Iwate Collider School 2024

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Appi highland, Iwate, Japan

Celine Degrande, Rikkert Frederix,
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What is MadGraph5_aMC@NLO?

- It is an automatic meta-code that write the code for computing the cross-section and generating events for any process at colliders
- For details

MadGraph 5 : Going Beyond
1106.0522

Johan Alwall[(1)], Michel Herquet[(2)], Fabio Maltoni[(3)], Olivier Mattelaer[(3)], Tim Stelzer[(4)]

The automation of next-to-leading order electroweak calculations
1804.10017

R. Frederix,[a] S. Frixione,[b] V. Hirschi,[c] D. Pagani,[a] H.-S. Shao,[d] M. Zaro[e]

The automated computation of tree-level and next-to-leading order differential cross sections, and their matching to parton shower simulations
1405.0301

J. Alwall[a], R. Frederix[b], S. Frixione[b], V. Hirschi[c], F. Maltoni[d], O. Mattelaer[d], H.-S. Shao[e], T. Stelzer[f], P. Torrielli[g], M. Zaro[hi]

Older (but still useful!) papers:
Alwall, Demin, De Visscher, Frederix, Herquet, 0706.2334
Maltoni, Stelzer, hep-ph/0208156

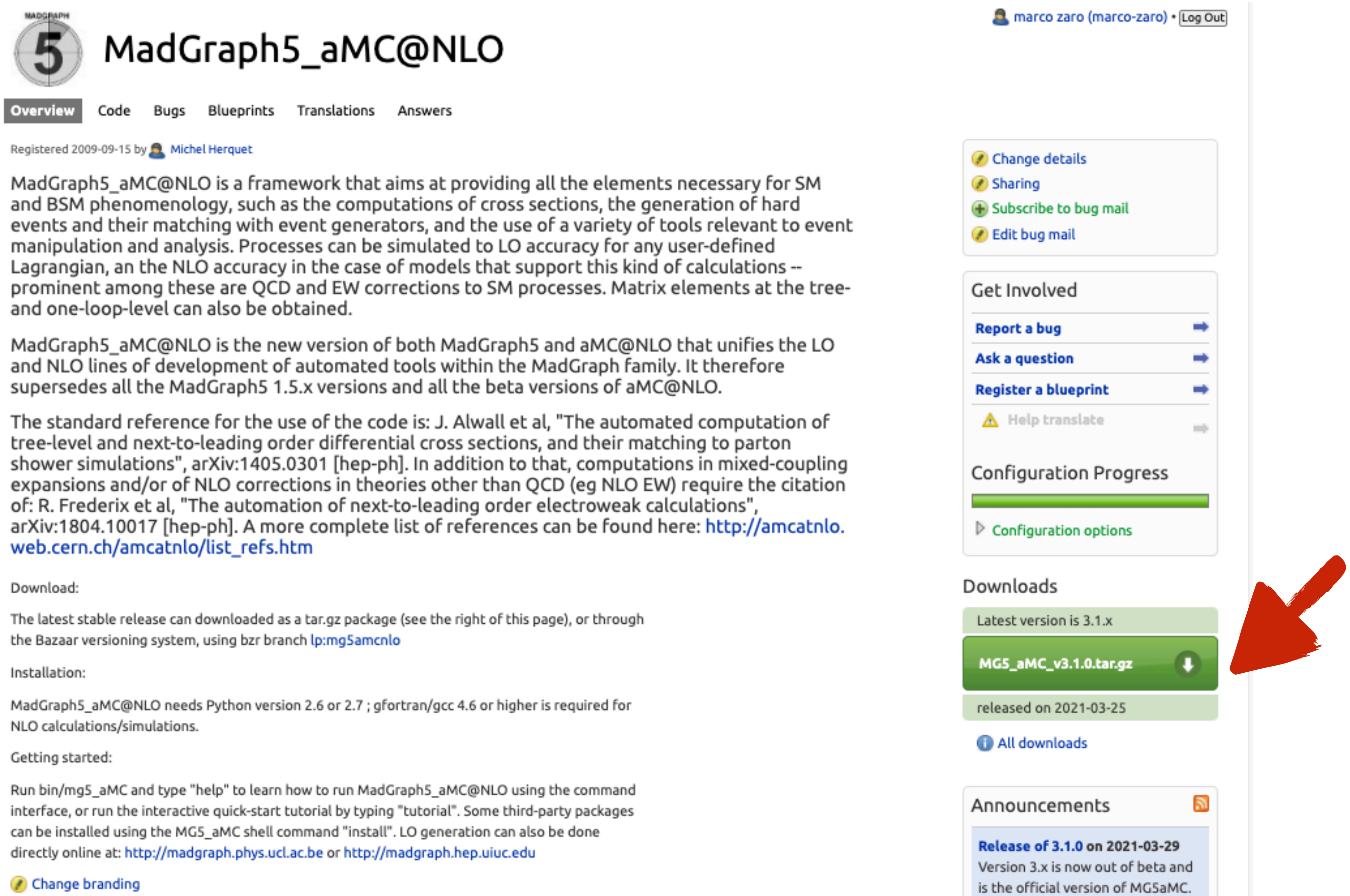
- NLO QCD and EW corrections can be included
- Matrix elements of different multiplicities can be combined
  - at LO (CKKW or MLM)
  - at NLO (FxFx or UNLOPS)

Software prerequisites:

- Python 3.7+ (still compatible with Python 2.7)
- Fortran compiler supporting quadruple precision (for NLO)
  - gfortran v4.6+ OK
- Optional:
  - gnuplot
  - FastJet (FJcore is included in the tarball)
  - LHAPDF
  - Herwig++ / Pythia8
  - …

Where do I get it?

- On LaunchPad: https://launchpad.net/mg5amcnlo



marco zaro (marco-zaro) • Log Out

MadGraph5_aMC@NLO

Overview | Code | Bugs | Blueprints | Translations | Answers

Registered 2009-09-15 by Michel Herquet

MadGraph5_aMC@NLO is a framework that aims at providing all the elements necessary for SM and BSM phenomenology, such as the computations of cross sections, the generation of hard events and their matching with event generators, and the use of a variety of tools relevant to event manipulation and analysis. Processes can be simulated to LO accuracy for any user-defined Lagrangian, an the NLO accuracy in the case of models that support this kind of calculations -- prominent among these are QCD and EW corrections to SM processes. Matrix elements at the tree- and one-loop-level can also be obtained.

MadGraph5_aMC@NLO is the new version of both MadGraph5 and aMC@NLO that unifies the LO and NLO lines of development of automated tools within the MadGraph family. It therefore supersedes all the MadGraph5 1.5.x versions and all the beta versions of aMC@NLO.

The standard reference for the use of the code is: J. Alwall et al, "The automated computation of tree-level and next-to-leading order differential cross sections, and their matching to parton shower simulations", arXiv:1405.0301 [hep-ph]. In addition to that, computations in mixed-coupling expansions and/or of NLO corrections in theories other than QCD (eg NLO EW) require the citation of: R. Frederix et al, "The automation of next-to-leading order electroweak calculations", arXiv:1804.10017 [hep-ph]. A more complete list of references can be found here: http://amcatnlo.web.cern.ch/amcatnlo/list_refs.htm

Download:

The latest stable release can downloaded as a tar.gz package (see the right of this page), or through the Bazaar versioning system, using bzr branch lp:mg5amcnlo

Installation:

MadGraph5_aMC@NLO needs Python version 2.6 or 2.7 ; gfortran/gcc 4.6 or higher is required for NLO calculations/simulations.

Getting started:

Run bin/mg5_aMC and type "help" to learn how to run MadGraph5_aMC@NLO using the command interface, or run the interactive quick-start tutorial by typing "tutorial". Some third-party packages can be installed using the MG5_aMC shell command "install". LO generation can also be done directly online at: http://madgraph.phys.ucl.ac.be or http://madgraph.hep.uiuc.edu

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Configuration Progress

Configuration options

Downloads

Latest version is 3.1.x

MG5_aMC_v3.1.0.tar.gz

released on 2021-03-25

All downloads

Announcements

Release of 3.1.0 on 2021-03-29
Version 3.x is now out of beta and is the official version of MG5aMC.

Where do I get it?

- On LaunchPad: https://launchpad.net/mg5amcnlo
- `tar -xzf MG5_aMC_v3.5.2.tar.gz`
- `cd MG5_aMC_v3_5_2`
- `./bin/mg5_aMC`

Some exercises:

- Exercise 1: Top pair production at LO

- Exercise 2: Decay chains
- Exercise 3: Unitarity in gauge theories
- Exercise 4: Initial-state radiation in lepton collisions
- Exercise 5: Higgs production at the ILC

Exercise 1: Top pair production at LO

- Basic questions:
  - Generate the process (following the tutorial)
  - Which partonic subprocesses contribute?
  - How many Feynman diagrams has each subprocess?
  - Output the code
  - Compute the x-section at the LHC (13.6 TeV) for m_t=170 GeV
- Extra questions:
  - Are b-quarks included in the initial state? If not, how can I include them?
  - Are diagrams with photons/Z included? If not, how can I include them? How much does the cross-section change? What is 'WEIGHTED'?
  - Recompute the $t\bar{t}$ cross-section for m_t=170, 172, 174 … 180 GeV

Exercise 1: solution

- Generate the process (following the tutorial)
  - > generate p p > t t~

```
INFO: Checking for minimal orders which gives processes.
INFO: Please specify coupling orders to bypass this step.
INFO: Trying coupling order WEIGHTED=2
INFO: Trying process: g g > t t~ WEIGHTED=2
INFO: Process has 3 diagrams
INFO: Trying process: u u~ > t t~ WEIGHTED=2
INFO: Process has 1 diagrams
INFO: Trying process: u c~ > t t~ WEIGHTED=2
INFO: Trying process: c u~ > t t~ WEIGHTED=2
INFO: Trying process: c c~ > t t~ WEIGHTED=2
INFO: Process has 1 diagrams
INFO: Trying process: d d~ > t t~ WEIGHTED=2
INFO: Process has 1 diagrams
INFO: Trying process: d s~ > t t~ WEIGHTED=2
INFO: Trying process: s d~ > t t~ WEIGHTED=2
INFO: Trying process: s s~ > t t~ WEIGHTED=2
INFO: Process has 1 diagrams
INFO: Process u~ u > t t~ added to mirror process u u~ > t t~
INFO: Process c~ c > t t~ added to mirror process c c~ > t t~
INFO: Process d~ d > t t~ added to mirror process d d~ > t t~
INFO: Process s~ s > t t~ added to mirror process s s~ > t t~
5 processes with 7 diagrams generated in 0.075 s
Total: 5 processes with 7 diagrams
```

Exercise 1: solution

- Which partonic subprocesses contribute?
  - > display processes

```
Process: g g > t t~ WEIGHTED=2
Process: u u~ > t t~ WEIGHTED=2
Process: c c~ > t t~ WEIGHTED=2
Process: d d~ > t t~ WEIGHTED=2
Process: s s~ > t t~ WEIGHTED=2
```

Exercise 1: solution

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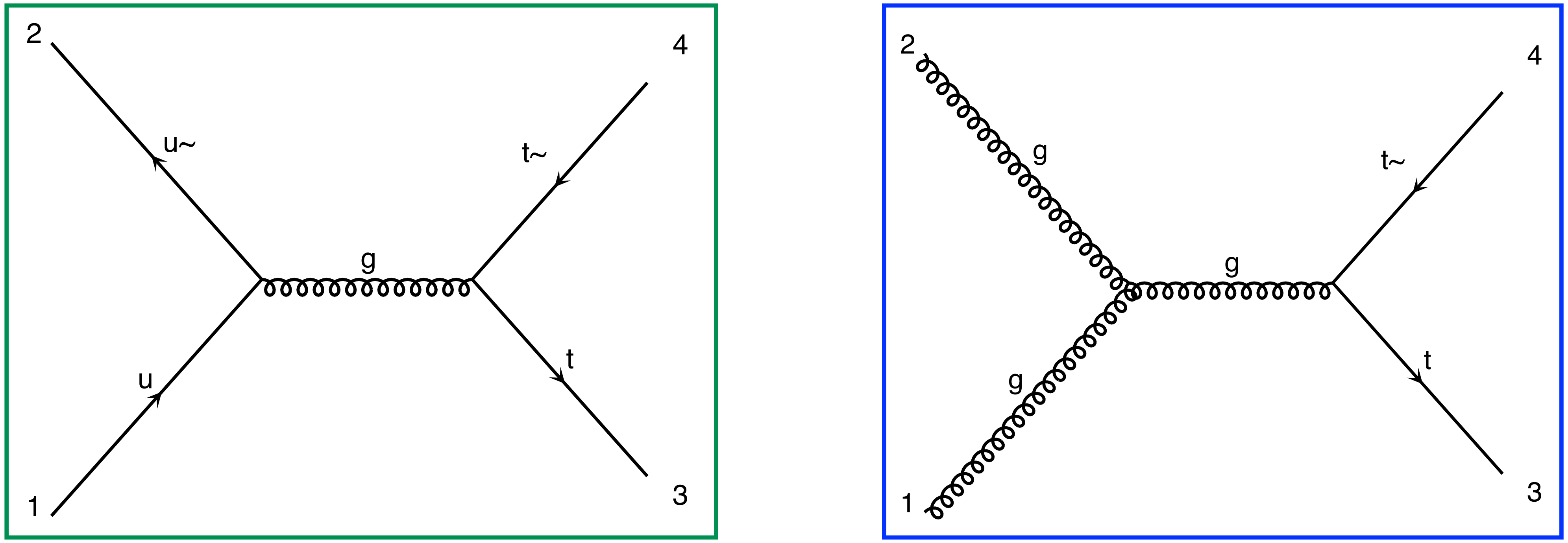
Process: u u~ > t t~ WEIGHTED=2
Process: c c~ > t t~ WEIGHTED=2
Process: d d~ > t t~ WEIGHTED=2
Process: s s~ > t t~ WEIGHTED=2
```



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Process: d d~ > t t~ WEIGHTED=2
Process: s s~ > t t~ WEIGHTED=2
```

QCD master formula:

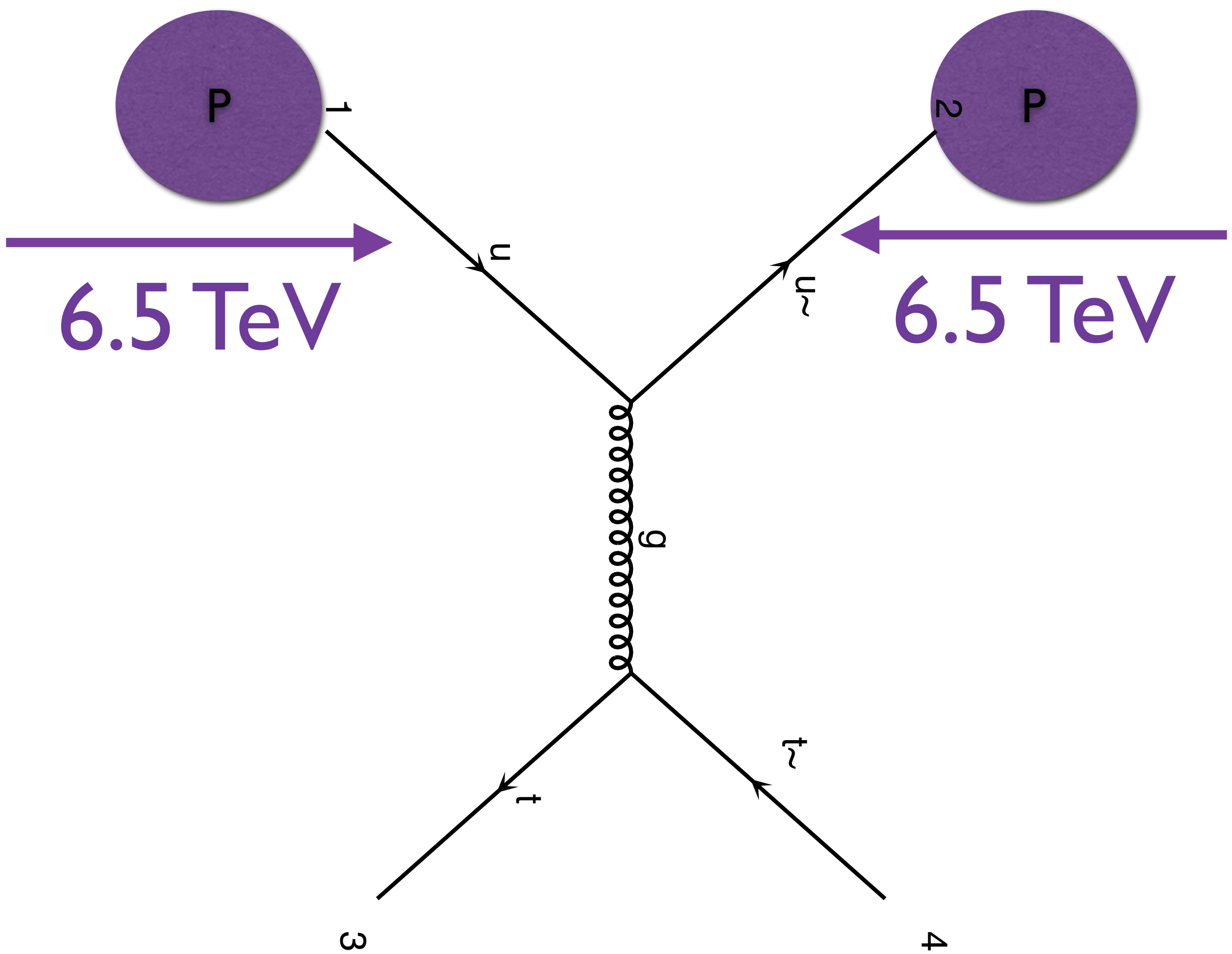
$$\sigma(pp \to t\bar{t}) = \sum_{ab} \int dx_1 dx_2 f_a(x_1, \mu_F) f_b(x_2, \mu_F) \times \hat{\sigma}(ab \to t\bar{t})$$

What does it mean?

$$\sigma(pp \to t\bar{t}) = \sum_{ab} \int dx_1 dx_2 f_a(x_1, \mu_F) f_b(x_2, \mu_F) \times \hat{\sigma}(ab \to t\bar{t})$$

- What is the probability to find parton a inside the proton with momentum fraction x? $f_a(x)$
- μ_F is a scale which separates low energy from high energy dynamics
- The partonic scattering occurs at a reduced energy:

$$\hat{s} = x_1 x_2 S = x_1 x_2 (13\text{TeV})^2$$



Exercise 1: solution

- How many Feynman diagrams has each subprocess?
  - > `display diagrams`

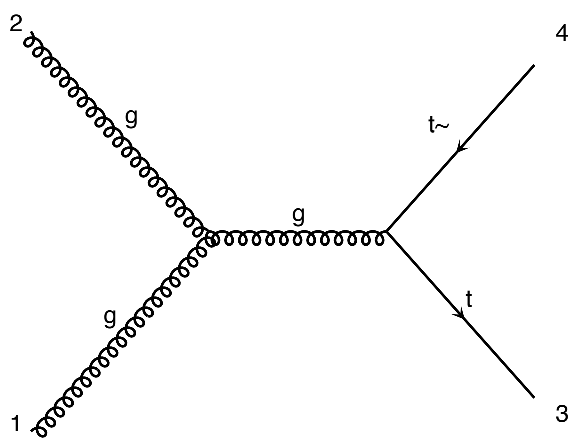


diagram 1 QCD=2, QED=0

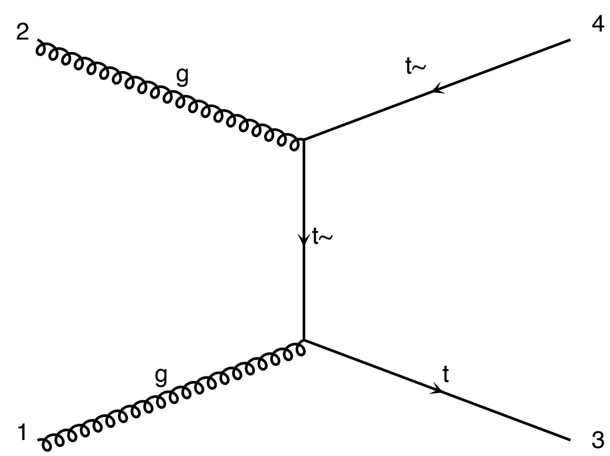


diagram 2 QCD=2, QED=0

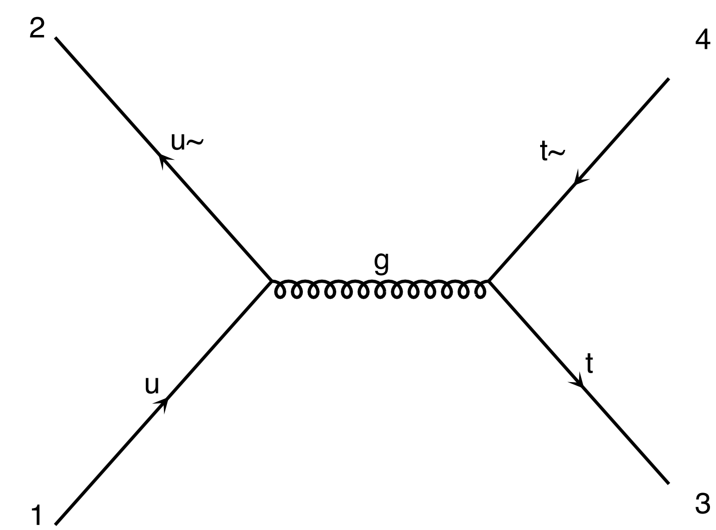


diagram 1 QCD=2, QED=0

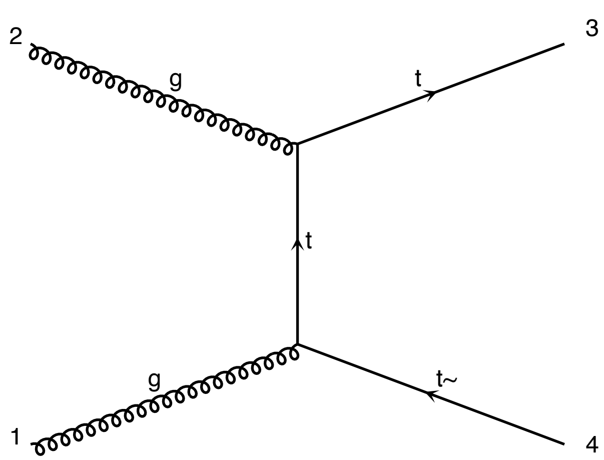


diagram 3 QCD=2, QED=0

gg: 3 diagrams

$q\bar{q}$: 1 diagram

Exercise 1: solution

- Output the code
  - > `output mytestdir`

```
INFO: initialize a new directory: mytestdir
INFO: remove old information in mytestdir
INFO: Creating files in directory P0_gg_ttx
INFO: Generating Feynman diagrams for Process: g g > t t~ WEIGHTED=2
INFO: Finding symmetric diagrams for subprocess group gg_ttx
INFO: Creating files in directory P0_qq_ttx
INFO: Generating Feynman diagrams for Process: u u~ > t t~ WEIGHTED=2
INFO: Finding symmetric diagrams for subprocess group qq_ttx
History written to /Users/marcozaro/Physics/MadGraph/MG5_aMC_v2_2_2/mytestdir/Cards/proc_card_mg5.dat
Generated helas calls for 2 subprocesses (0 diagrams) in 0.000 s
Wrote files for 16 helas calls in 0.102 s
Export UFO model to MG4 format
ALOHA: aloha creates FFV1 routines
ALOHA: aloha creates VVV1 set of routines with options: P0
save configuration file to /Users/marcozaro/Physics/MadGraph/MG5_aMC_v2_2_2/mytestdir/Cards/me5_configuration.txt
INFO: Use Fortran compiler gfortran
INFO: Generate jpeg diagrams
INFO: Generate web pages
Output to directory /Users/marcozaro/Physics/MadGraph/MG5_aMC_v2_2_2/mytestdir done.
```

Exercise 1: solution

- Compute the cross-section at the LHC (13.5 TeV) for m_t=170 GeV
  - > launch

```
The following switches determine which programs are run:
 1 Run the pythia shower/hadronization:                   pythia=NOT INSTALLED
 2 Run PGS as detector simulator:                            pgs=NOT INSTALLED
 3 Run Delphes as detector simulator:                    delphes=NOT INSTALLED
 4 Decay particles with the MadSpin module:              madspin=OFF
 5 Add weight to events based on coupling parameters:   reweight=OFF
  Either type the switch number (1 to 5) to change its default setting,
  or set any switch explicitly (e.g. type 'madspin=ON' at the prompt)
  Type '0', 'auto', 'done' or just press enter when you are done.
 [0, 4, 5, auto, done, madspin=ON, madspin=OFF, madspin, reweight=ON, ... ][60s to answer]
```

  - > 0 (let's keep it simple ;-)

```
Do you want to edit a card (press enter to bypass editing)?
  1 / param      : param_card.dat
  2 / run        : run_card.dat
 you can also
   - enter the path to a valid card or banner.
   - use the 'set' command to modify a parameter directly.
     The set option works only for param_card and run_card.
     Type 'help set' for more information on this command.
   - call an external program (ASperGE/MadWidth/...).
     Type 'help' for the list of available command
 [0, done, 1, param, 2, run, enter path][60s to answer]
```

Exercise 1: solution

- Compute the cross-section at the LHC (13.5 TeV) for m_t=170 GeV

run_card

```
#*********************
# Running parameters
#*********************
#
#*********************************************************************
# Tag name for the run (one word)                                    *
#*********************************************************************
  tag_1     = run_tag ! name of the run
#*********************************************************************
# Run to generate the grid pack                                      *
#*********************************************************************
  .false.     = gridpack  !True = setting up the grid pack
#*********************************************************************
# Number of events and rnd seed                                      *
# Warning: Do not generate more than 1M events in a single run       *
# If you want to run Pythia, avoid more than 50k events in a run.    *
#*********************************************************************
  10000 = nevents ! Number of unweighted events requested
      0       = iseed   ! rnd seed (0=assigned automatically=default))
#*********************************************************************
# Collider type and energy                                           *
# lpp: 0=No PDF, 1=proton, -1=antiproton, 2=photon from proton,      *
#                                         3=photon from electron     *
#*********************************************************************
        1     = lpp1    ! beam 1 type
        1     = lpp2    ! beam 2 type
     6500     = ebeam1  ! beam 1 total energy in GeV
     6500     = ebeam2  ! beam 2 total energy in GeV
#*********************************************************************
# Beam polarization from -100 (left-handed) to 100 (right-handed)    *
#*********************************************************************
        0     = polbeam1 ! beam polarization for beam 1
        0     = polbeam2 ! beam polarization for beam 2
#*********************************************************************
# PDF CHOICE: this automatically fixes also alpha_s and its evol.    *
#*********************************************************************
                                                    47,1          5%
```

param_card

```
###################################
## INFORMATION FOR MASS
###################################
Block mass
    5 4.700000e+00 # MB
    6 1.730000e+02 # MT
   15 1.777000e+00 # MTA
   23 9.118800e+01 # MZ
   25 1.250000e+02 # MH
## Dependent parameters, given by model restrictions.
## Those values should be edited following the
## analytical expression. MG5 ignores those values
## but they are important for interfacing the output of MG5
## to external program such as Pythia.
  1 0.000000 # d : 0.0
  2 0.000000 # u : 0.0
  3 0.000000 # s : 0.0
  4 0.000000 # c : 0.0
  11 0.000000 # e- : 0.0
  12 0.000000 # ve : 0.0
  13 0.000000 # mu- : 0.0
  14 0.000000 # vm : 0.0
  16 0.000000 # vt : 0.0
  21 0.000000 # g : 0.0
  22 0.000000 # a : 0.0
  24 80.419002 # w+ : cmath.sqrt(MZ__exp__2/2. + cmath.sqrt(MZ__exp__4
/4. - (aEW*cmath.pi*MZ__exp__2)/(Gf*sqrt__2)))
<_v2_2_2/mytestdir/Cards/param_card.dat" 78L, 2770C 1,1          Top
```

Exercise 1: solution

- Compute the cross-section at the LHC (8 TeV) for m_t=172 GeV
  - One can also set the parameters without editing the cards (useful for scripting)
  - `> set ebeam1 6800`
  - `> set ebeam2 6800`
  - `> set MT 172.`
  - `> done`

Exercise 1: solution

- Compute the cross-section at the LHC (8 TeV) for m_t=172 GeV
  - One can also set the parameters without editing the cards (useful for scripting)
  - > set ebeam1 6800
  - > set ebeam2 6800
  - > set MT 172.
  - > done

```
...
Working on SubProcesses
    P0_gg_ttx
    P0_qq_ttx
INFO:  Idle: 0,  Running: 1,  Completed: 1 [ current time: 15h13 ]
INFO: End survey
refine 10000
Creating Jobs
INFO: Refine results to 10000
    P0_gg_ttx
    P0_qq_ttx
INFO:  Idle: 6,  Running: 4,  Completed: 3 [  3.2s  ]
INFO:  Idle: 2,  Running: 4,  Completed: 7 [  6.6s  ]
INFO:  Idle: 0,  Running: 1,  Completed: 12 [  9.7s  ]
INFO: Combining runs
INFO: finish refine
refine 10000
Creating Jobs
INFO: Refine results to 10000
    P0_gg_ttx
    P0_qq_ttx
INFO: Combining runs
INFO: finish refine
combine_events
INFO: Combining Events
  === Results Summary for run: run_01 tag: tag_1 ===

     Cross-section :   160.1 +- 0.2302 pb
     Nb of events :  10000
```

Monitor via the web interface

Results in the sm for p p > t t~

Currently Running

Run Name	Tag Name	Cards	Results	Status/Jobs		
				Queued	Running	Done
run_01	tag_1	param_card run_card plot_card	160.1 ± 0.2302 (pb)	Combining Events		

Available Results

Run	Collider	Banner	Cross section (pb)	Events	Data	Output	Action
run_01	p p 4000 x 4000 GeV	tag_1	160.1 ± 0.23	No events yet		banner only	remove run / re-run from the banner

Main Page

Exercise 1: solution

- Script it:
  - open a text file (`mymg5amc.txt`) and put the commands inside:

```
generate p p > t t~
output mytestdir
launch
set ebeam1 6800
set ebeam2 6800
set MT 172
```

  - launch MG5_aMC@NLO with that file
  - `./bin/mg5_amc mymg5amc.txt`

Exercise 1: Extra questions:

- Are b-quarks included in the initial state? If not, how can I include them?
- > display processes

```
Process: g g > t t~ WEIGHTED=2
Process: u u~ > t t~ WEIGHTED=2
Process: c c~ > t t~ WEIGHTED=2
Process: d d~ > t t~ WEIGHTED=2
Process: s s~ > t t~ WEIGHTED=2
```

- No b-quark appears. Note that at the startup you have

```
Defined multiparticle p = g u c d s u~ c~ d~ s~
Defined multiparticle j = g u c d s u~ c~ d~ s~
```

- You can add the b/$\bar{b}$ to the multiparticle labels
- > define p = p b b~

```
Defined multiparticle p = g u c d s u~ c~ d~ s~ b b~
```

- > display multiparticles
- For consistency one should use a model with m_b=0
- > import model sm-no_b_mass

Exercise 1:
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- Are b-quarks included in the initial state? If not, how can I include them?

Exercise 1: Extra questions:

- Are b-quarks included in the initial state? If not, how can I include them?
- Regenerate the process
  - `> generate p p > t t~`
  - `> display processes`

```
Process: g g > t t~ WEIGHTED=2
Process: u u~ > t t~ WEIGHTED=2
Process: c c~ > t t~ WEIGHTED=2
Process: d d~ > t t~ WEIGHTED=2
Process: s s~ > t t~ WEIGHTED=2
Process: b b~ > t t~ WEIGHTED=2
```

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Process: s s~ > t t~ WEIGHTED=2
Process: b b~ > t t~ WEIGHTED=2
```

- Does it make a big difference?
  - > output
  - > launch
  - > set ebeam1 4000
  - > set ebeam2 4000
  - > set MT 172

Exercise 1: Extra questions:

- Are b-quarks included in the initial state? If not, how can I include them?
- Regenerate the process
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Process: u u~ > t t~ WEIGHTED=2
Process: c c~ > t t~ WEIGHTED=2
Process: d d~ > t t~ WEIGHTED=2
Process: s s~ > t t~ WEIGHTED=2
Process: b b~ > t t~ WEIGHTED=2
```

- Does it make a big difference?
  - > output
  - > launch
  - > set ebeam1 4000
  - > set ebeam2 4000
  - > set MT 172

```
Cross-section :   160.4 +- 0.231 pb
Nb of events :  10000
```

Without b

```
Cross-section :   160.1 +- 0.2302 pb
Nb of events :  10000
```

Exercise 1:
Extra questions:

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- Are diagrams with photons/z included? If not, how can I include them? How much does the cross-section change? What is that 'WEIGHTED'?

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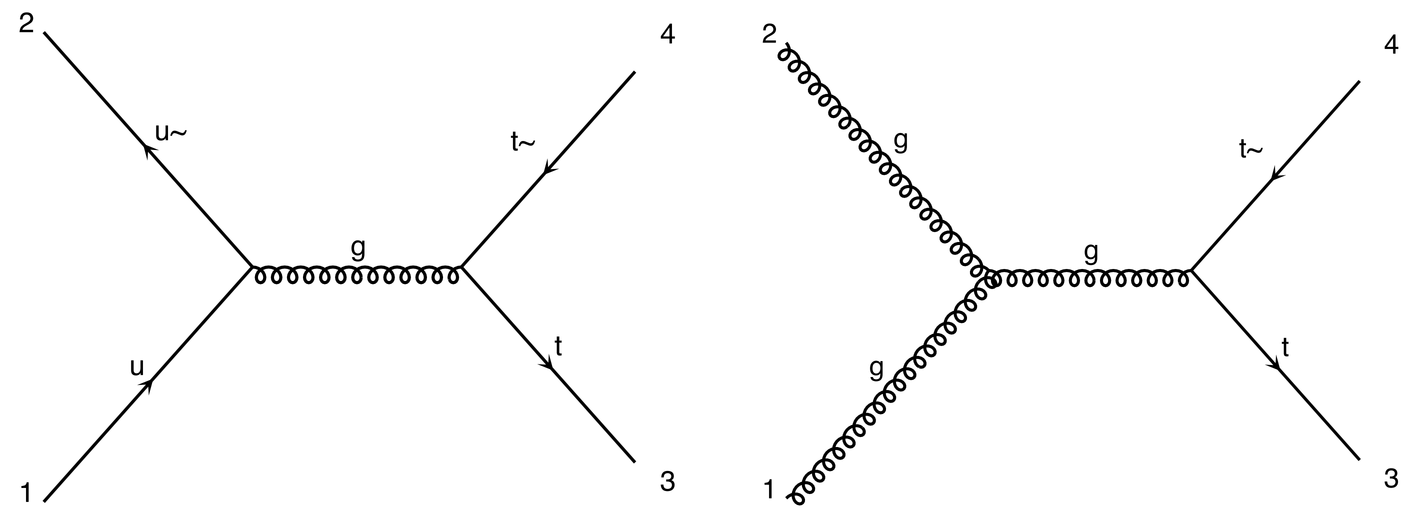
Extra questions:

- Are diagrams with photons/z included? If not, how can I include them? How much does the cross-section change? What is that 'WEIGHTED'?
  - > display diagrams



  - No photon/z appear.
  - Are we missing anything important?

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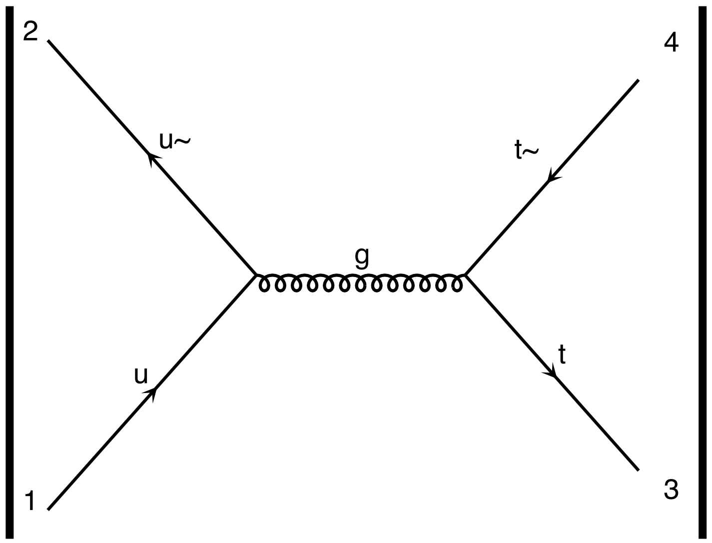
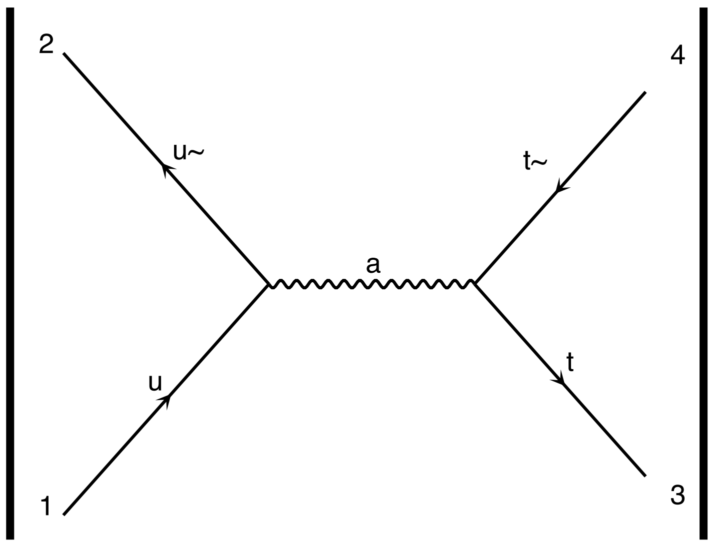


$$\left| \cdots \right|^2 \sim \alpha_s^2$$



$$\left| \cdots \right|^2 \sim \alpha_e^2$$

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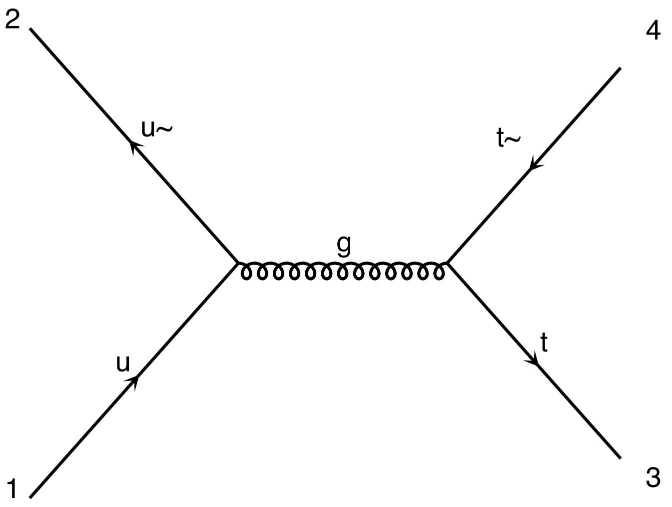
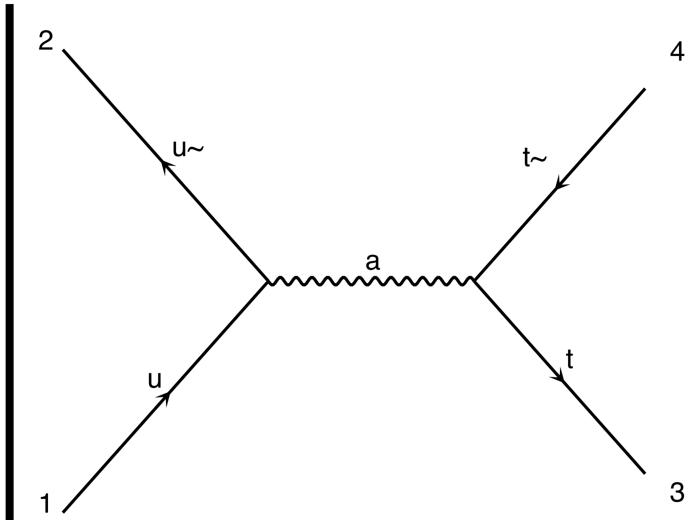


$$\left| \cdots \right|^2 \sim \alpha_s^2$$



$$\left| \cdots \right|^2 \sim \alpha_e^2 \quad \frac{\alpha_e}{\alpha_s} \lesssim 0.1$$

Exercise 1: Extra questions:

- Are diagrams with photons/z included? If not, how can I include them? How much does the cross-section change? What is ‘WEIGHTED’?
  - `> display diagrams`
  - No photon/z appear.
  - Are we missing anything important? Does not seem the case
  - How to have them anyway?
  - MG5 exploits the hierarchy between QCD and QED couplings in order to give the leading (i.e. with most QCD) contribution to the cross-section by default
  - It assign WEIGHTED order =1(=2) to QCD (QED) vertices and generates the process with minimum WEIGHTED order

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  - Are we missing anything important? Does not seem the case
  - How to have them anyway?
  - MG5 exploits the hierarchy between QCD and QED couplings in order to give the leading (i.e. with most QCD) contribution to the cross-section by default
  - It assign WEIGHTED order =1(=2) to QCD (QED) vertices and generates the process with minimum WEIGHTED order

Exercise 1:
Extra questions:

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Extra questions:

- Are diagrams with photons/z included? If not, how can I include them? How much does the cross-section change?
  - `> generate p p > t t~ WEIGHTED=4`
  - `> display diagrams`

Exercise 1:
Extra questions:

- Are diagrams with photons/z included? If not, how can I include them? How much does the cross-section change?
  - > generate p p > t t~ WEIGHTED=4
  - > display diagrams

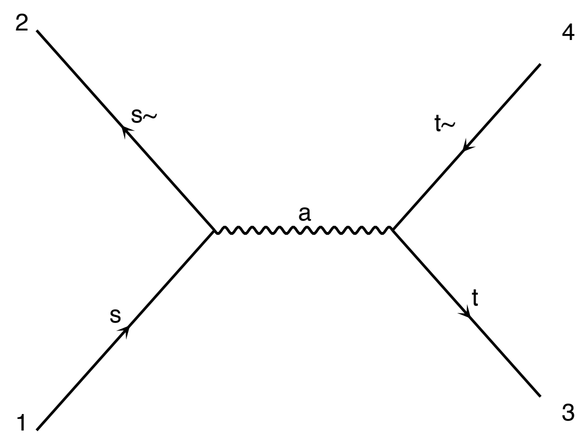


diagram 1 QCD=0, QED=2

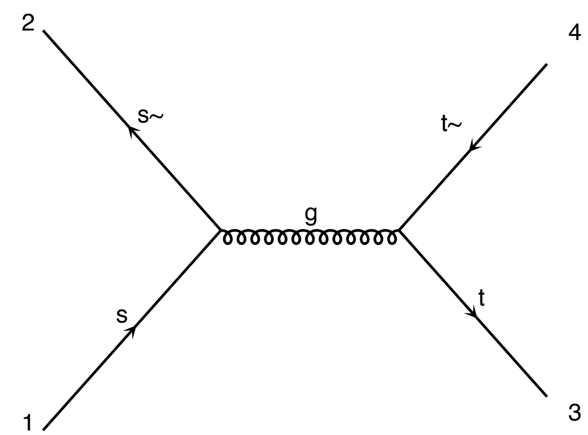


diagram 2 QCD=2, QED=0

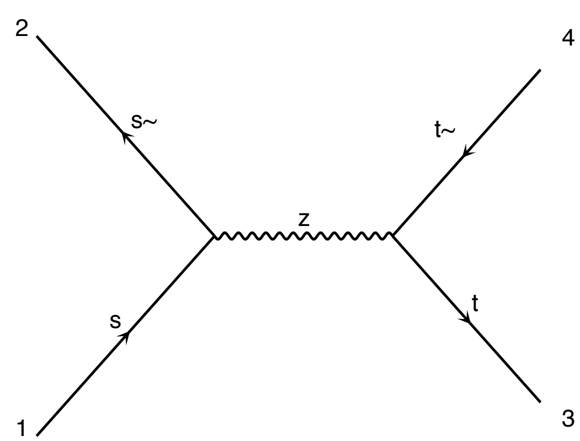


diagram 3 QCD=0, QED=2

Exercise 1:
Extra questions:

- Are diagrams with photons/z included? If not, how can I include them? How much does the cross-section change?
  - > `generate p p > t t~ WEIGHTED=4`
  - > `display diagrams`
  - > `output …`
  - > `launch`
  - > `…`

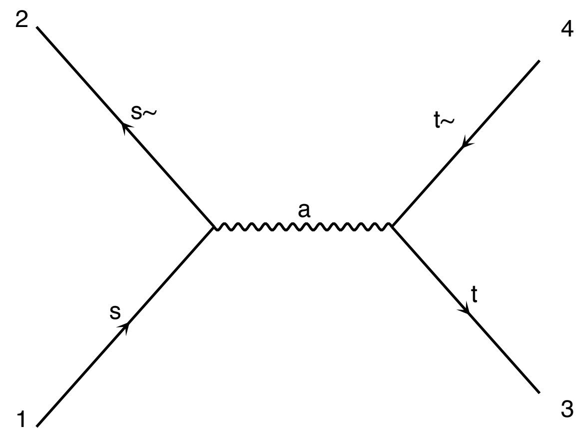


diagram 1 QCD=0, QED=2

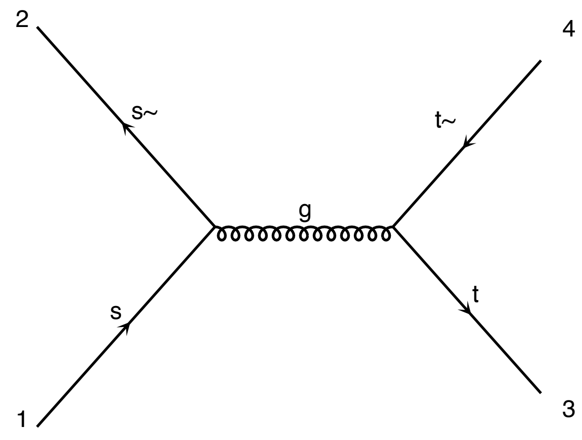


diagram 2 QCD=2, QED=0

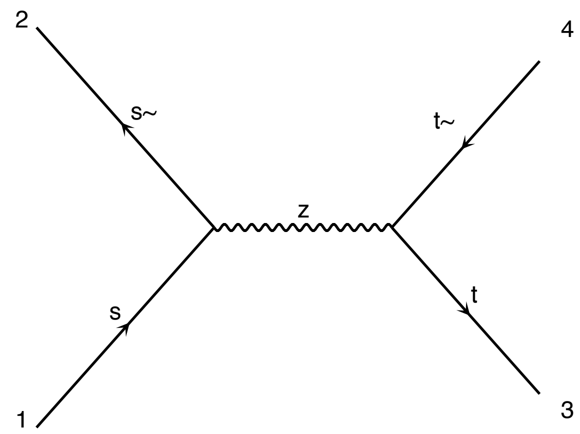
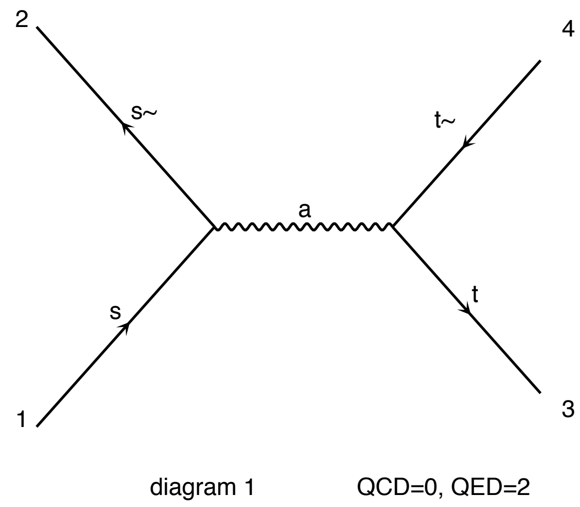
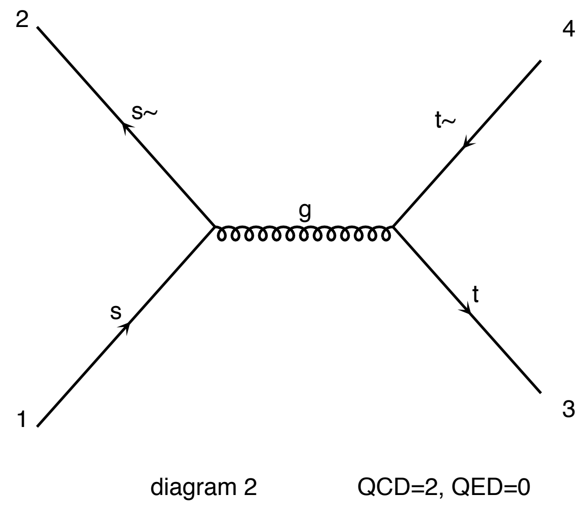


diagram 3 QCD=0, QED=2

Exercise 1: Extra questions:

- Are diagrams with photons/z included? If not, how can I include them? How much does the cross-section change?
  - > generate p p > t t~ WEIGHTED=4
  - > display diagrams
  - > output …
  - > launch
  - > …

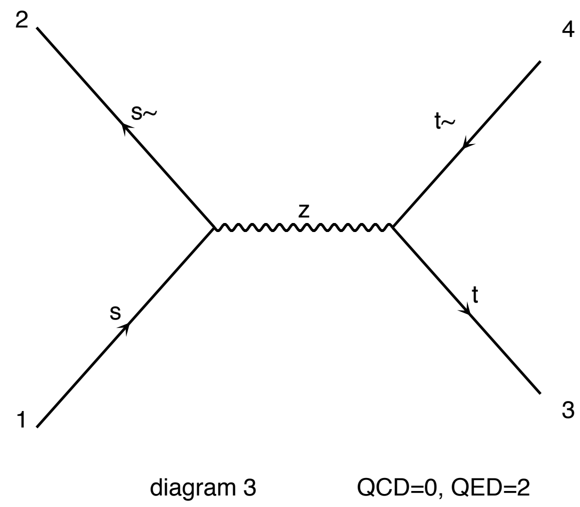





```
Cross-section :   160.8 +- 0.1999 pb
Nb of events :  10000
```

WEIGHTED=2

```
Cross-section :   160.4 +- 0.231 pb
Nb of events :  10000
```



Exercise 1:
Extra questions:

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- Alternatively, one can specify the coupling powers
  - `> generate p p > t t~ QED=2`
  - orders which are not specified are unconstrained

Exercise 1: Extra questions:

- Alternatively, one can specify the coupling powers
  - `> generate p p > t t~ QED=2`
  - orders which are not specified are unconstrained
- In order to have only the QED contribution
  - `> generate p p > t t~ QED=2 QCD=0`

Exercise 1: Extra questions:

- Recompute the $t\bar{t}$ cross-section for m_t=170, 172, 174 … 180 GeV
- Be smart! Script it!
- Create a txt file `myttbar_scan.txt`

```
generate p p > t t~
output mytestdir2
launch
set ebeam1 4000
set ebeam2 4000
set MT 170
launch
set MT 172
launch
set MT 174
launch
set MT 176
launch
set MT 178
launch
set MT 180
```

- `./bin/mg5_aMC myttbar_scan.txt`

Exercise 1:
Extra questions:

- Recompute the $t\bar{t}$ cross-section for m_t=170, 172, 174 … 180 GeV
- Be smart! Script it!
- You can also launch an existing folder, without regenerating the code

```
launch mytestdir2
set ebeam1 4000
set ebeam2 4000
set MT 170
launch
set MT 172
launch
set MT 174
launch
set MT 176
launch
set MT 178
launch
set MT 180
```

Exercise 1:
Extra questions:

- Recompute the $t\bar{t}$ cross-section for m_t=170, 172, 174 … 180 GeV

Results in the sm for p p > t t~

Available Results

Run	Collider	Banner	Cross section (pb)	Events	Data	Output	Action
run_01	p p 4000 x 4000 GeV	tag_1	169.8 ± 0.24	10000	parton madevent	LHE	remove run launch detector simulation
run_02	p p 4000 x 4000 GeV	tag_1	160.1 ± 0.28	10000	parton madevent	LHE	remove run launch detector simulation
run_03	p p 4000 x 4000 GeV	tag_1	151.1 ± 0.2	10000	parton madevent	LHE	remove run launch detector simulation
run_04	p p 4000 x 4000 GeV	tag_1	142.9 ± 0.18	10000	parton madevent	LHE	remove run launch detector simulation
run_05	p p 4000 x 4000 GeV	tag_1	134.7 ± 0.19	10000	parton madevent	LHE	remove run launch detector simulation
run_06	p p 4000 x 4000 GeV	tag_1	127.3 ± 0.16	10000	parton madevent	LHE	remove run launch detector simulation

Main Page

Exercise 1:
Extra questions:

- Recompute the $t\bar{t}$ cross-section for m_t=170, 172, 174 … 180 GeV

Results in the sm for p p > t t~

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run_05	p p 4000 x 4000 GeV	tag_1	134.7 ± 0.19	10000	parton madevent	LHE	remove run / launch detector simulation
run_06	p p 4000 x 4000 GeV	tag_1	127.3 ± 0.16	10000	parton madevent	LHE	remove run / launch detector simulation

Main Page

which folder is what?

Exercise 1: Extra questions:

- Recompute the $t\bar{t}$ cross-section for m_t=170, 172, 174 … 180 GeV
- Be smart! Script it!
- You can specify the name (instead of `run_01…`) with `-n NAME`

```
launch mytestdir2 -n run_MT170
set ebeam1 4000
set ebeam2 4000
set MT 170
launch -n run_MT172
set MT 172
launch -n run_MT174
set MT 174
launch -n run_MT176
set MT 176
launch -n run_MT178
set MT 178
launch -n run_MT180
set MT 180
```

Exercise 1: Extra questions:

- Recompute the $t\bar{t}$ cross-section for m_t=170, 172, 174 … 180 GeV

Run	Collider	Banner	Cross section (pb)	Events	Data	Output	Action
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run_06	p p 4000 x 4000 GeV	tag_1	127.3 ± 0.16	10000	parton madevent	LHE	remove run launch detector simulation
run_MT170	p p 4000 x 4000 GeV	tag_1	170 ± 0.22	10000	parton madevent	LHE	remove run launch detector simulation
run_MT172	p p 4000 x 4000 GeV	tag_1	159.6 ± 0.22	10000	parton madevent	LHE	remove run launch detector simulation
run_MT174	p p 4000 x 4000 GeV	tag_1	151.1 ± 0.22	10000	parton madevent	LHE	remove run launch detector simulation
run_MT176	p p 4000 x 4000 GeV	tag_1	142.6 ± 0.19	10000	parton madevent	LHE	remove run launch detector simulation
run_MT178	p p 4000 x 4000 GeV	tag_1	134.7 ± 0.18	10000	parton madevent	LHE	remove run launch detector simulation
run_MT180	p p 4000 x 4000 GeV	tag_1	127.2 ± 0.24	10000	parton madevent	LHE	remove run launch detector simulation

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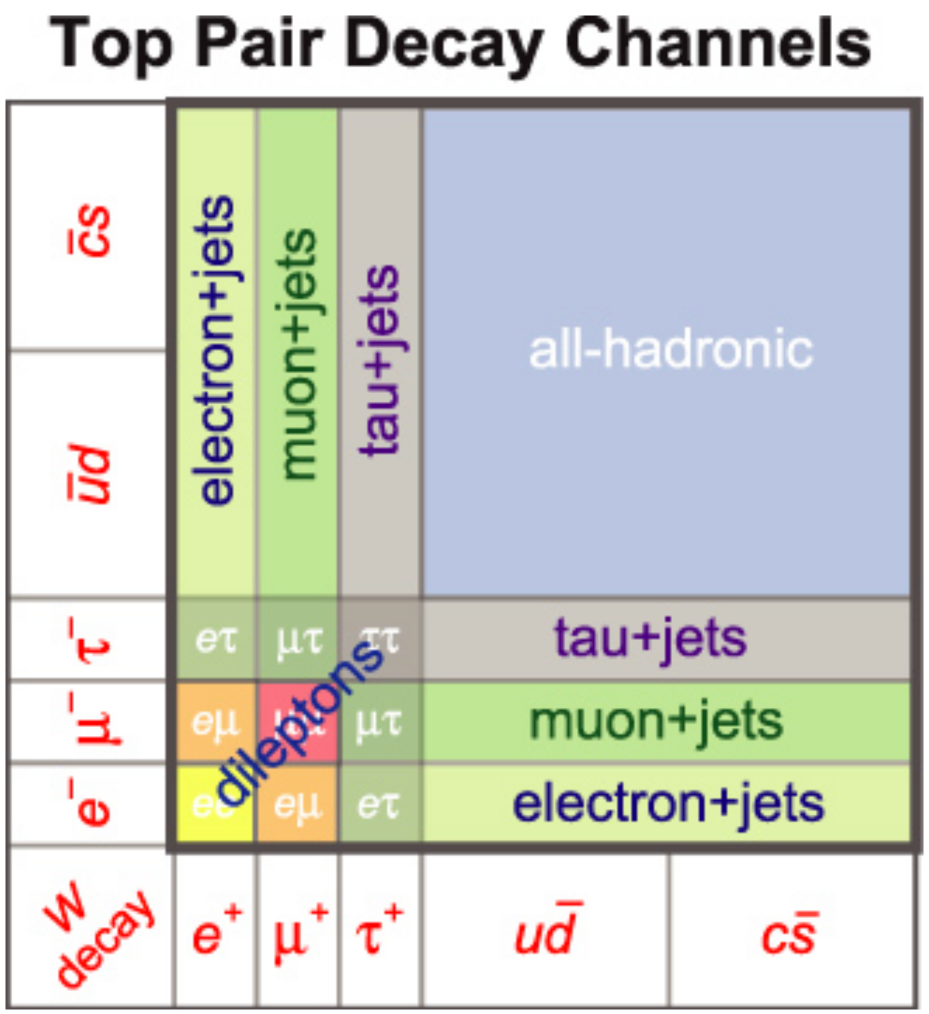
Exercise 2: decay chains

- Theory: the top quark is an unstable particle:
  - It decays: ~100% of times into b W
  - The W boson decays too:
    - 67% (2/3) of times into hadrons
    - 22% (2/9) of times into "leptons" (e-ν_e or μ-ν_μ)
    - 11% (1/9) of times into τ-ν_τ
- A decayed pair of top quarks can be classified as:
  - hadronic (both tops to hadrons)
  - semileptonic (one top to hadrons, the other to leptons)
  - dileptonic (both quarks to leptons)

Exercise 2: decay chains

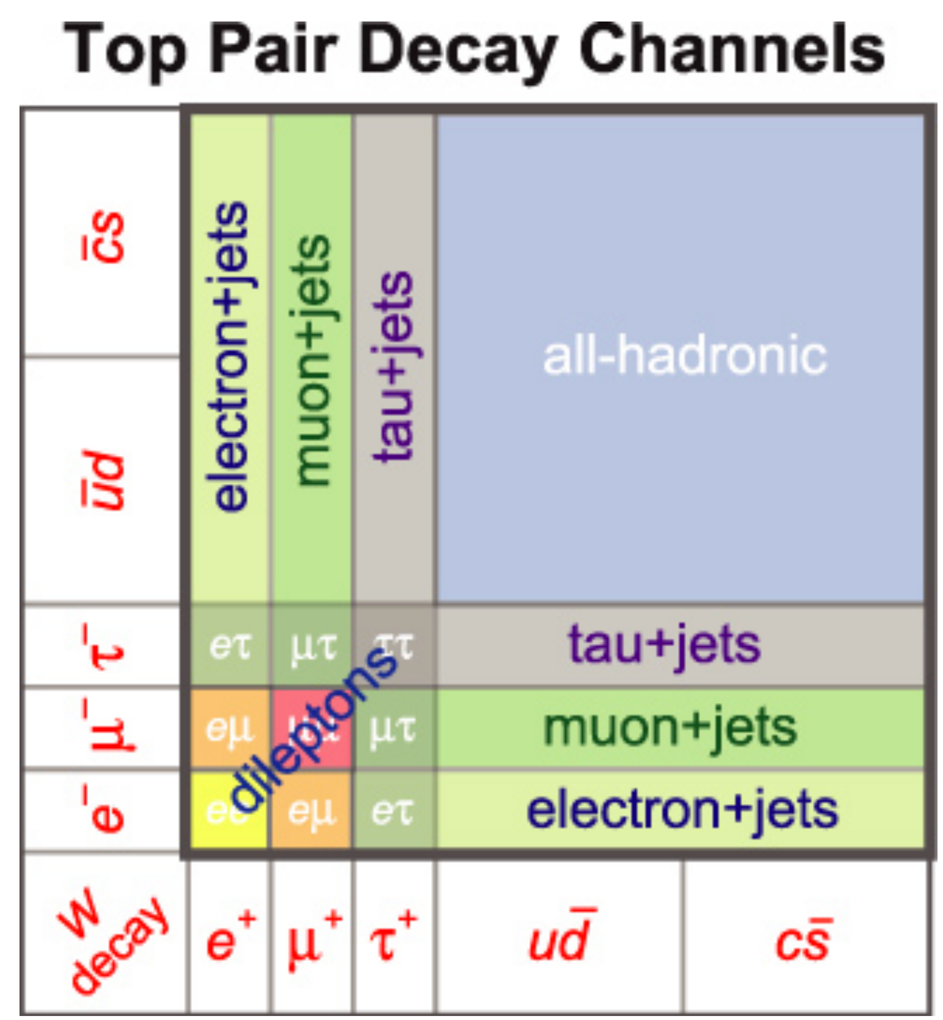
- Questions:
  - How often a top pair decays hadronically/semi-leptonically/di-leptonically?
  - Learn the syntax to specify decay chains
  - Generate the code for dileptonic top decay and compute the cross-section. Compare with the case where the top does not decay (leave all parameters as default)
  - Compute the cross section for m_t=170, 175 and 180 GeV. Do you see anything strange?
  - What is the difference with `p p > l+ l- vl vl~ b b~`?

Exercise 2: Solution



Exercise 2: Solution

- Questions:
  - How often a top pair decays hadronically/semi-leptonically/di-leptonically?
    - Since the top always decays to Wb, look at how a pair of W decays (b's are stable)



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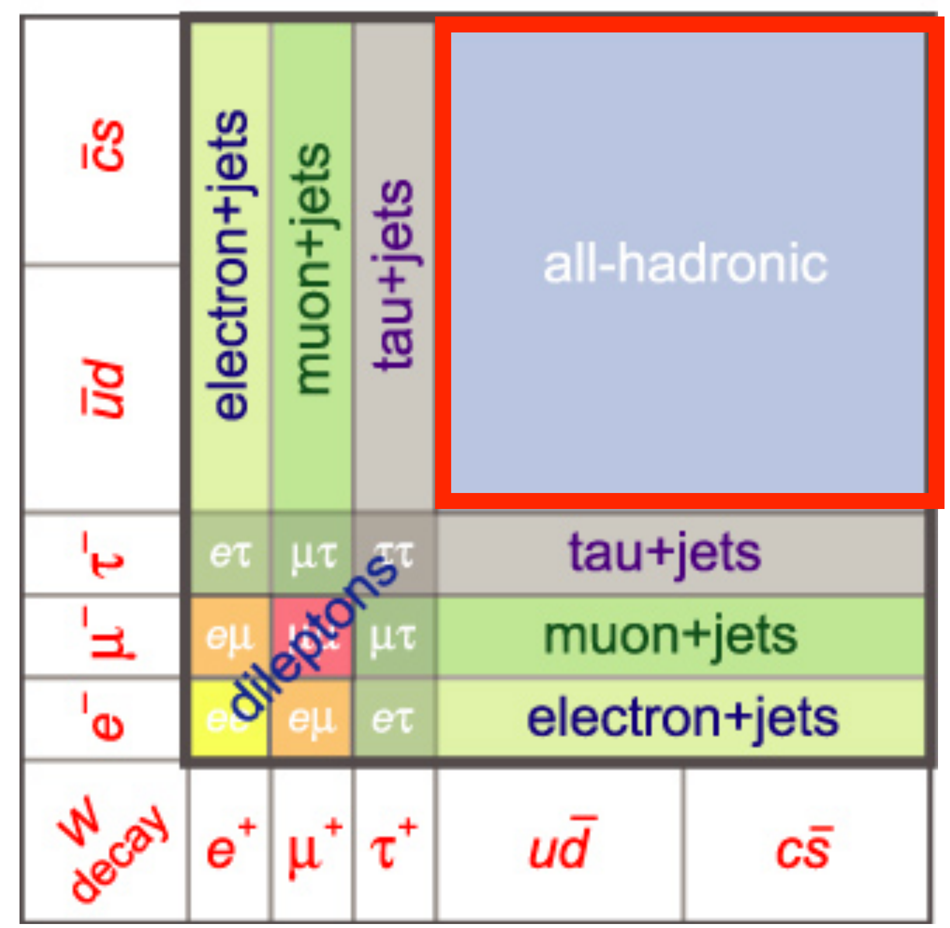
    - Hadronically: 2/3 * 2/3 = 4/9

Top Pair Decay Channels



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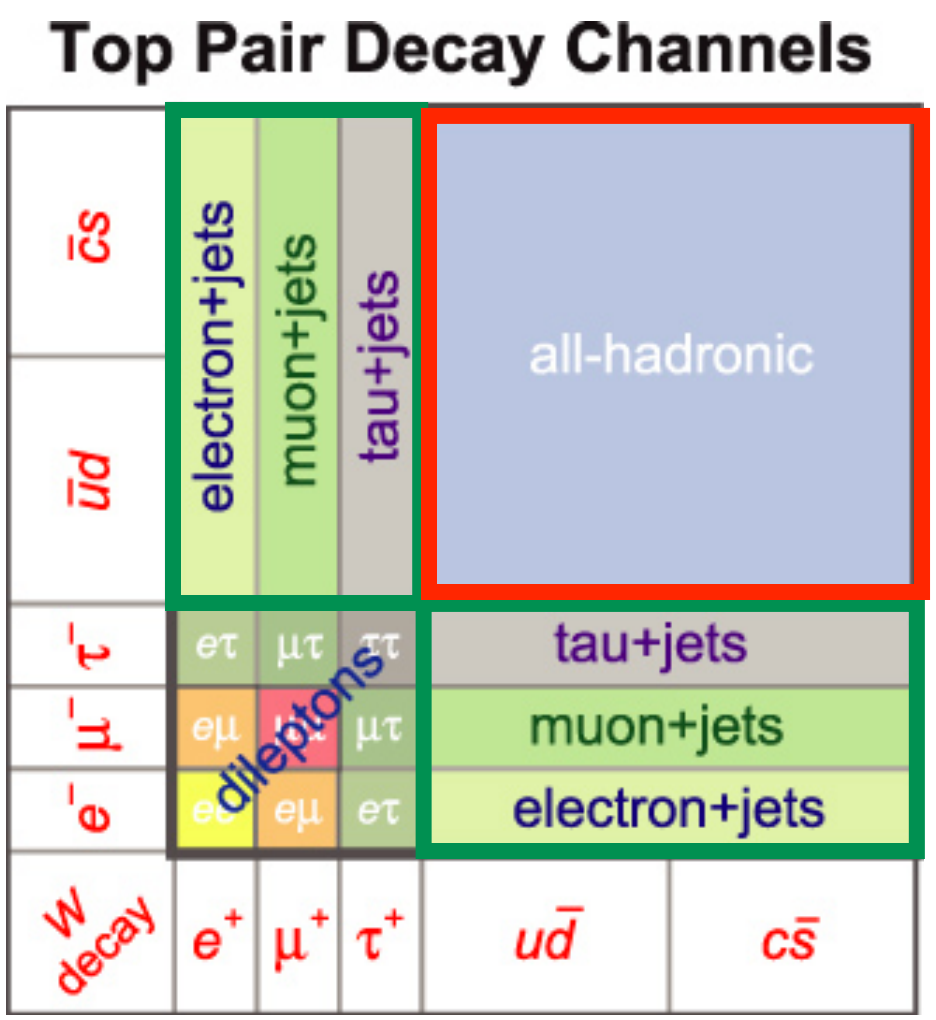

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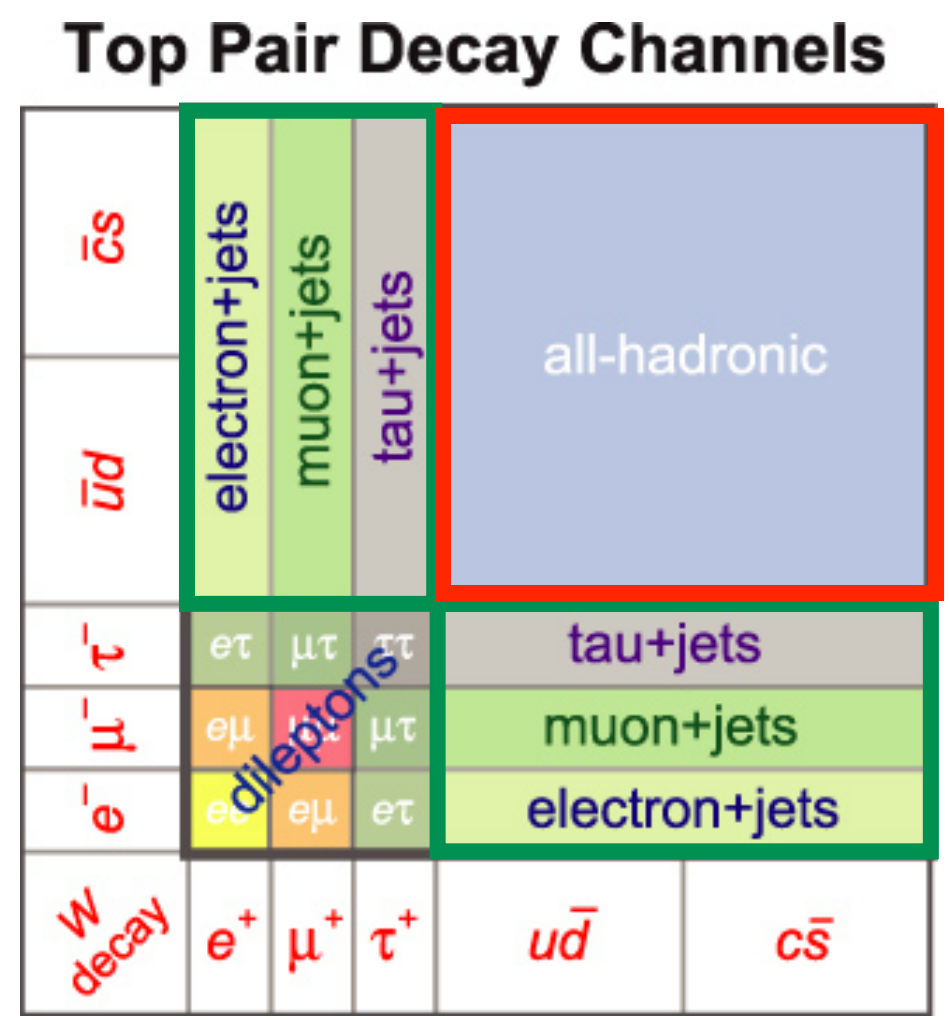
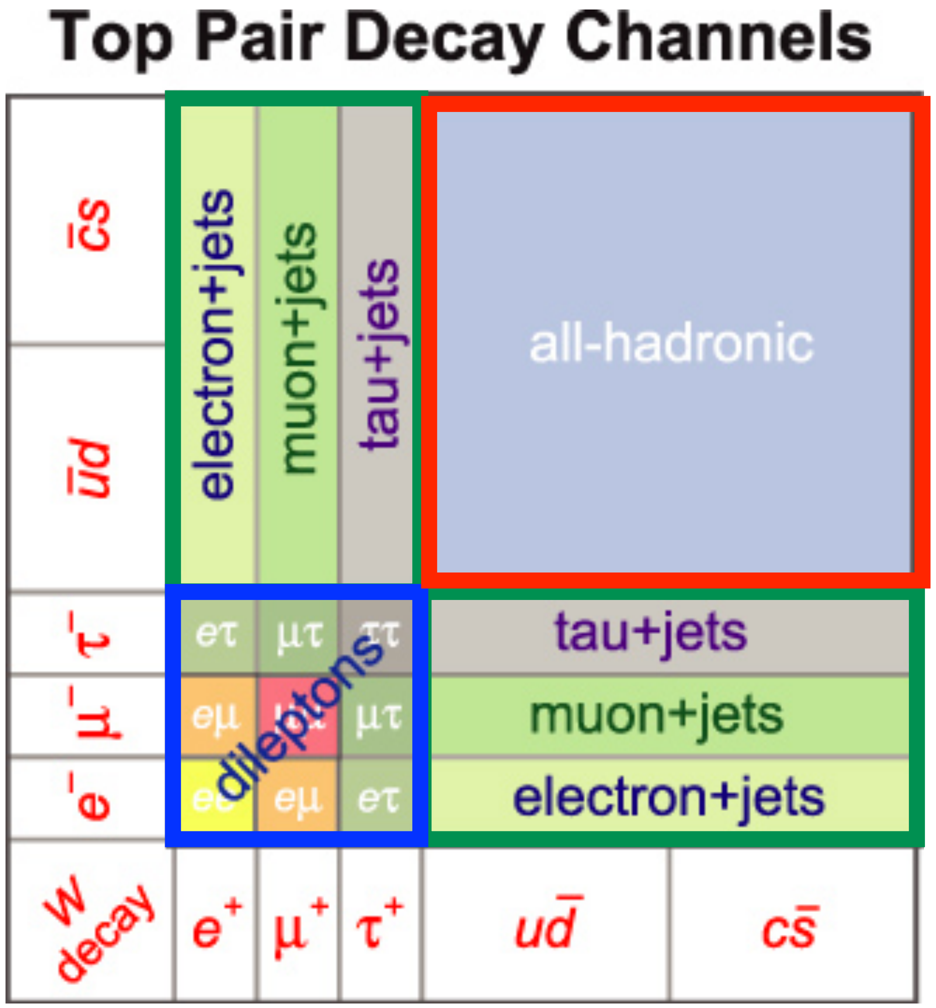
- Questions:
  - How often a top pair decays hadronically/semi-leptonically/di-leptonically?
    - Since the top always decays to Wb, look at how a pair of W decays (b's are stable)
    - Hadronically: 2/3 * 2/3 = 4/9
    - Semi-lep. (incl. τ): 2 * 1/3 * 2/3 = 4/9



Exercise 2: Solution

- Questions:
  - How often a top pair decays hadronically/semi-leptonically/di-leptonically?
    - Since the top always decays to Wb, look at how a pair of W decays (b's are stable)
    - Hadronically: 2/3 * 2/3 = 4/9
    - Semi-lep. (incl. τ): 2 * 1/3 * 2/3 = 4/9
    - Di-lep. (incl. τ): 1/3 * 1/3 = 1/9



Exercise 2: Solution

- Questions:
  - Learn the syntax to specify decay chains
  - > help generate

```
-- generate diagrams for a given process
General leading-order syntax:
 o generate INITIAL STATE > REQ S-CHANNEL > FINAL STATE $ EXCL S-CHANNEL / FORBIDDEN PARTICLES COUP1=ORDER1
COUP2^2=ORDER2 @N
 o Example: generate l+ vl > w+ > l+ vl a $ z / a h QED=3 QCD=0 @1
 > Alternative required s-channels can be separated by "|":
   b b~ > W+ W- | H+ H- > ta+ vt ta- vt~
 > If no coupling orders are given, MG5 will try to determine
   orders to ensure maximum number of QCD vertices.
 > Desired coupling orders combination can be specified directly for
   the squared matrix element by appending '^2' to the coupling name.
   For example, 'p p > j j QED^2==2 QCD^==2' selects the QED-QCD
   interference terms only. The other two operators '<=' and '>' are
   supported. Finally, a negative value COUP^2==-I refers to the
   N^(-I+1)LO term in the expansion of the COUP order.
 > To generate a second process use the "add process" command
Decay chain syntax:
 o core process, decay1, (decay2, (decay2', ...)), ...  etc
 o Example: generate p p > t~ t QED=0, (t~ > W- b~, W- > l- vl~), t > j j b @2
 > Note that identical particles will all be decayed
```

Something like this!

  - > generate p p > t t~, (t > w+ b, w+ > l+ vl), (t~ > w- b~, w- > l- vl~)

Exercise 2: Solution

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- Questions:
  - Generate the code for dileptonic top decay and compute the cross-section. Compare with what computed in Ex.1

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- Questions:
  - Generate the code for dileptonic top decay and compute the cross-section. Compare with what computed in Ex.1
    - `> generate p p > t t~, (t > w+ b, w+ > l+ vl), (t~ > w- b~, w- > l- vl~)`
    - `> output myttbardecayed`
    - `> launch`
  - What do we expect?
    - Something like 505 * 1/9 = 56 pb?
  - Wait: what is `l+/l-`?

Exercise 2: Solution

- Questions:
  - Generate the code for dileptonic top decay and compute the cross-section. Compare with what computed in Ex.1
    - `> generate p p > t t~, (t > w+ b, w+ > l+ vl), (t~ > w- b~, w- > l- vl~)`
    - `> output myttbardecayed`
    - `> launch`
  - What do we expect?
    - Something like 505 * 1/9 = 56 pb?
  - Wait: what is `l+`/`l-`?
    - `> display multi particles`

```
Multiparticle labels:
all = g u c d s u~ c~ d~ s~ a ve vm vt e- mu- ve~ vm~ vt~ e+ mu+
t b t~ b~ z w+ h w- ta- ta+
l- = e- mu-
j = g u c d s u~ c~ d~ s~
vl = ve vm vt
l+ = e+ mu+
p = g u c d s u~ c~ d~ s~
vl~ = ve~ vm~ vt~
```

Exercise 2: Solution

- Questions:
  - Generate the code for dileptonic top decay and compute the cross-section. Compare with what computed in Ex.1
    - `> generate p p > t t~, (t > w+ b, w+ > l+ vl), (t~ > w- b~, w- > l- vl~)`
    - `> output myttbardecayed`
    - `> launch`
  - What do we expect? 4/81 = 25
    - Something like 505 * ~~1/9 = 56~~ pb?
  - Wait: what is `l+/l-`?
    - `> display multi particles`

```
Multiparticle labels:
all = g u c d s u~ c~ d~ s~ a ve vm vt e- mu- ve~ vm~ vt~ e+ mu+
t b t~ b~ z w+ h w- ta- ta+
l- = e- mu-
j = g u c d s u~ c~ d~ s~
vl = ve vm vt
l+ = e+ mu+
p = g u c d s u~ c~ d~ s~
vl~ = ve~ vm~ vt~
```

```
Cross-section :   22.63 +- 0.01553 pb
Nb of events :  10000
```

last bit of discrepancy comes from more subtle things (essentially scales)

Exercise 2: Solution

- Questions:
  - Compute the cross section for m_t=170, 175 and 180 GeV. Do you see anything strange?

```
launch run_170
set mt 170
done
launch run_175
set mt 175
done
launch run_180
set mt 180
done
```

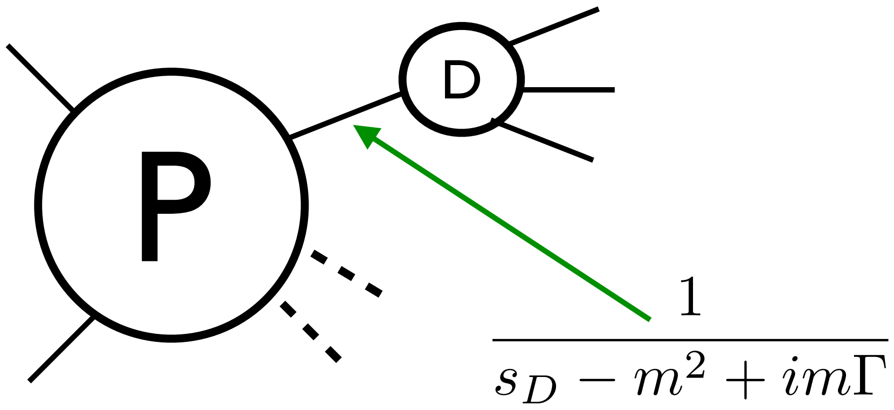
Available Results

Run	Collider	Banner	Cross section (pb)	Events	Data	Output	Action
run_170	p p 6500.0 x 6500.0 GeV	tag_1	21.83 ± 0.061	10000	parton madevent	LHE	remove run / launch detector simulation
run_175	p p 6500.0 x 6500.0 GeV	tag_1	23.41 ± 0.064	10000	parton madevent	LHE	remove run / launch detector simulation
run_180	p p 6500.0 x 6500.0 GeV	tag_1	24.92 ± 0.058	10000	parton madevent	LHE	remove run / launch detector simulation

Main Page

- The cross section grows with m_t!?!

What is happening?



$$\sigma_{P\times D} = \int d\mathrm{PS}\,|M_P|^2 \frac{1}{(s_D - m^2)^2 + m^2\Gamma^2} |M_D|^2$$

$$= \int d\mathrm{PS}\,|M_P|^2 \frac{\pi}{m\Gamma} \delta(s_D - m^2) |M_D|^2 + \mathcal{O}(\Gamma^0)$$

The total width Γ depends on m and should be updated!

Exercise 2: Solution

- Questions:
  - Compute the cross section for m_t=170, 175 and 180 GeV. Do you see anything strange?

```
launch run_170_gammaok
set mt 170
set wt auto
done
launch run_175_gammaok
set mt 175
set wt auto
done
launch run_180_gammaok
set mt 180
set wt auto
done
```

run_170	p p 6500.0 x 6500.0 GeV	tag_1	21.83 ± 0.061	10000	parton madevent	LHE
run_175	p p 6500.0 x 6500.0 GeV	tag_1	23.41 ± 0.064	10000	parton madevent	LHE
run_180	p p 6500.0 x 6500.0 GeV	tag_1	24.92 ± 0.058	10000	parton madevent	LHE
run_170_gammaok	p p 6500.0 x 6500.0 GeV	tag_1	24.71 ± 0.071	10000	parton madevent	LHE
run_175_gammaok	p p 6500.0 x 6500.0 GeV	tag_1	21.54 ± 0.064	10000	parton madevent	LHE
run_180_gammaok	p p 6500.0 x 6500.0 GeV	tag_1	18.8 ± 0.05	10000	parton madevent	LHE

  - With "set wt auto" the top width is re-computed from the param_card parameters

Exercise 2: Solution

- Questions:
  - What is the difference with `p p > l+ l- vl vl~ b b~`?

Exercise 2: Solution

- Questions:
  - What is the difference with `p p > l+ l- vl vl~ b b~`?
    - It is a much more complex process (will not run in 10s on a laptop)
      - Each subprocess has O(100) diagrams rather than O(1)

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  - What is the difference with `p p > l+ l- vl vl~ b b~`?
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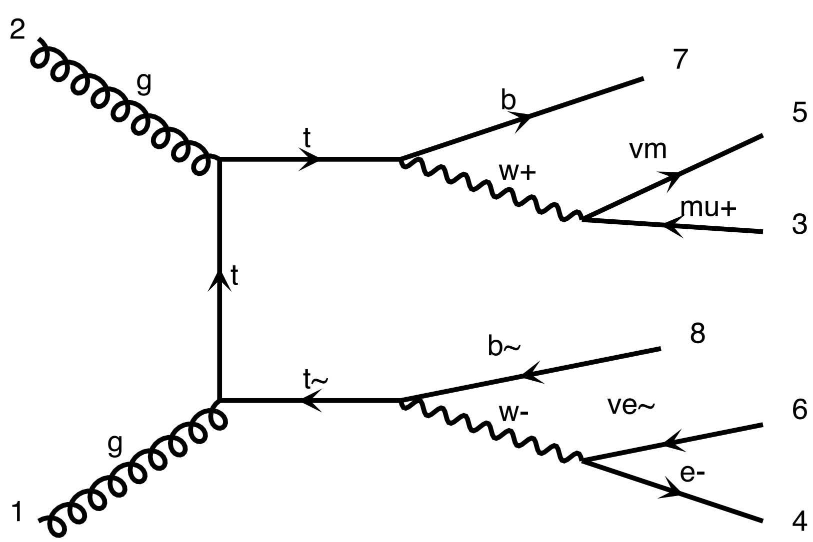

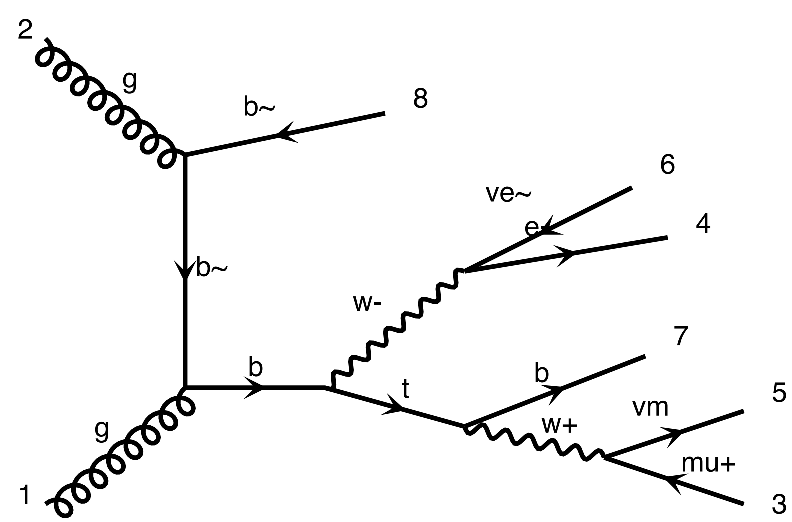

diagram 81 QCD=2, QED=4

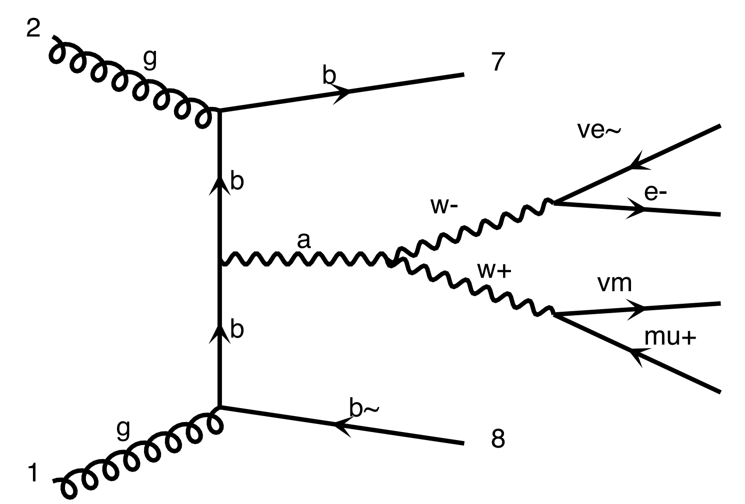

diagram 46 QCD=2, QED=4

Exercise 2: Solution

- Questions:
  - What is the difference with `p p > l+ l- vl vl~ b b~`?
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  - Which one is correct?

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    - If one searches for (on-shell) top-pair production (e.g.imposing cuts on l, v, b mass), the full process will give little extra contribution

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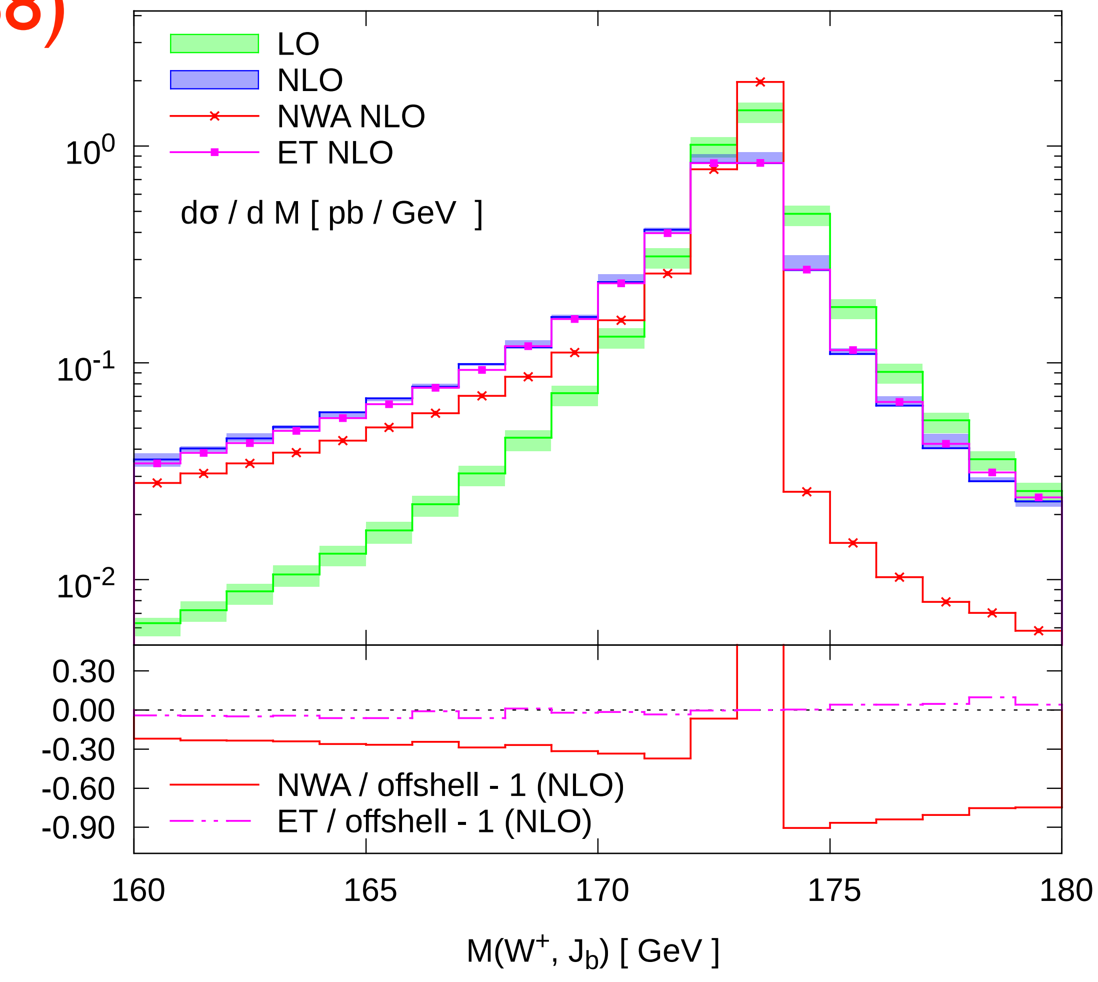
    - Strictly speaking $t\bar{t}$ decayed, is correct only in the limit $\Gamma_t=0$ i.e. when tops are on-shell
    - If one searches for (on-shell) top-pair production (e.g.imposing cuts on l, v, b mass), the full process will give little extra contribution
    - If one wants to look away from the resonant region, then the full

Exercise 2: Solution

- Questions:
  - What is the difference with `p p > l+ l- vl vl~ b b~`?
  - Have a look at single-top production (Papanastasiou et al. arXiv:1305.7088)



Exercise 3: Unitarity in gauge theories

- Consider the process $e^+e^-\to W^+W^-$:
  - Which diagrams contribute?
    - Generate the full process, the process with no ZWW vertex and the process with only the neutrino diagram
    - Use the `/ x y` syntax in the `generate` command to veto specific particles (see also `help generate`)
  - Calculate the cross section at $\sqrt{s}$=165, 175, …, 205, 400 GeV (script it!) and comment the behaviour
    Hint: set ebeam 200 sets both beams' energies to 200

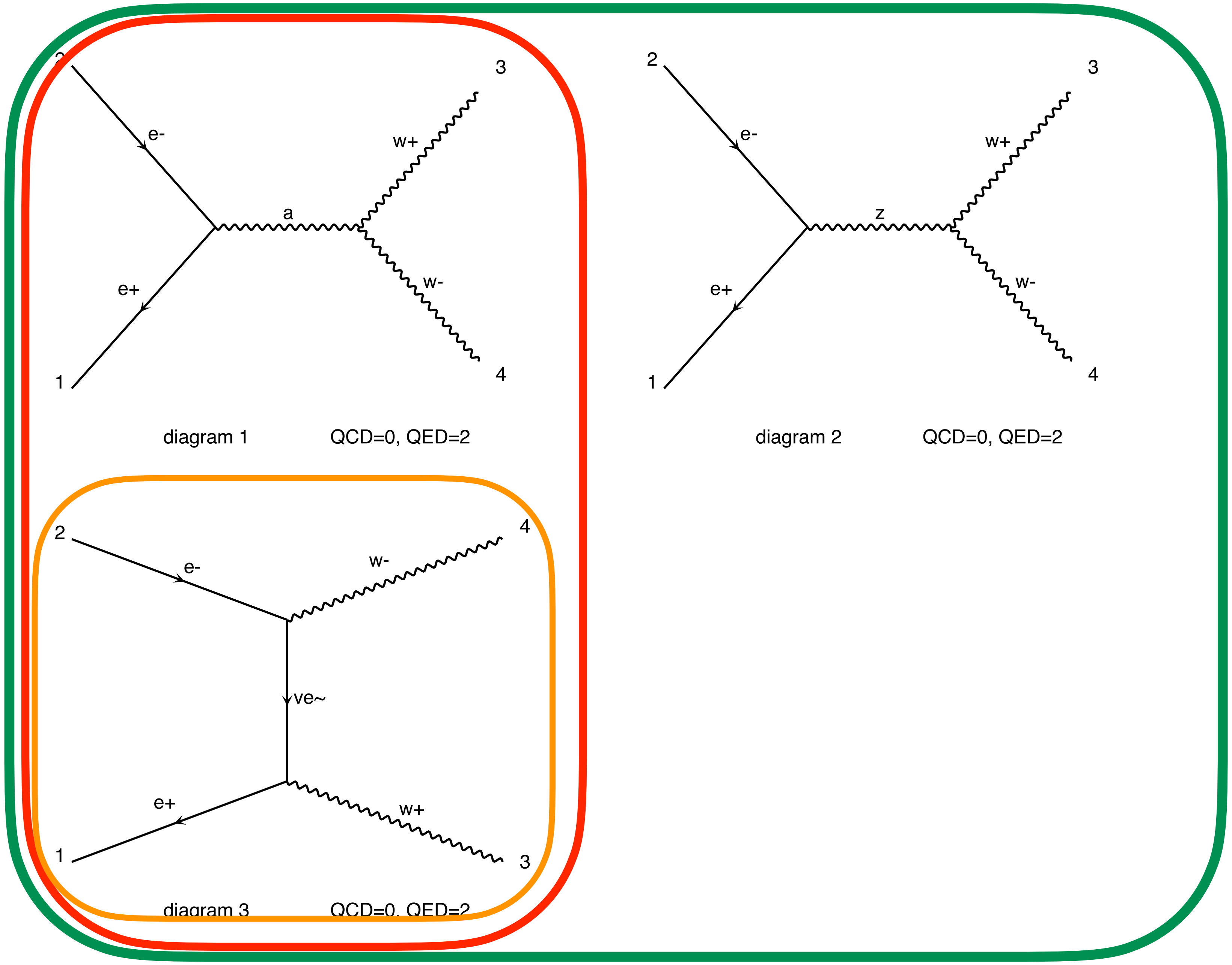
Exercise 3:
Unitarity in gauge theories

Feynman Diagrams:

generate e+ e- > w+ w-

generate e+ e- > w+ w- / z

generate e+ e- > w+ w- / z a



Exercise 3: Unitarity in gauge theories

- Script to calculate the cross sections

```
generate_events run_165
set ebeam 82.5
generate_events run_175
set ebeam 87.5
generate_events run_185
set ebeam 92.5
generate_events run_195
set ebeam 97.5
generate_events run_205
set ebeam 102.5
generate_events run_400
set ebeam 200
```

Exercise 3:
Unitarity in gauge theories

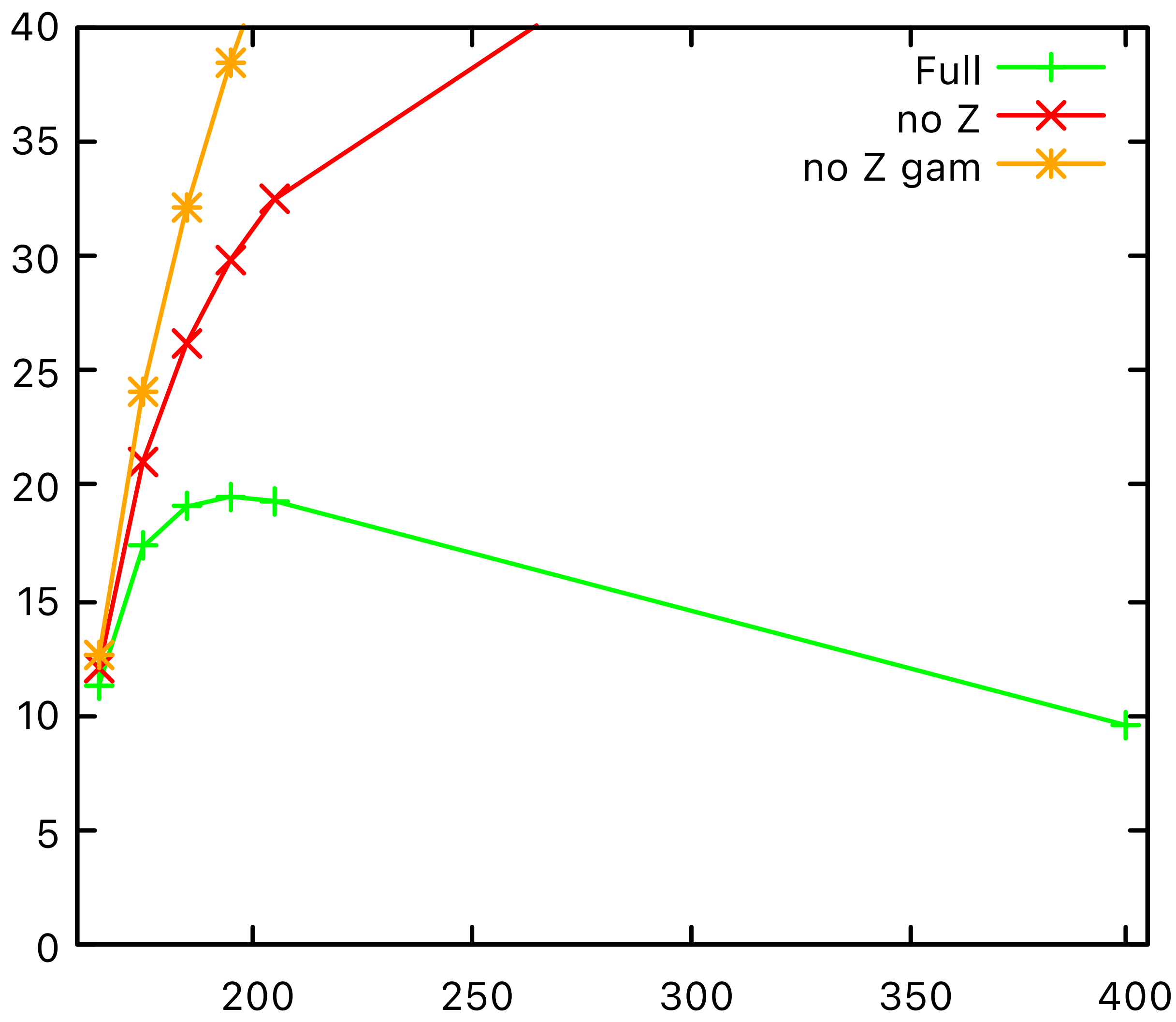
- Results

e+ e- > w+ w-

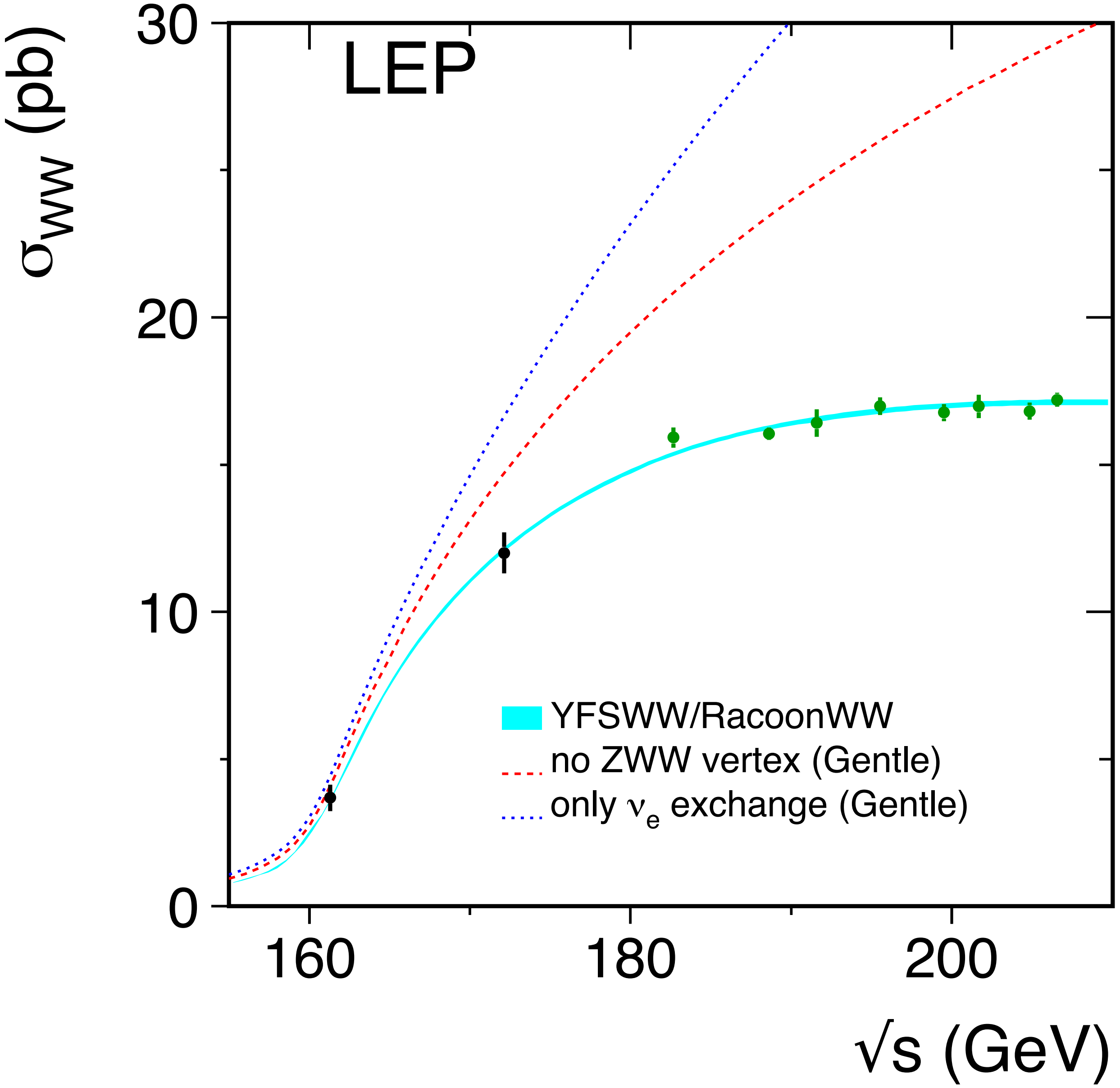
e+ e- > w+ w- / z

e+ e- > w+ w- / z a

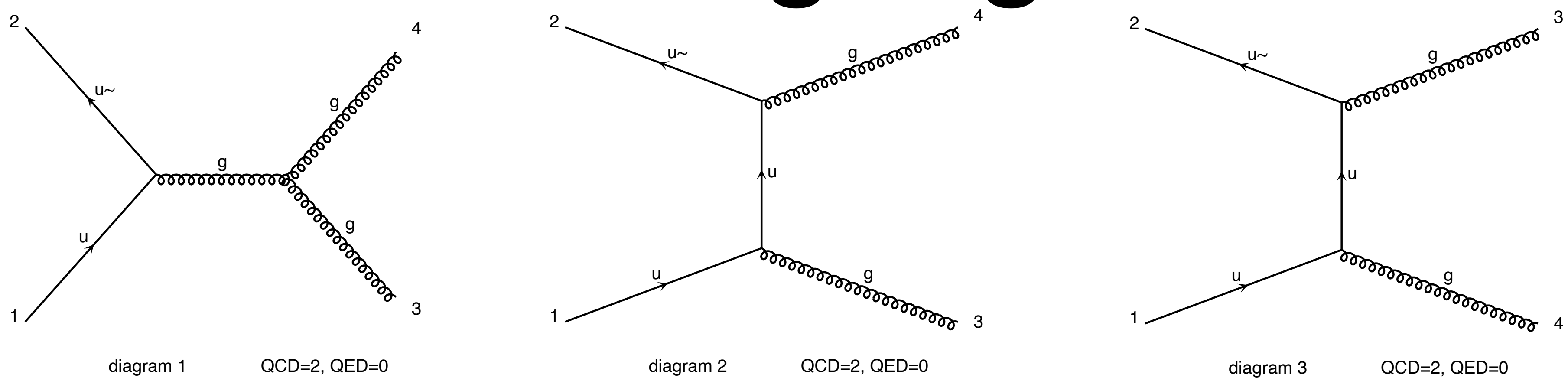
Run	Collider	Banner	Cross section (pb)	Cross section (pb)	Cross section (pb)
run_165	e+ e- 82.5 x 82.5 GeV	tag_1	11.38 ± 0.021	12.09 ± 0.019	12.66 ± 0.016
run_175	e+ e- 87.5 x 87.5 GeV	tag_1	17.37 ± 0.04	21.07 ± 0.032	24.18 ± 0.043
run_185	e+ e- 92.5 x 92.5 GeV	tag_1	19.1 ± 0.043	26.19 ± 0.045	32.07 ± 0.043
run_195	e+ e- 97.5 x 97.5 GeV	tag_1	19.53 ± 0.061	29.8 ± 0.057	38.39 ± 0.056
run_205	e+ e- 102.5 x 102.5 GeV	tag_1	19.35 ± 0.064	32.43 ± 0.071	43.73 ± 0.054
run_400	e+ e- 200.0 x 200.0 GeV	tag_1	9.579 ± 0.03	57.02 ± 0.074	101.8 ± 0.13



arXiv:1302.3415



What's going on?



- Consider a simpler case $u\bar{u}\rightarrow gg$ in QCD:
  - In a non-abelian gauge theory, in order to fulfil the Ward identity $\mathcal{M}^{\mu_3\mu_4}p_{\mu_3}\varepsilon_{\mu_4} = 0$
    one must include the diagram with the 3-gauge vertex
    $\mathcal{M}_2^{\mu_3\mu_4} \sim g^2 t^{a_3} t^{a_4}$ $\quad$ $\mathcal{M}_3^{\mu_3\mu_4} \sim -g^2 t^{a_4} t^{a_3}$ $\quad$ $\mathcal{M}_1^{\mu_3\mu_4} \sim g^2 f^{a_3 a_4 b} t^b$
  - Otherwise, the Ward identity is violated
    → no gauge invariance
    → possible violation of unitarity at high energies: in the case with the W's, the longitudinal component has terms ~E/m_W, whose contribution cancels in a gauge invariant amplitude

Exercise 4: Initial-state radiation in lepton collisions

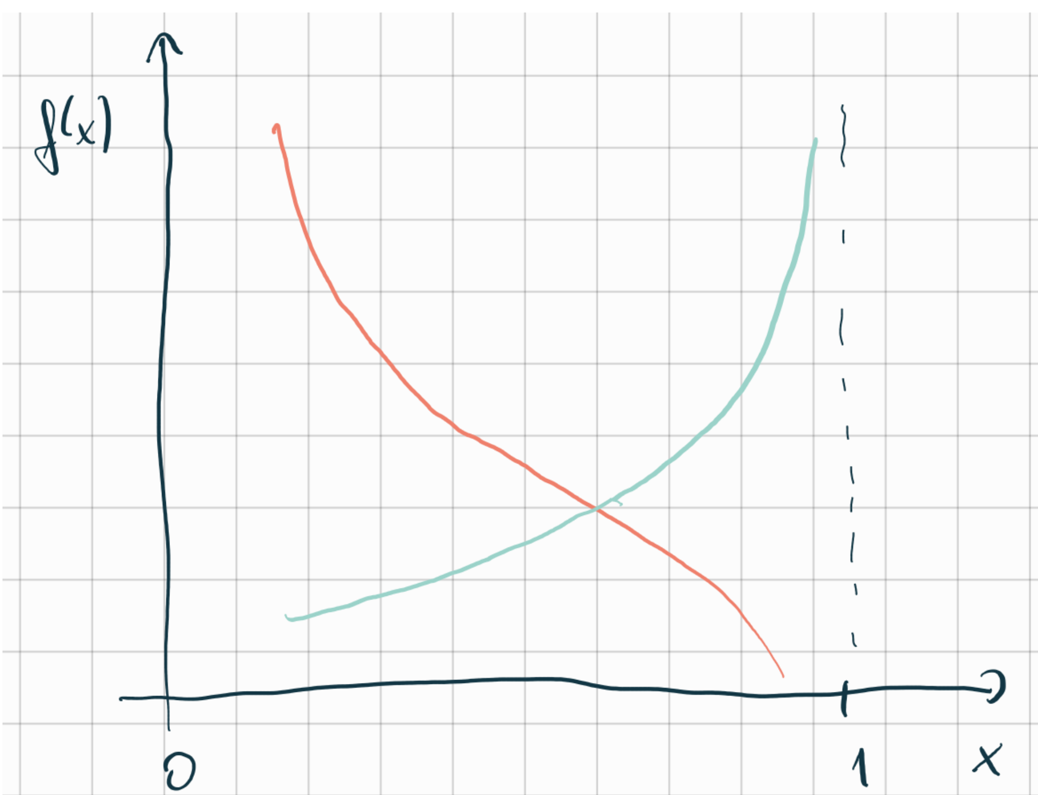
- Consider muon-pair production at an electron-positron collider of 500 GeV.
- Set `pdlabel=isronlyll` and `lpp1(2)=-3(+3)` in the run_card. This will tell the code to include ISR effects for the electrons
- Plot the invariant mass of the muon pair (MadAnalysis5 does it automatically). What do you see? How do you explain the double peak?

ISR (at LL)

GRIBOV V. N. and LIPATOV L. N.
Sow. J . Nucl. Phys., 15 (1972) 438

$$D_{GL}(x, Q^2) = \frac{\exp[(1/2)\eta(3/4 - \gamma_E)]}{\Gamma(1 + (1/2)\eta)} \frac{1}{2}\eta(1-x)^{(1/2)\eta - 1} \simeq \frac{1}{(1-x)^{1-\eta/2}}$$

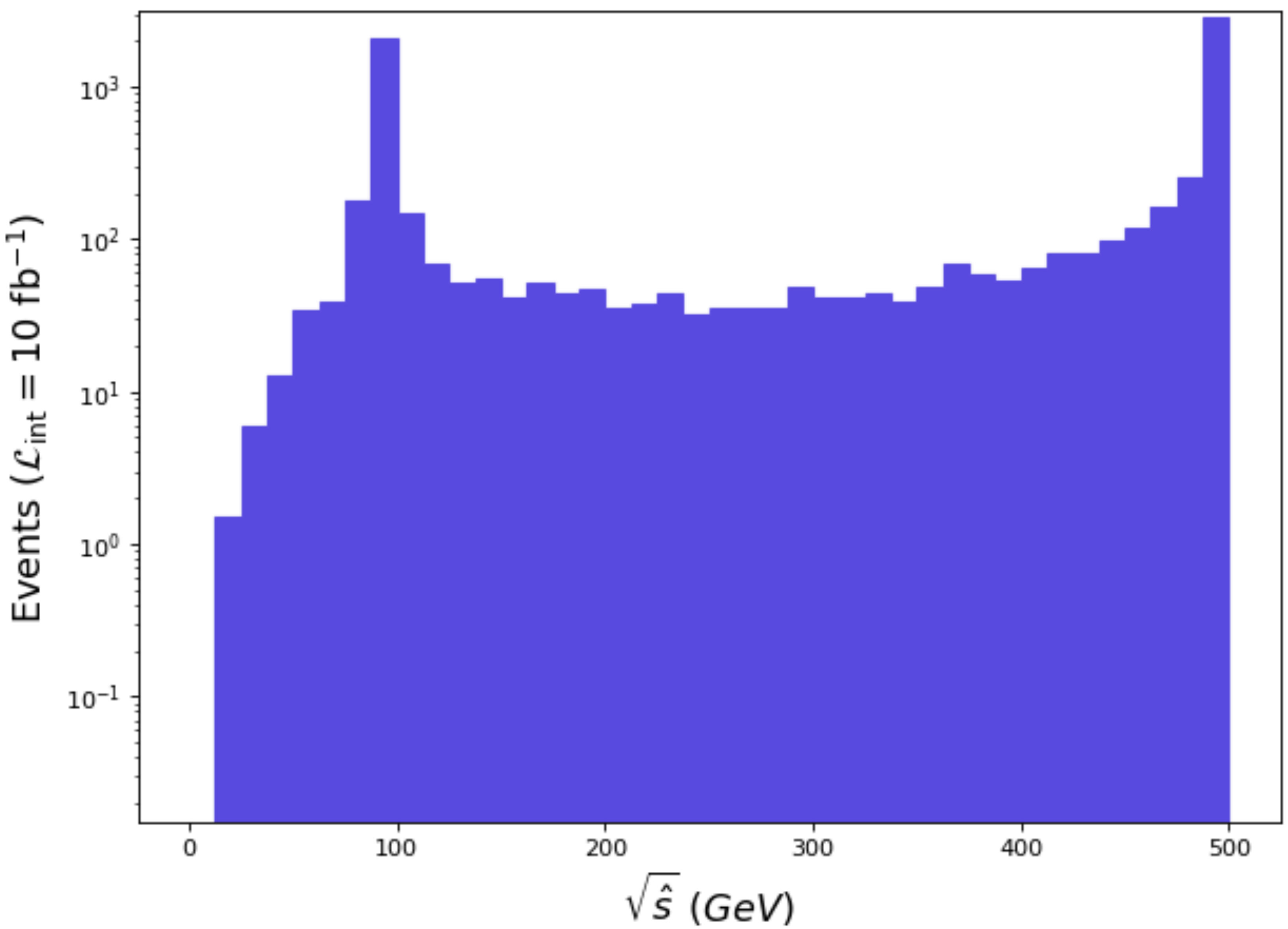
$$\left(\eta = \frac{2\alpha}{\pi}\log\frac{Q^2}{m^2}\right)$$ ~0.05 for Q=100 GeV



- **Hadronic PDFs** vanish at large x (divergence at small-x avoided by cuts)
- **Leptonic PDFs** diverge (but are integrable) at large x
- While leptonic PDFs have been substantially improved since 1972, the asymptotic behaviour is unchanged
- A different phase space mapping is required wrt pp collisions

Exercise 4: Solution

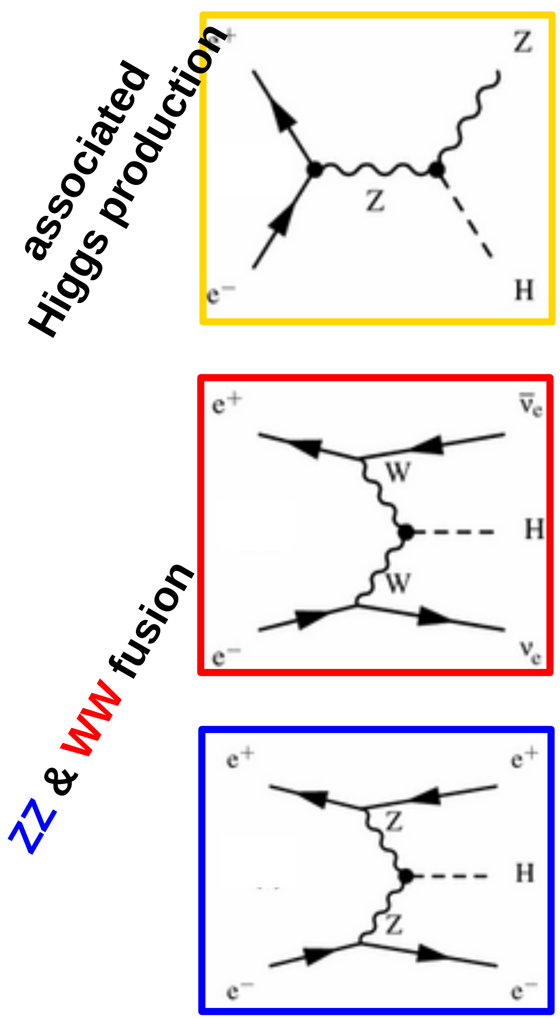
Z-mass peak　　　　peak corresponding to ISR with z=1

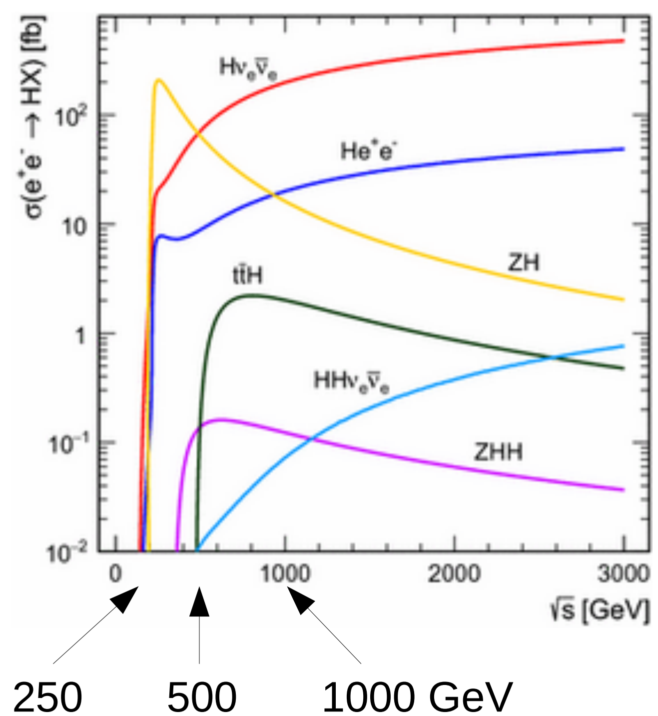


Exercise 5:
Higgs production at the ILC

- Try to reproduce some of the curves in this plot

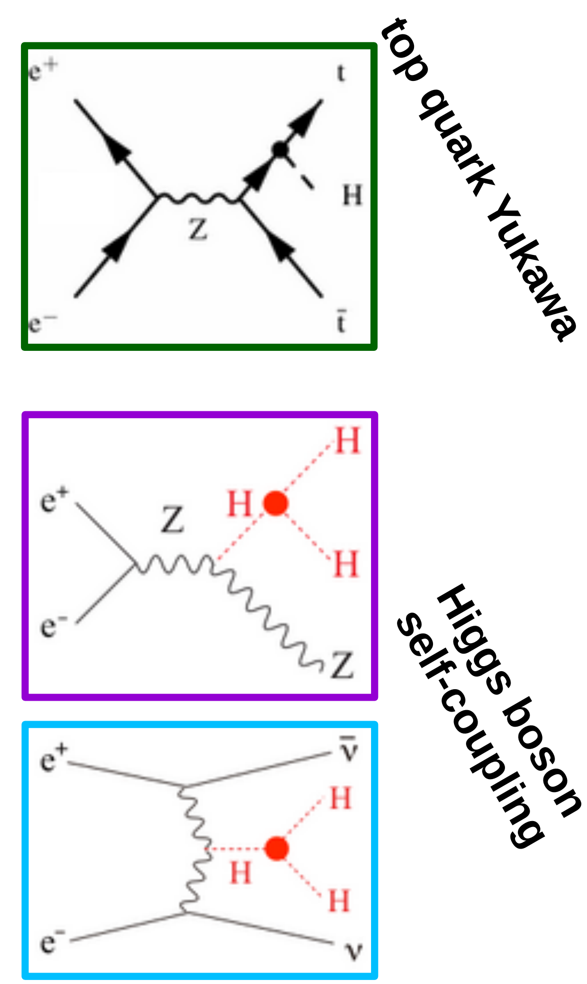
Higgs production in electron-positron collisions





Higgs studies can start at **250 GeV**

full set of Higgs measurements:
add ~**500** & ~**1000 GeV**



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From Daniel Jeans