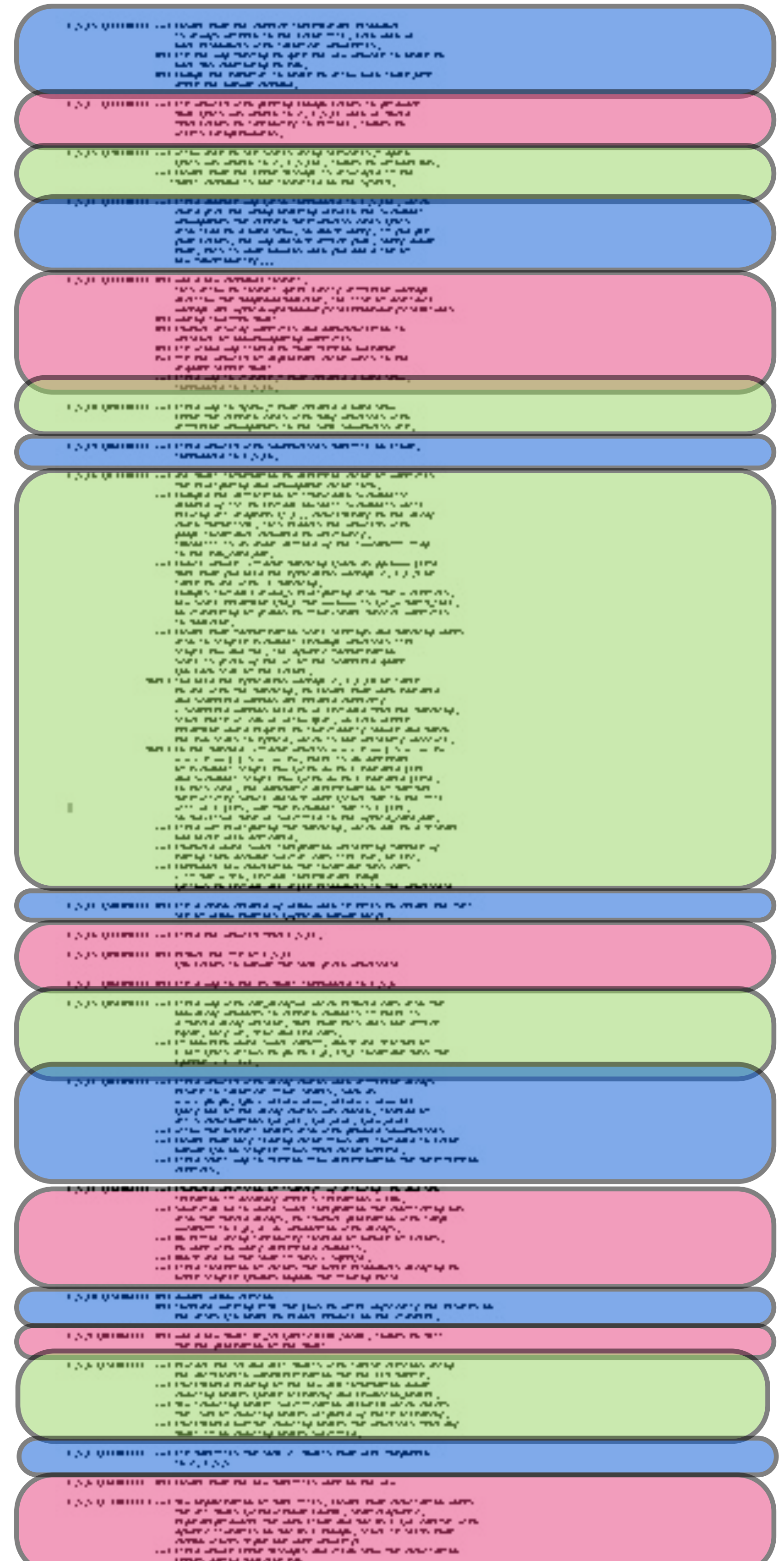
MADGRAPH 5

MADGRAPH

MADGRAPH



1.4.0



MADGRAPH

Not possible to detail everything

1.4.0

MadGraph

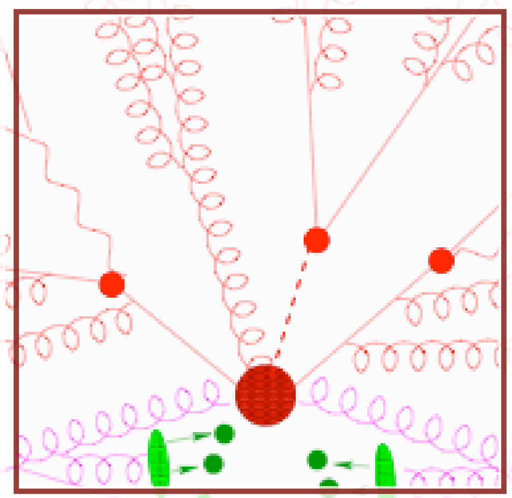
- Original MadGraph by Tim Stelzer was written in Fortran, first version from 1994

hep-ph/9401258

1. High-Q^2 Scattering

2. Parton Shower

☞ where new physics lies



☞ process dependent

☞ first principles description

3. Hadronization

4. Underlying Event

MadGraph

- Original MadGraph by Tim Stelzer was written in Fortran, first version from 1994 hep-ph/9401258
- Event generation by MadEvent using the single diagram enhanced multichannel integration technique in 2002 (Stelzer, Maltoni) hep-ph/0208156

Master formula

$$\int \hat{\sigma}_{ab\to X}(\hat{s},\ldots)\, f_a(x_1) f_b(x_2)\, dx_1 dx_2 d\Phi_{FS}$$

Parton level cross section | Parton density functions | Phase space integral

- Parton level cross section from matrix element
- Parton density (or distribution) functions:
  Process independent, determined by particle type

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  - ➡ Full automatic support of BSM
- First version of aMC@NLO in 2013 In preparation

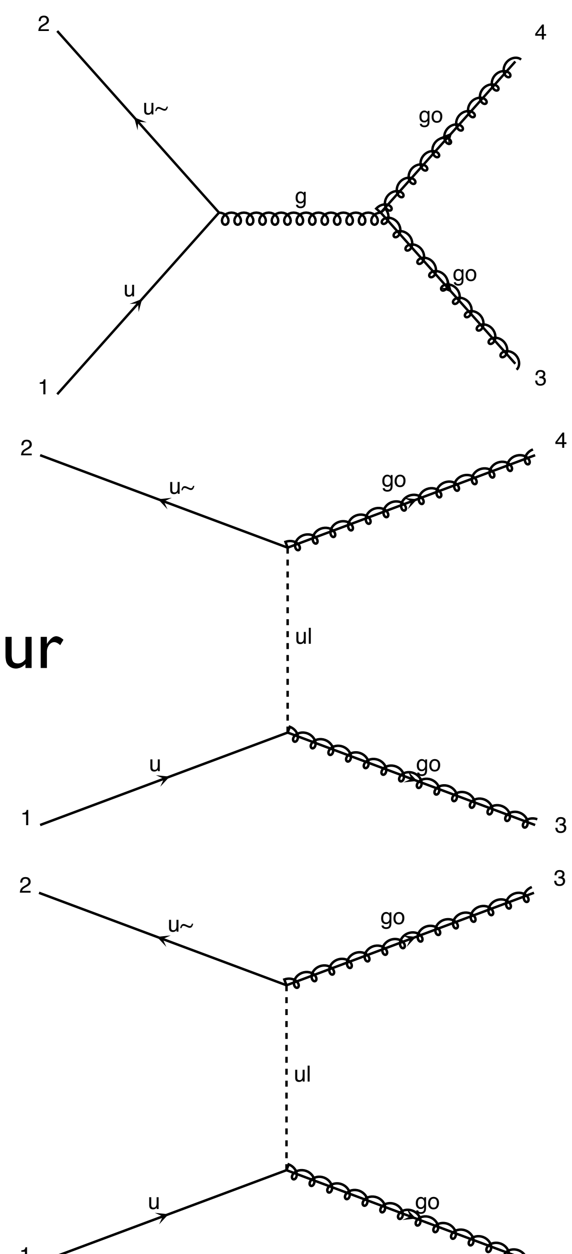
Decay chains

- p p > t t~ w+, (t > w+ b, w+ > l+ vl), \
  (t~ > w- b~, w- > j j), \
  w+ > l+ vl
- Separately generate core process and each decay
  - Decays generated with the decaying particle as resulting wavefunction
- Iteratively combine decays and core processes
- Difficulty: Multiple diagrams in decays

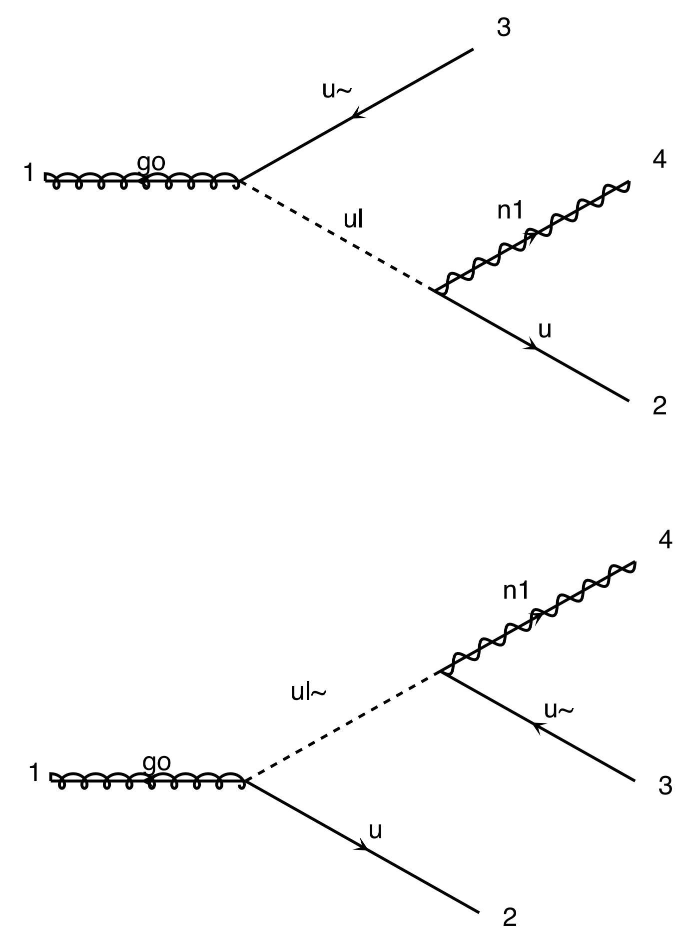
Decay chains

- If multiple diagrams in decays, need to multiply together core process and decay diagrams:

u u~ > go go / ur



x



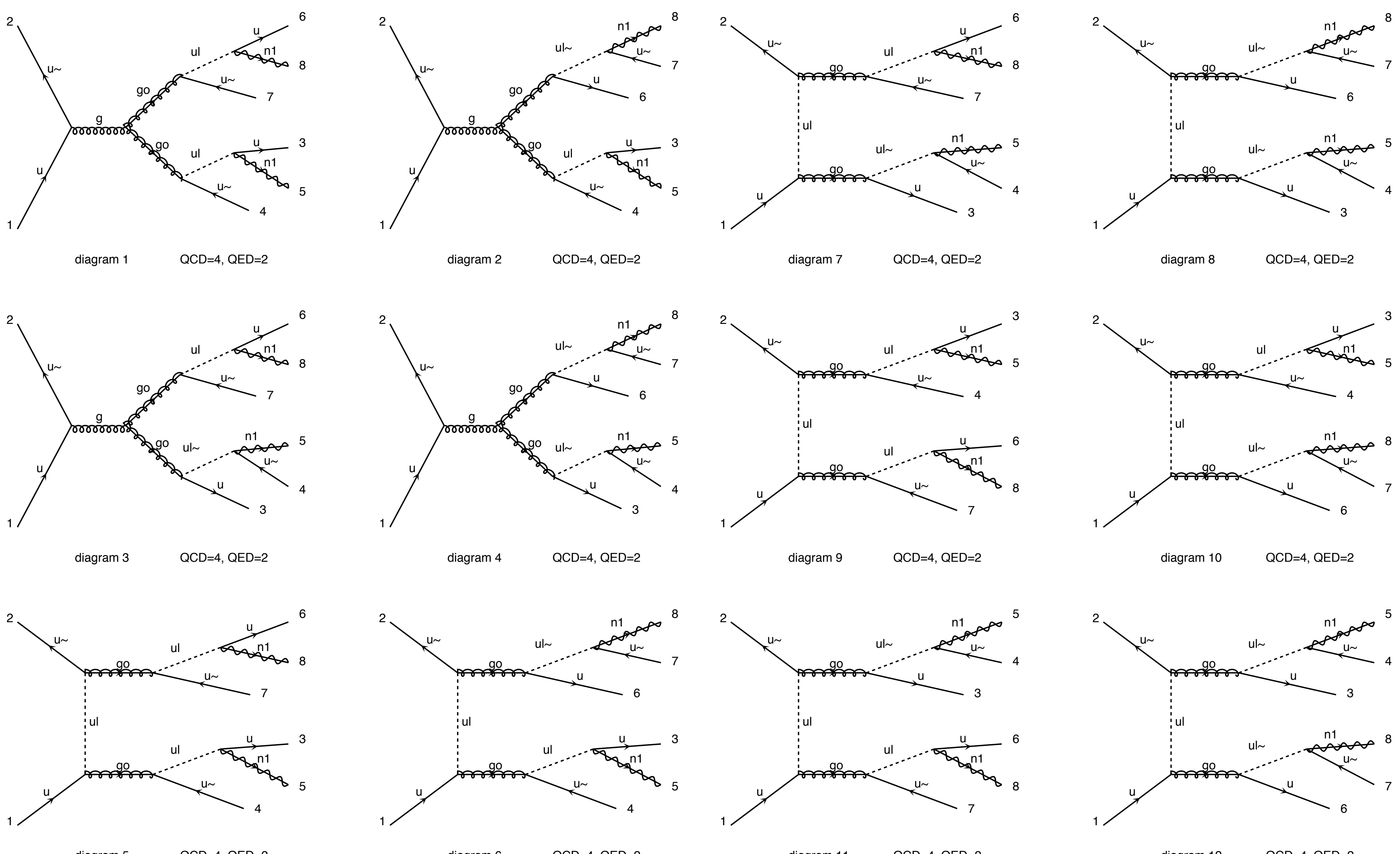
go > u u~ n1 / ur

(to the second power since both gluinos decay)

Decay chains

- If multiple diagrams in decays, need to multiply together core process and decay diagrams:

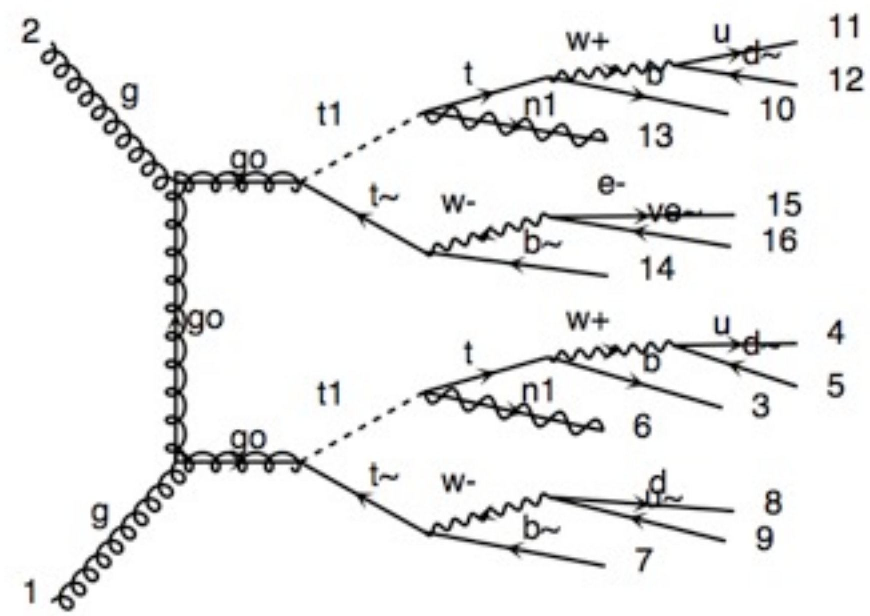
u u~ > go go / ur, go > u u~ n1 / ur



Decay chains

- Decay chains retain **full matrix element** for the diagrams compatible with the decay
- Full spin correlations (within and between decays)
- Full width effects
- However, no interference with non-resonant diagrams
  - ➡ Description only valid close to pole mass
  - ➡ Cutoff at $|m \pm n\Gamma|$ where n is set in run_card.

Decay chains



Online Event Generation

file://localhost/Users/alwall/MadGraph/version_1_0_1/PROC_gogo_t1tx_tn1_ballall/HTML/crossx.html

Results for g g > go go , (go > t1 t~ , t~ > b~ all all / h+ , (t1 > t n1 , t > b all all / h+)) in the mssm

Available Results

Links	Events	Tag	Run	Collider	Cross section (pb)	Events
results banner	Parton-level LHE	fermi	test	p p 7000 x 7000 GeV	.33857E-03	10000

Main Page

Thanks to developments in MadEvent, also (very) long decay chains possible to simulate directly in MadGraph!

Output formats in MadGraph 5

- Thanks to UFO/ALOHA, we now have automatic helicity amplitude routines in any language
  - ➡ So it makes sense to have also matrix element output in multiple languages!
- Presently implemented: Fortran, C++, Python
  - ➡ Fortran - for MadEvent and Standalone
  - ➡ C++ - for Pythia 8 and Standalone
  - ➡ Python - for internal use in MG5 (checks of gauge, perturbation and Lorentz invariance)

Pythia 8 Matrix Element output

- Library of process .h and .cc files, sorted by model
  + all needed model and helicity amplitude files
  + example main file (for user convenience!)
- Run as standard internal Pythia processes
- Allows using Pythia for ANY (2→1,2,3) process in ANY model at the push of a key!

Sigma_sm_qq_ttx.h

```
#include "SigmaProcess.h"
#include "Parameters_sm.h"

using namespace std;

namespace Pythia8
{
//==========================================================
// A class for calculating the matrix elements for
// Process: u u~ > t t~
// Process: c c~ > t t~
// Process: d d~ > t t~
// Process: s s~ > t t~
//----------------------------------------------------------
class Sigma_sm_qq_ttx : public Sigma2Process
{
  public:

    // Constructor.
    Sigma_sm_qq_ttx() {}

    // Initialize process.
    virtual void initProc();

    // Calculate flavour-independent parts of cross section.
    virtual void sigmaKin();

    // Evaluate sigmaHat(sHat).
    virtual double sigmaHat();

    // Select flavour, colour and anticolour.
    virtual void setIdColAcol();
 ...
```

MADGRAPH 5
Life Demonstration

Examples shown

- p p > t t~
  This gives only (the dominant) QCD vertices, and ignores (the negligible) QED vertices.
- p p > t t~ QED=2
  This gives both QED and QCD vertices.
- p p > w+ j j, w+ > l+ vl
  More complicated example.

More syntax examples

- p p > t t~ j QED=2: Generate all combinations of processes for particles defined in multiparticle labels p / j, including up to two QED vertices (and unlimited QCD vertices)
- p p > t t~, (t > b w+, w+ > l+ vl), t~ > b~ j j :
  - Only diagrams compatible with given decay
  - Only t / t~ and W+ close to mass shell in event generation
- p p > w+ w- / h : Exclude any diagrams with h
- p p > w+ w- $ h : Exclude on-shell h in event generation (but retain interference effects)

MadSpin

Decay with Full Spin correlation

[P. Artoisenet, R. Frederix, OM, R. RietKerk (2012)]

MADSPIN

- Separate production from decay
  - ➡ Matrix Element can't be integrate
    - ✦ NLO
- This is valid in the Narrow width approximation

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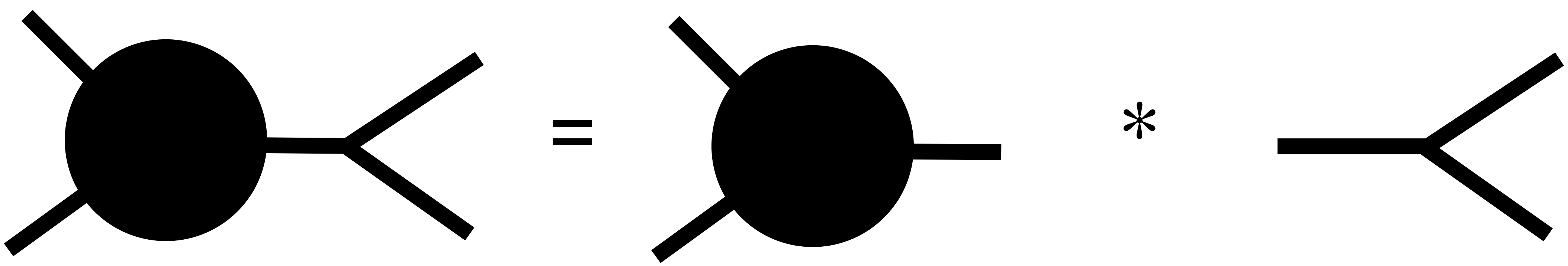

$$\sigma_{N+1} \simeq \sigma_N * \frac{\Gamma_{1\to 2}}{\Gamma_{tot}}$$

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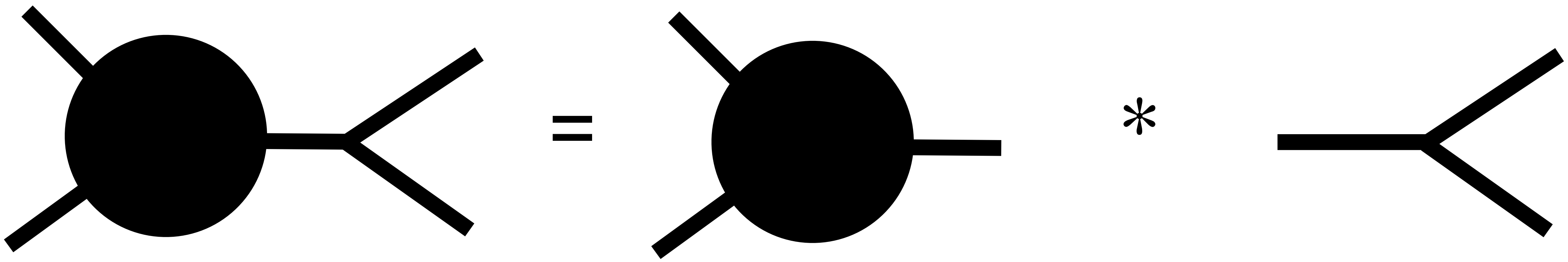

$$\sigma_{N+1} \simeq \sigma_N * \frac{\Gamma_{1\to 2}}{\Gamma_{tot}}$$

- You loose:
  - ➡ Full spin correlation
  - ➡ finite width effect

MADSPIN

Read Event

generate a virtual mass

generate a decay

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

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- Finite width
- Spin correlation
- unweighted events

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$$|M_{LO}^{P}|^2 \longrightarrow |M_{LO}^{P+D}|^2$$

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

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

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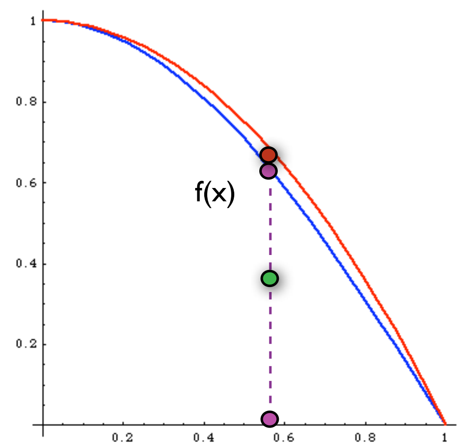
unweighting



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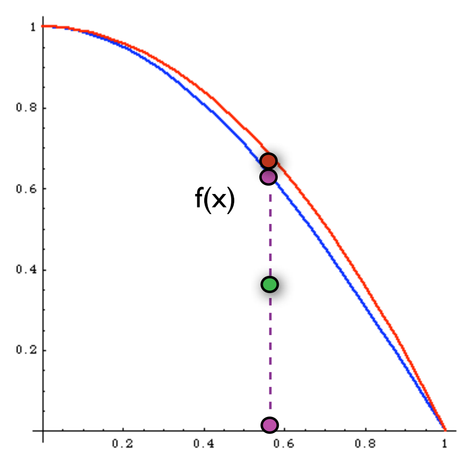

PASS

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

MADSPIN

Read Event

generate a virtual mass

generate a decay

$$|M^{P}_{LO}|^2 \longrightarrow |M^{P+D}_{LO}|^2$$

- Finite width
- Spin correlation
- unweighted events

associate a weight to the event

$$|M^{P+D}_{LO}|^2/|M^{P_{LO}}|^2$$

- Finite width
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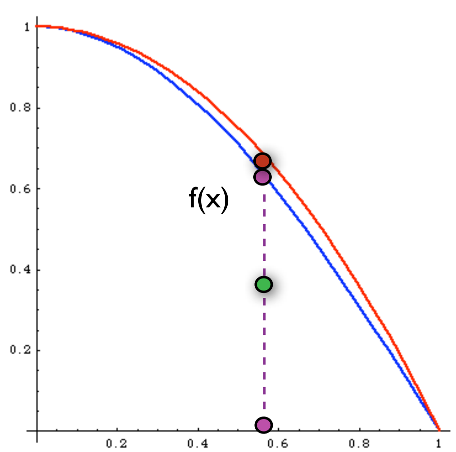
unweighting

FAIL

PASS



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

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generate a virtual mass

generate a decay

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- Finite width
- Spin correlation
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associate a weight to the event

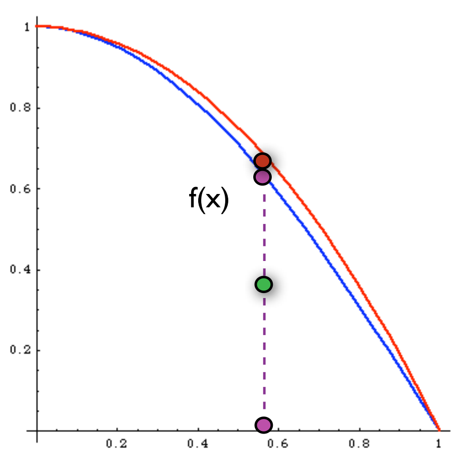
$$|M_{LO}^{P+D}|^2 / |M^{P_{LO}}|^2$$

- Finite width
- Spin correlation
- unweighted events

unweighting

FAIL

PASS



- Finite width
- Spin correlation
- unweighted events

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

MadSpin

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

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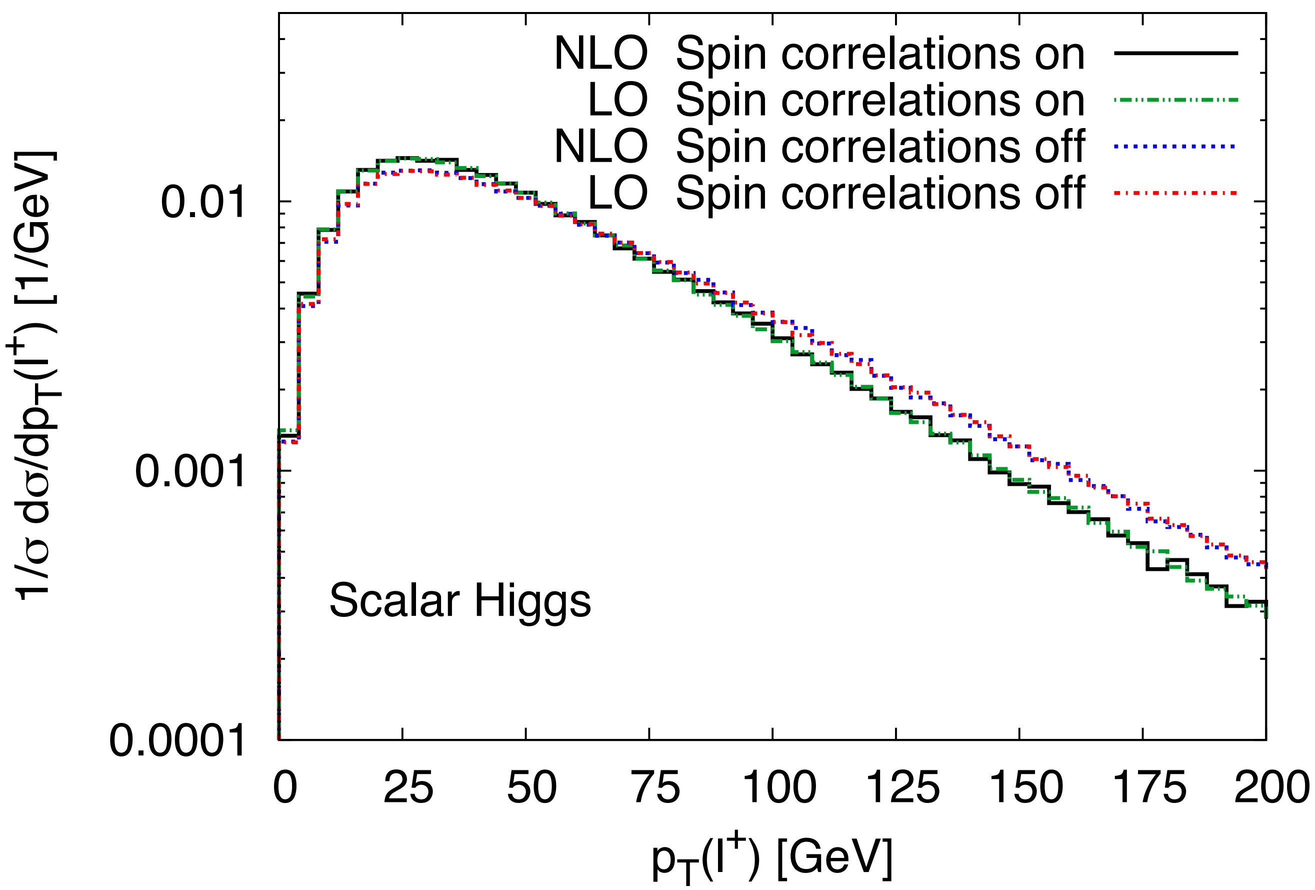
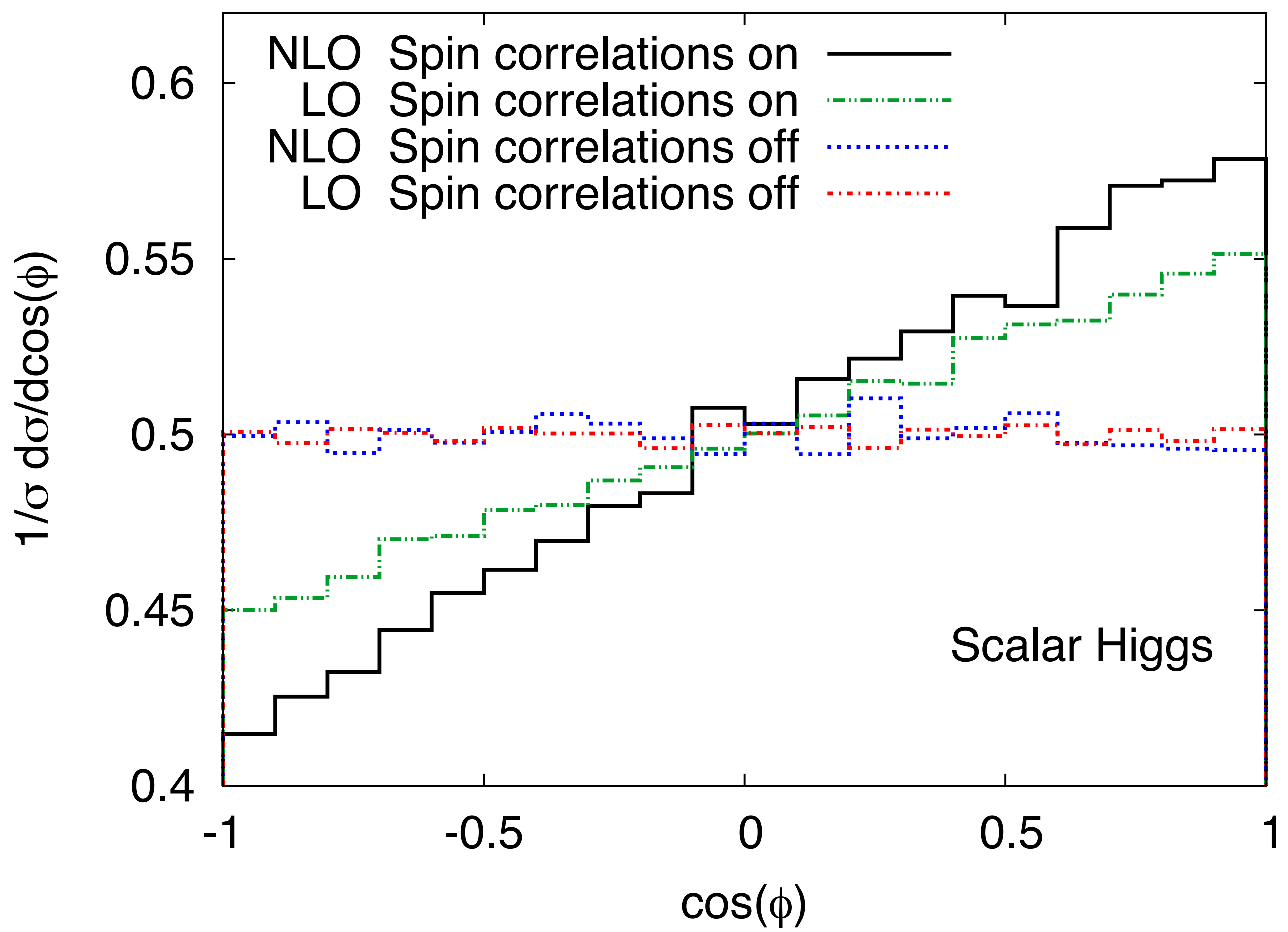
- Fully automatic
  - ➡ Fully integrated in MG5 [LO and NLO]
  - ➡ Can be run in StandAlone
- Example t t~ h:





Tutorial

- MG5 Tutorial today
  - ➡ Learn how to generate simple process
    - ✦ Learn the syntax
  - ➡ Learn the meaning of the cards
  - ➡ Learn decay chains syntax and the associate limitations

Conclusion

- UFO + ALOHA + MG5:
  - ➡ ANY BSM is available
  - ➡ HELAS Routine => very fast
- MG5
  - ➡ decay chains
  - ➡ nice interface
  - ➡ easy to use
- MadSpin
  - ➡ Efficient decay