Learning MG5_aMC

Today: LO

Next Week: NLO

Where to find help?

- Ask us
- Use the command "help" / "help XXX"
  - ➡ "help" tell you the next command that you need to do.
- Launchpad:
  - ➡ https://answers.launchpad.net/madgraph5
  - ➡ FAQ: https://answers.launchpad.net/madgraph5/+faqs

Minimal tutorial

- Launch the code
  - ➡ ./bin/mg5_aMC
    - Run by default python3 (need 3.7+)
    - Also compatible with python2.7 via
      - Python2.7 ./bin/mg5_aMC
- Type the word “tutorial” in the shell
  - ➡ Follow instructions

What are those cards?

- Read the Cards and identify what they do
  - ➡ param_card: model parameters
  - ➡ run_card: beam/run parameters and cuts

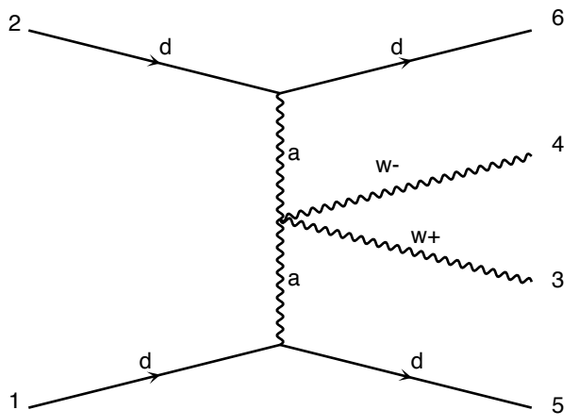
- https://answers.launchpad.net/madgraph5/+faq/2014

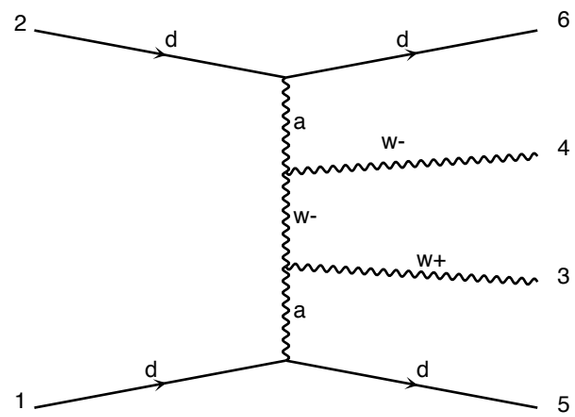
Exercise II: Cards Meaning

- How do you change
  - ➡ top mass
  - ➡ top width
  - ➡ W mass
  - ➡ beam energy
  - ➡ pt cut on the lepton

Exercise II : Syntax

- What's the meaning of the order QED/QCD
- What's the difference between
  - ➡ p p > t t~
  - ➡ p p > t t~ QED=2
  - ➡ p p > t t~ QED=0
- Compute the cross-section for each of those and check the diagram
  - ➡ p p > t t~ QCD=0
  - ➡ p p > t t~ QED<=2
  - ➡ p p > t t~ QCD^2==2
- Generate VBF process





Exercise III: Syntax

- Generate the cross-section and the distribution (invariant mass) for
  - ➡ p p > e+ e-
  - ➡ p p > z, z > e+ e-
  - ➡ p p > e+ e- $ z
  - ➡ p p > e+ e- / z

Hint :To plot automatically distributions:
mg5> install MadAnalysis5

- Use the invariant mass distribution to determine the

Exercise 1V:
Top pair production at LO

- Basic questions:
  - Generate the process
  - Which partonic subprocesses contribute?
  - How many Feynman diagrams has each subprocess?
  - Output the code
  - Compute the cross-section at the LHC (8 TeV) for m_t=170 GeV
- Extra questions:
  - Are b-quarks included in the initial state? If not, how can I include them?
  - Recompute the $t\bar{t}$ cross-section for m_t=170, 172, 174 … 180 GeV
  - Add the top decay and redo the mass scan. Anything strange?

Exercise IV: hint

- Compute the cross-section for the top pair production for 3 different mass points.
  - ➡ Do NOT use the interactive interface
    - hint: you can edit the param_card/run_card via the "set" command [After the launch]
    - hint: All command [including answer to question] can be put in a file. (run ./bin/mg5 PATH_TO_FILE)

Examples

File:

```
import model EWDim6
generate p p > z z
ouput TUTO_DIM6
launch
  set nevents 5000
  set MZ 100
```

How to Run: `./bin/mg5_amc PATH`

Solution Learning MG5_aMC

Exercise II: Cards Meaning

- How do you change
  - ➡ top mass
  - ➡ top width
  - ➡ W mass
  - ➡ beam energy
  - ➡ pt cut on the lepton

Param_card

Run_card

- top mass

```
###################################
## INFORMATION FOR MASS
###################################
Block mass
    6 1.730000e+02 # MT
   23 9.118800e+01 # MZ
   25 1.200000e+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 # nu- : 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)))
```

```
###################################
## 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 1.200000e+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 # nu- : 0.0
 14 0.000000 # vm : 0.0
 16 0.000000 # vt : 0.0
 21 0.000000 # g : 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)))
```

W Mass is an internal parameter!

MG5 didn't use this value!

So you need to change MZ or Gf or alpha_EW

Exercise III: Syntax

- What's the meaning of the order QED/QCD
- What's the difference between
  - ➡ p p > t t~
  - ➡ p p > t t~ QED=2
  - ➡ p p > t t~ QED=0
  - ➡ p p > t t~ QCD^2==2

Solution 1 : Syntax

- What's the meaning of the order QED/QCD
  - ➡ By default MG5 takes the lowest order in QED!
  - ➡ p p > t t~ => p p > t t~ QED=0
  - ➡ p p > t t~ QED=2
    - additional diagrams (photon/z exchange)

p p > t t~

Cross section (pb)
555 ± 0.84

p p > t t~ QED=2

Cross section (pb)
555.8 ± 0.91

No significant QED contribution

- QED<=2 is the SAME as QED=2
  - ➡ quite often source of confusion since most of the people use the = syntax
- QCD^2==2
  - ➡ returns the interference between the QCD and the QED diagram

Cross section (pb)
5.455e-17 ± 4.7e-19 ± systematics

Solution I Syntax

- generate p p > w+ w- j j
  - ➡ 76 processes
  - ➡ 1432 diagrams
  - ➡ None of them are VBF

- generate p p > w+ w- j j QED = 2
  - ➡ 76 processes
  - ➡ 1432 diagrams
  - ➡ None of them are VBF

- generate p p > w+ w- j j QED = 4
  - ➡ 76 processes
  - ➡ 5332 diagrams
  - ➡ VBF present! + those not VBF

- generate p p > w+ w- j j QCD = 0
  - ➡ 60 processes
  - ➡ 3900 diagrams
  - ➡ VBF present!

- generate p p > w+ w- j j QCD = 2
  - ➡ 76 processes
  - ➡ 5332 diagrams

- generate p p > w+ w- j j QCD = 4
  - ➡ 76 processes
  - ➡ 5332 diagrams

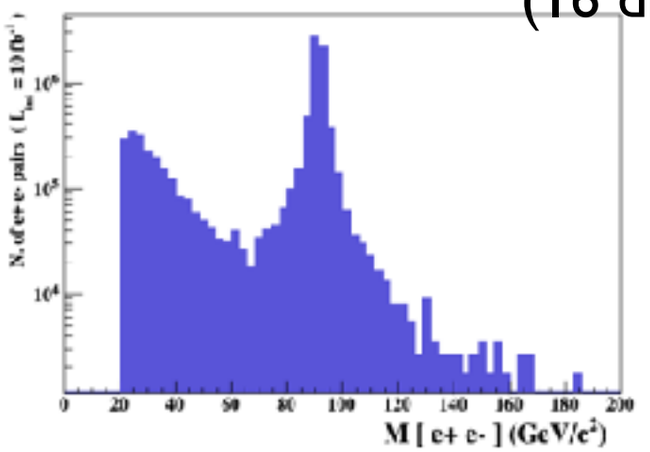
Exercise IV: Syntax

- Generate the cross-section and the distribution (invariant mass) for
  - ➡ p p > e+ e-
  - ➡ p p > z, z > e+ e-
  - ➡ p p > e+ e- $ z
  - ➡ p p > e+ e- / z

Hint : To have automatic distributions:
mg5> install MadAnalysis

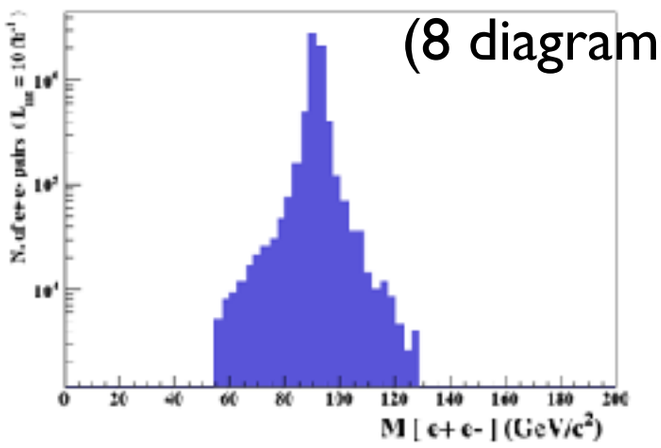
p p > e+ e-

(16 diagrams)



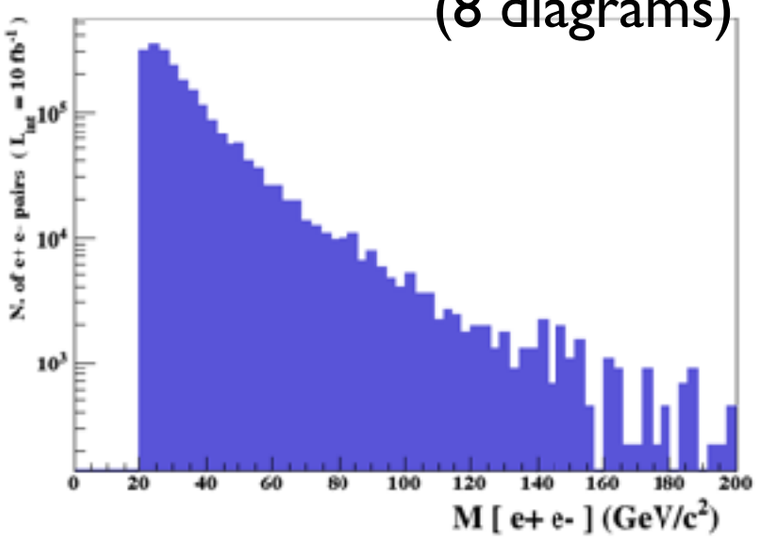
p p >z , z > e+ e-

(8 diagrams)



p p > e+ e- /z

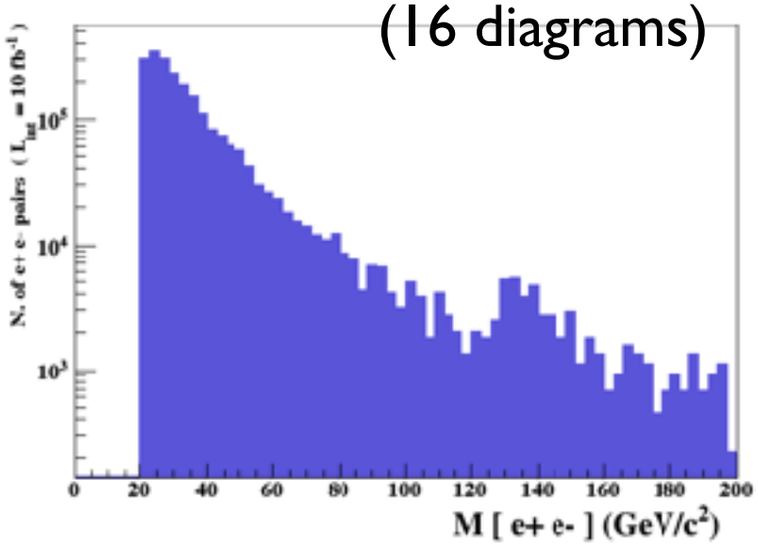
(8 diagrams)



No Z

p p > e+ e- $ z

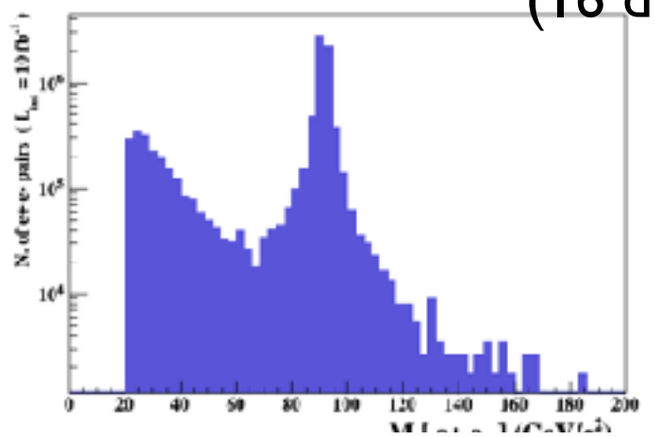
(16 diagrams)



Z- onshell veto

p p > e+ e-

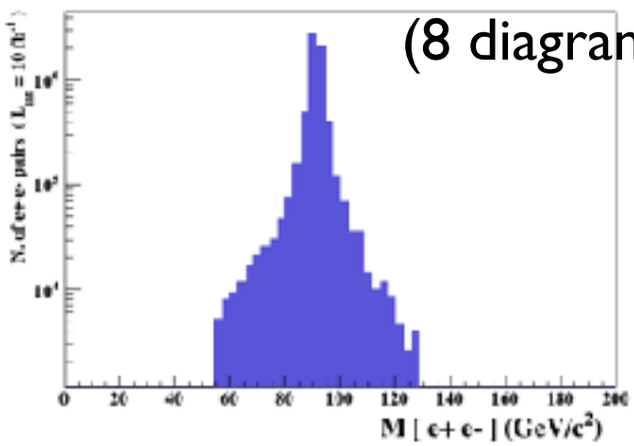
(16 diagrams)



Correct Distribution

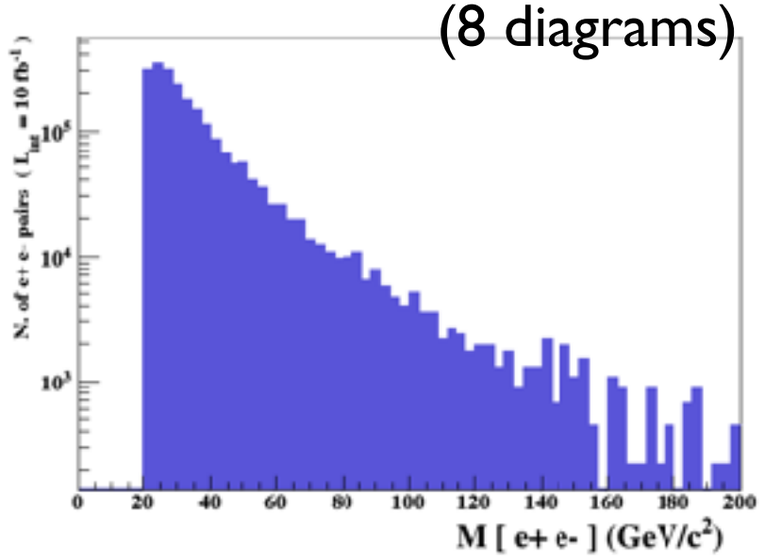
p p >z , z > e+ e-

(8 diagrams)



p p > e+ e- /z

(8 diagrams)



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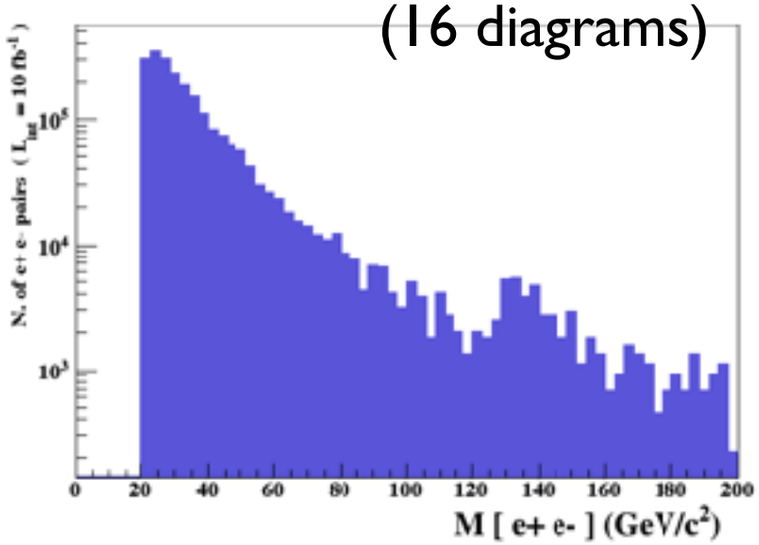

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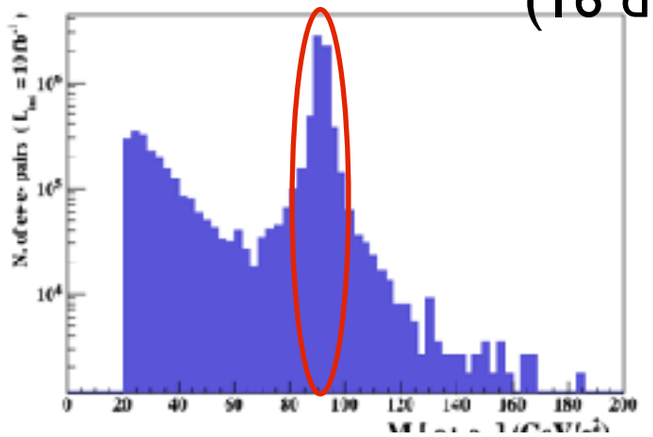
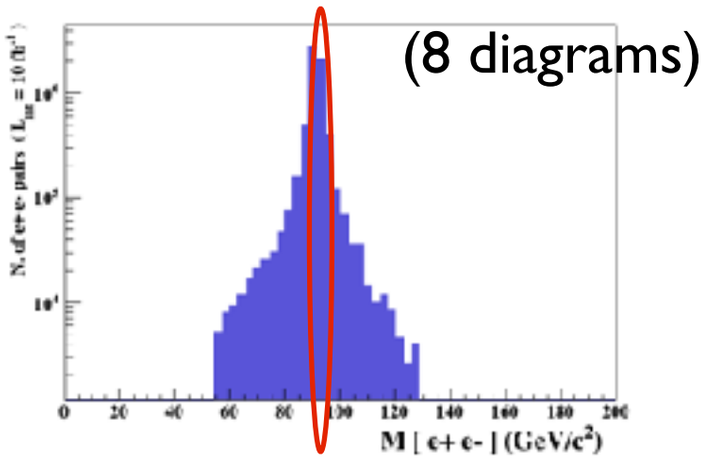


Correct Distribution

Z Peak

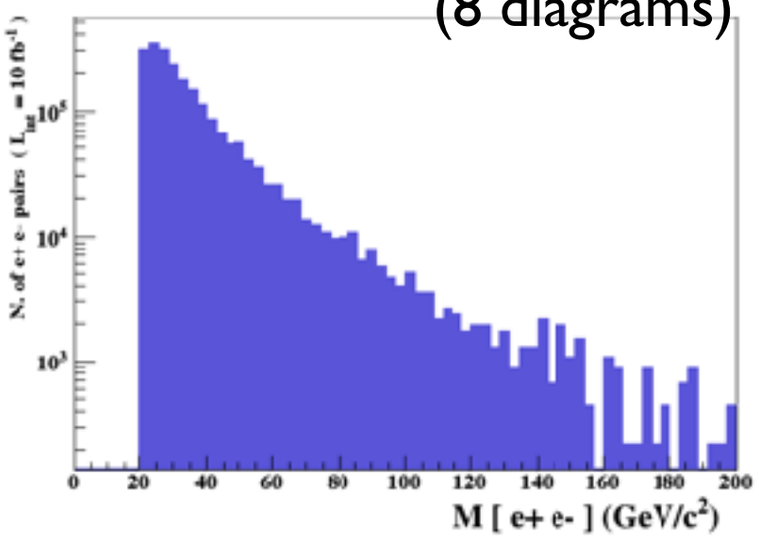
p p >z , z > e+ e-

(8 diagrams)



p p > e+ e- /z

(8 diagrams)

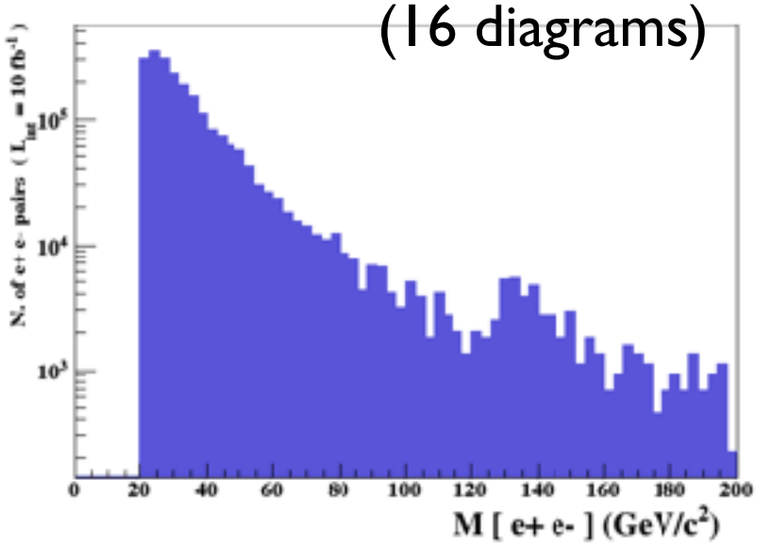


No Z

NO Z Peak

p p > e+ e- $ z

(16 diagrams)



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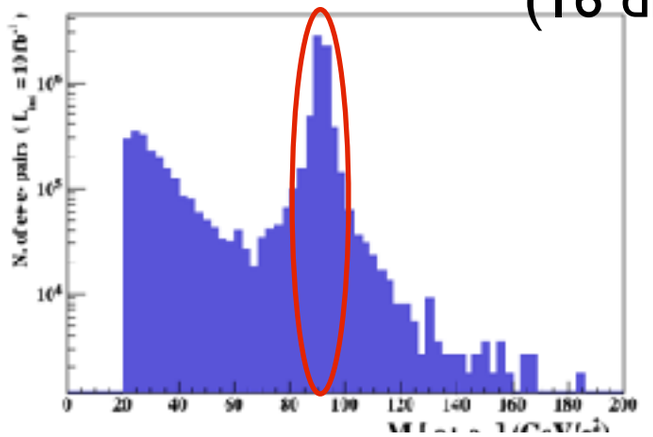

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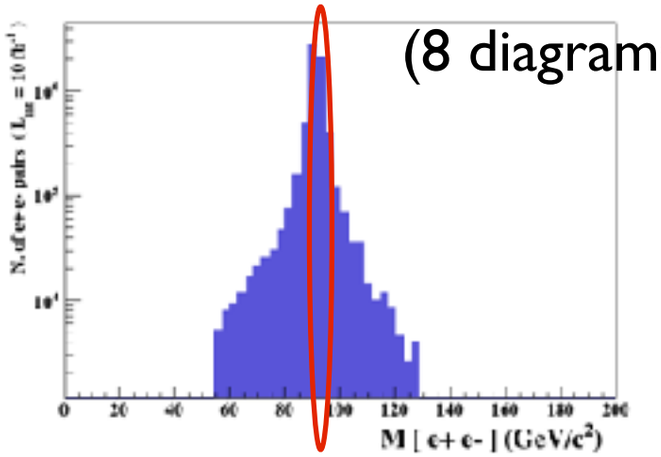
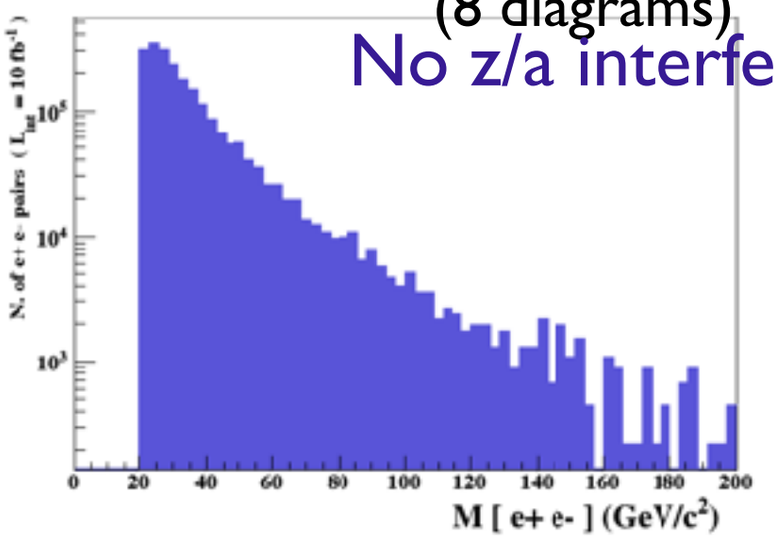


p p > e+ e- /z

(8 diagrams)

No z/a interference



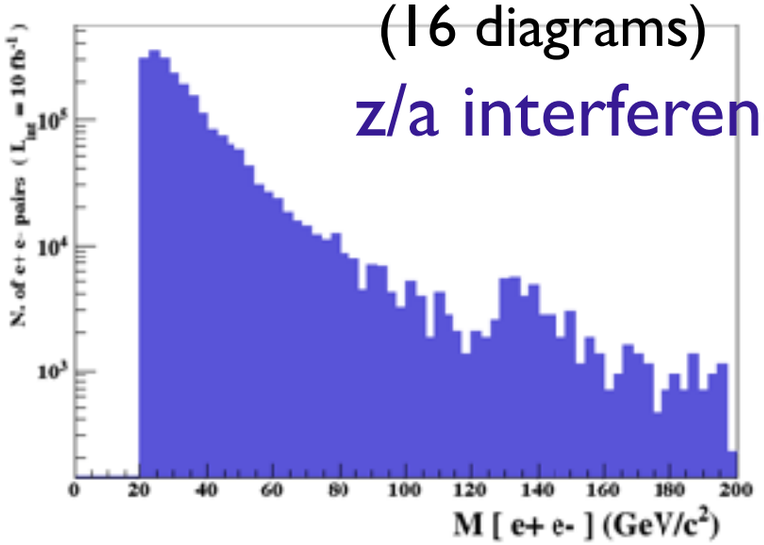
No Z

NO Z Peak

p p > e+ e- $ z

(16 diagrams)

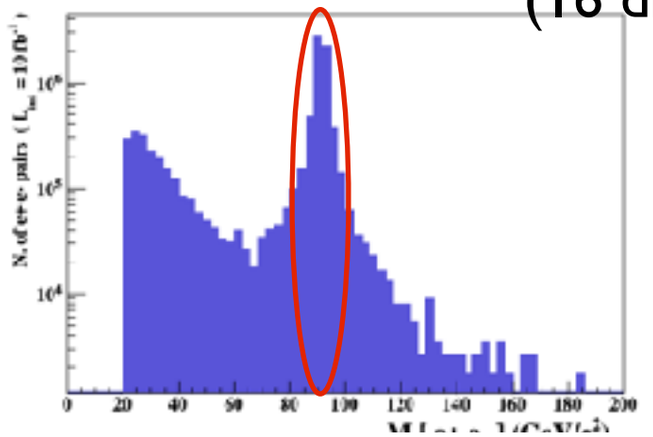
z/a interference



Z- onshell veto

p p > e+ e-

(16 diagrams)



Correct Distribution

Z Peak

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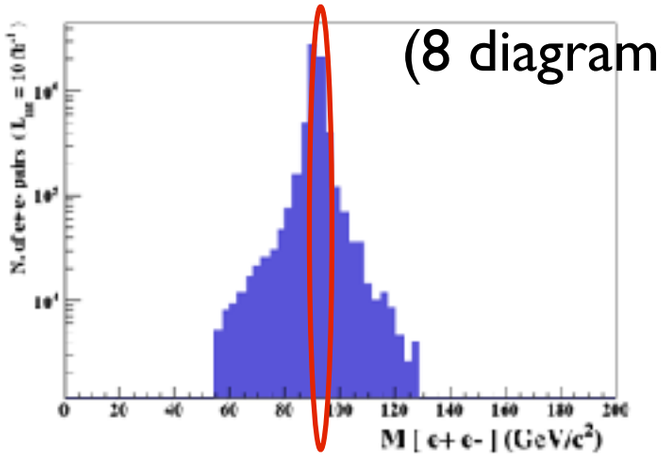
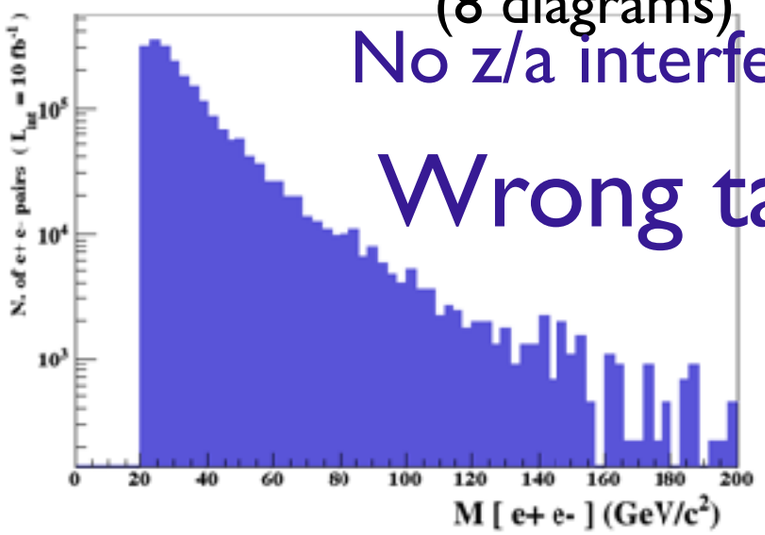


p p > e+ e- /z

(8 diagrams)

No z/a interference



NO Z Peak

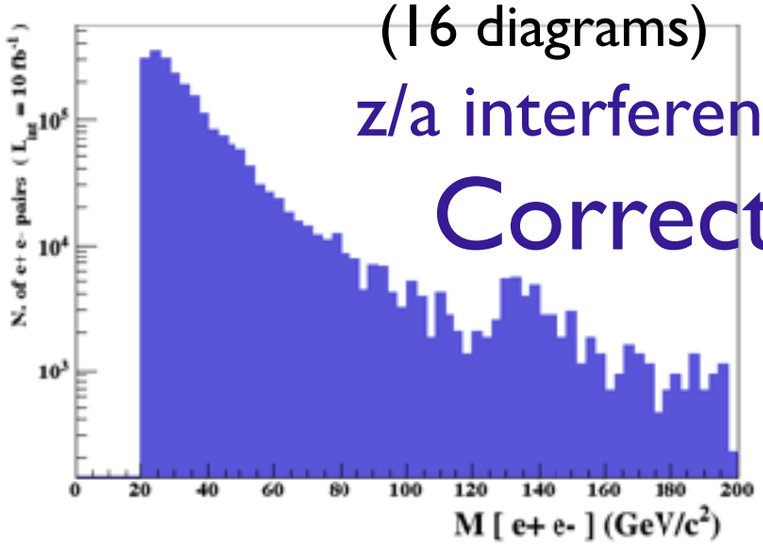
Wrong tail

No Z

p p > e+ e- $ z

(16 diagrams)

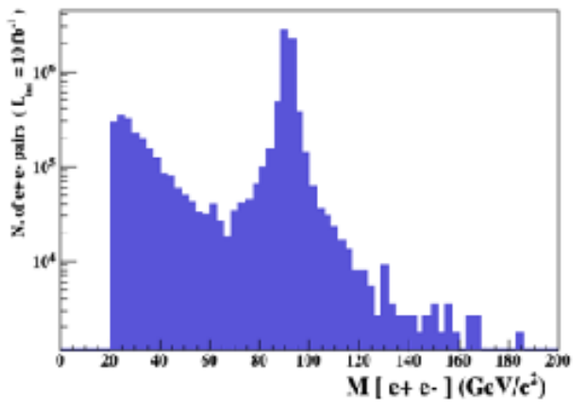
z/a interference



Correct tail

Z- onshell veto

p p > e+ e-



(16 diagrams)

=

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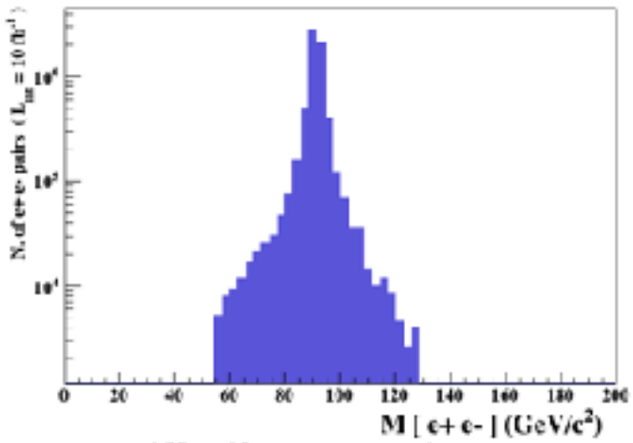
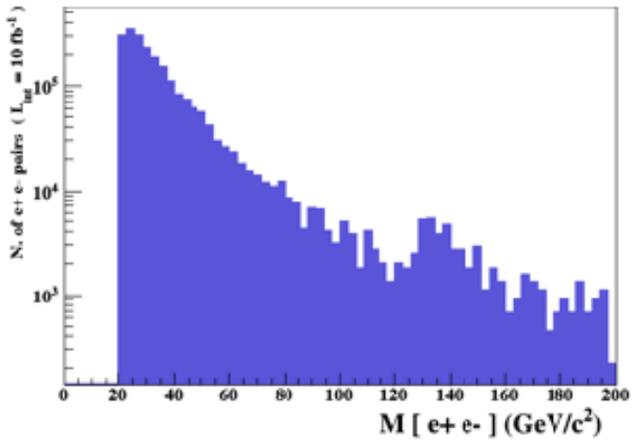


(8 diagrams)

+

p p > e+ e- $ z



(16 diagrams)

Onshell cut: BW_cut

$$|M^* - M| < BW_{cut} * \Gamma$$

- The Physical distribution is (very close to) exact sum of the two other one.
- The "$" forbids the Z to be onshell but the photon invariant mass can be at MZ (i.e. on shell substraction).
- The "/" is to be avoid if possible since this leads to violation of gauge invariance.

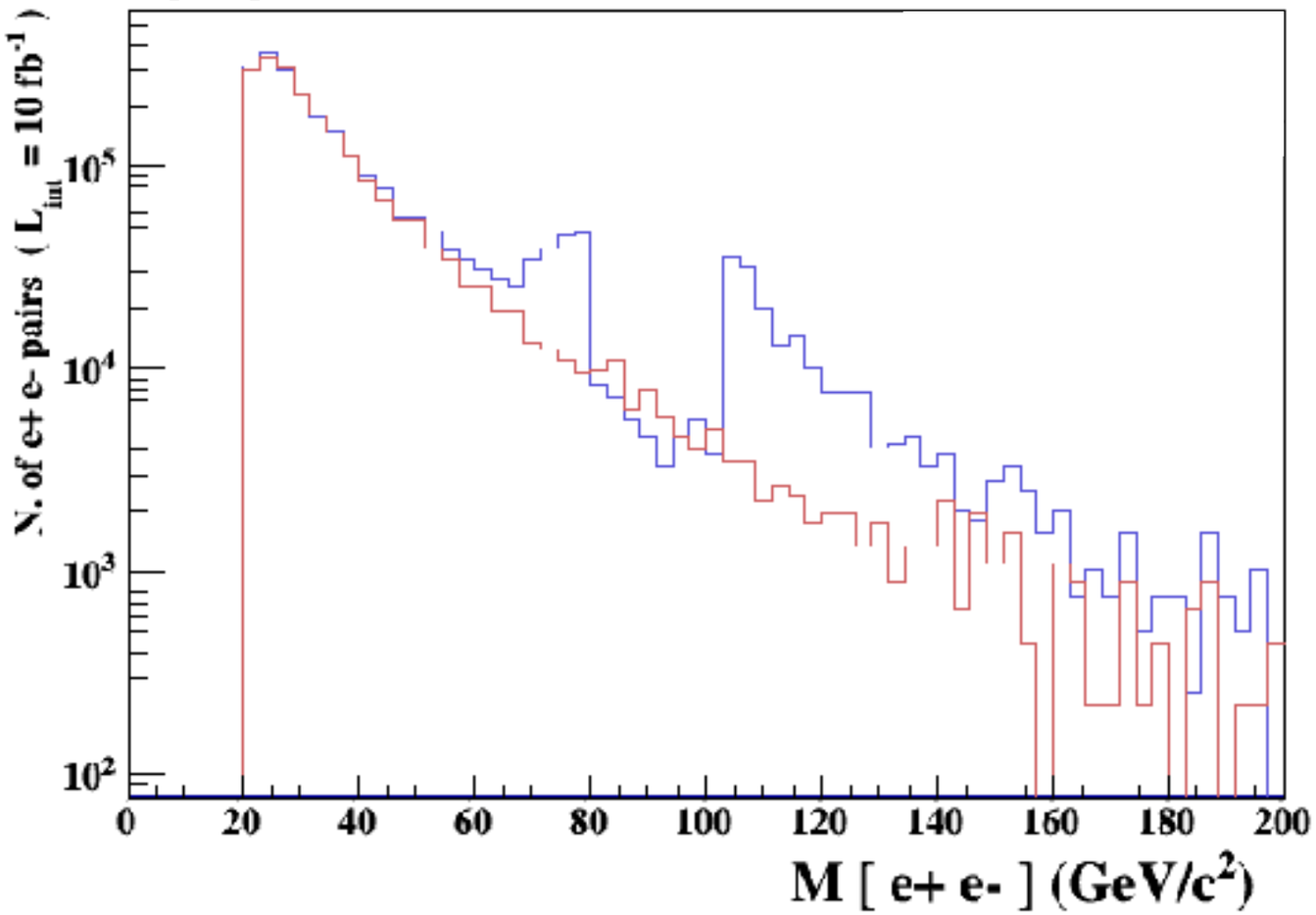
WARNING

- NEXT SLIDE is generated with bw_cut =5
- This is TOO SMALL to have a physical meaning (15 the default value used in previous plot is better)
- This was done to illustrate more in detail how the "$" syntax works.

$ explanation

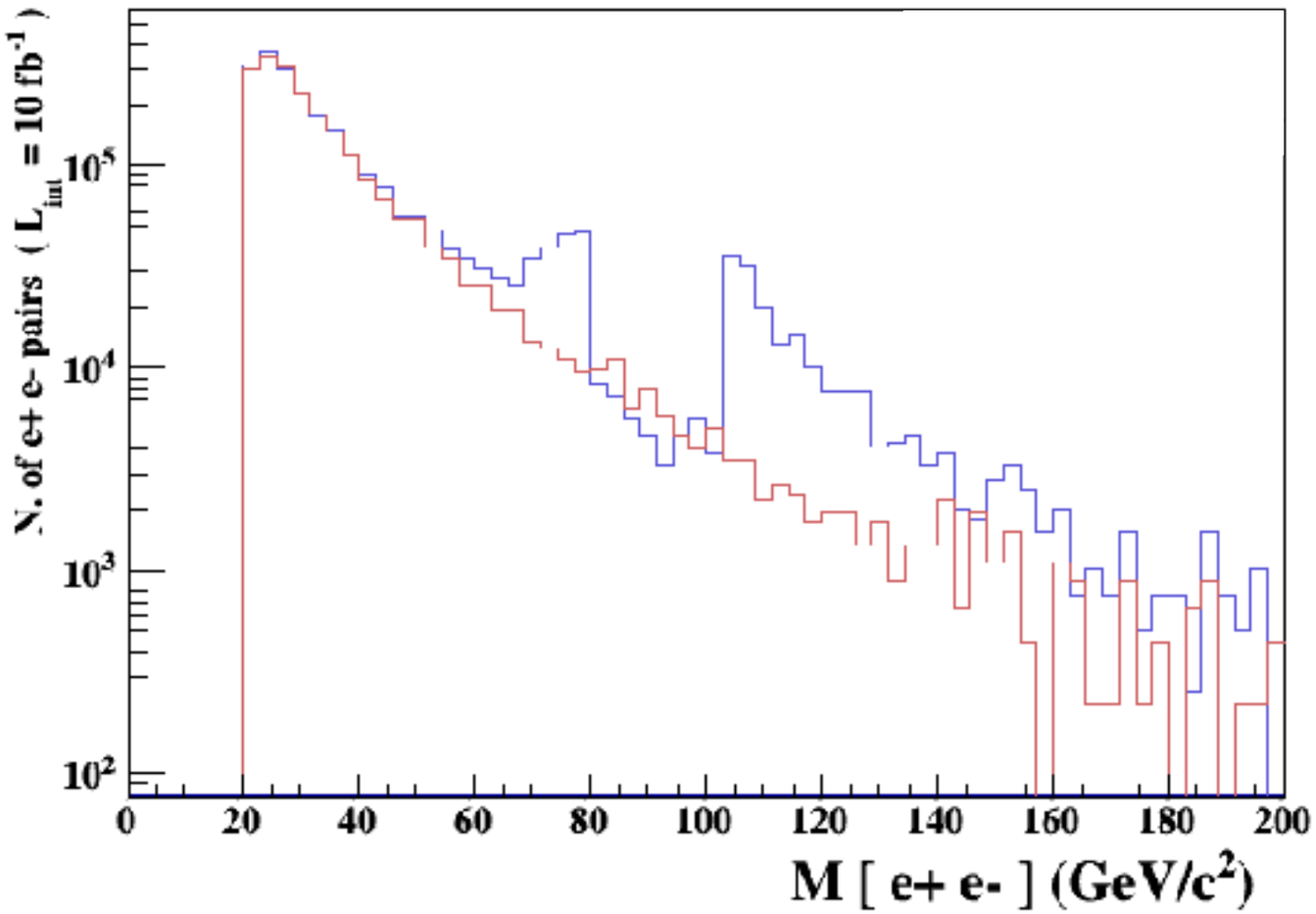
p p > e+ e- / Z (red curve)

(blue curve)



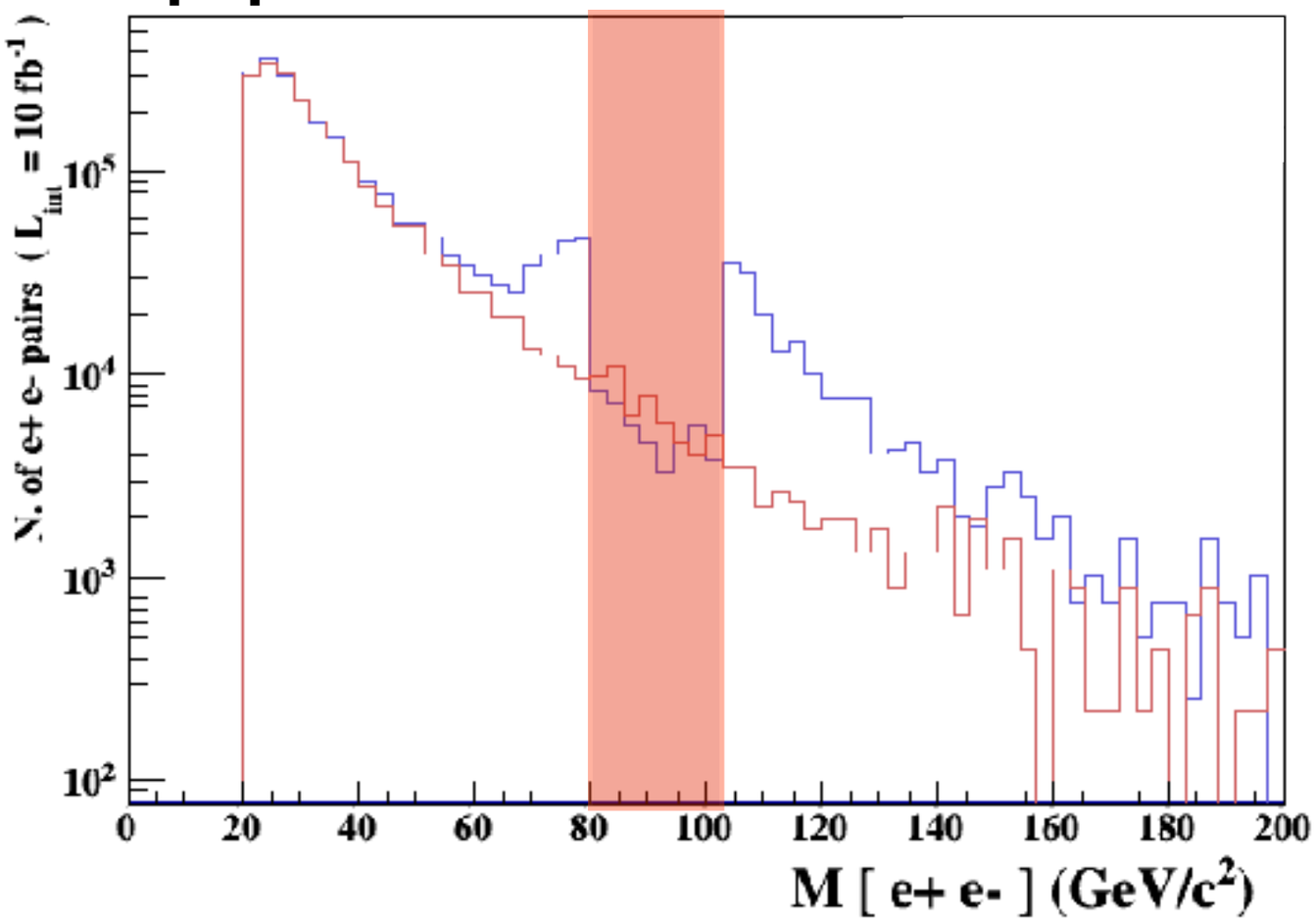
$ explanation

p p > e+ e- / Z (red curve) adding p p > e+ e- $ Z (blue curve)



$ explanation

p p > e+ e- / Z (red curve) adding p p > e+ e- $ Z (blue curve)



- Z onshell veto

5 times width area

$ explanation

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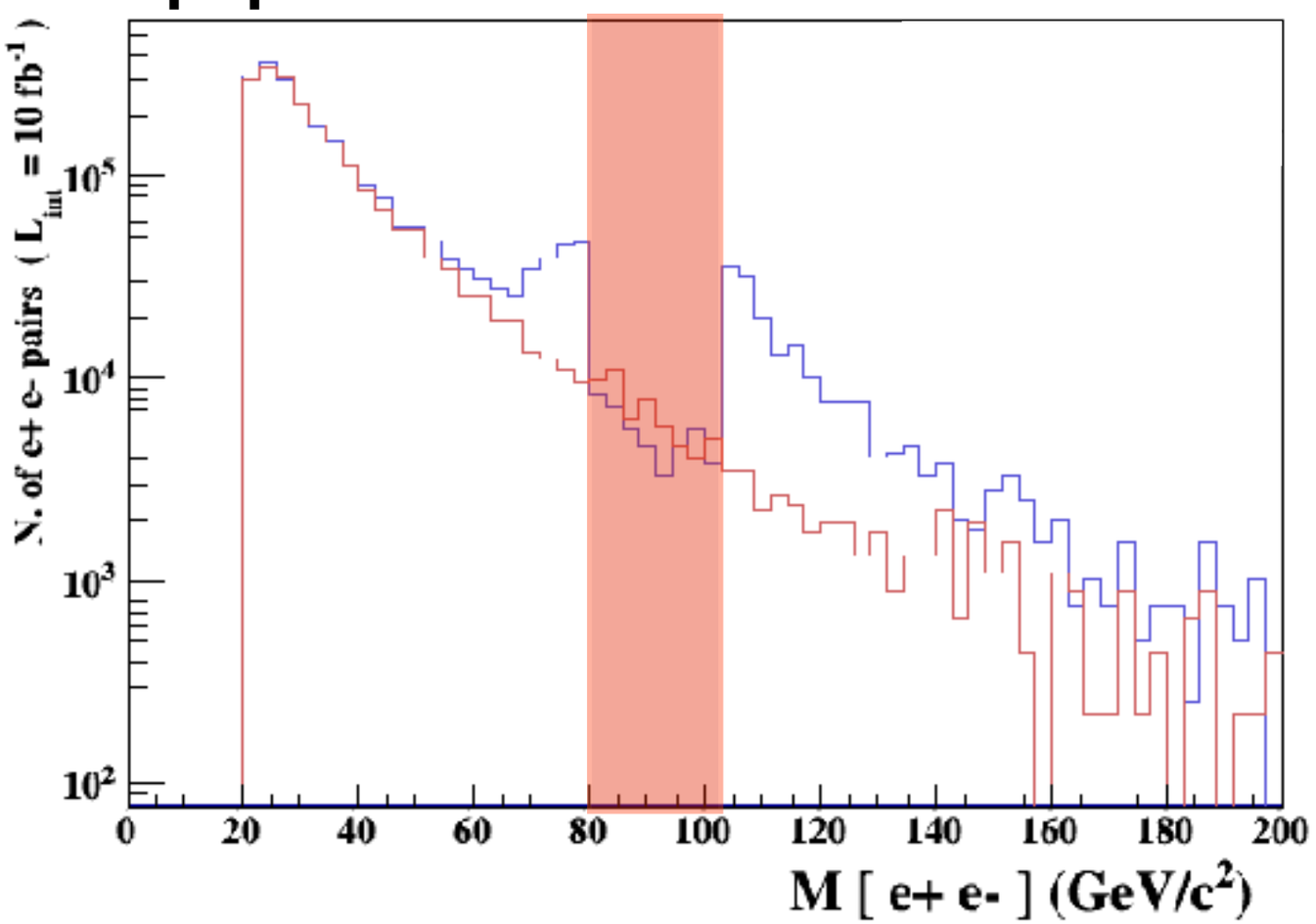

- Z onshell veto
- In veto area only photon contribution

5 times width area

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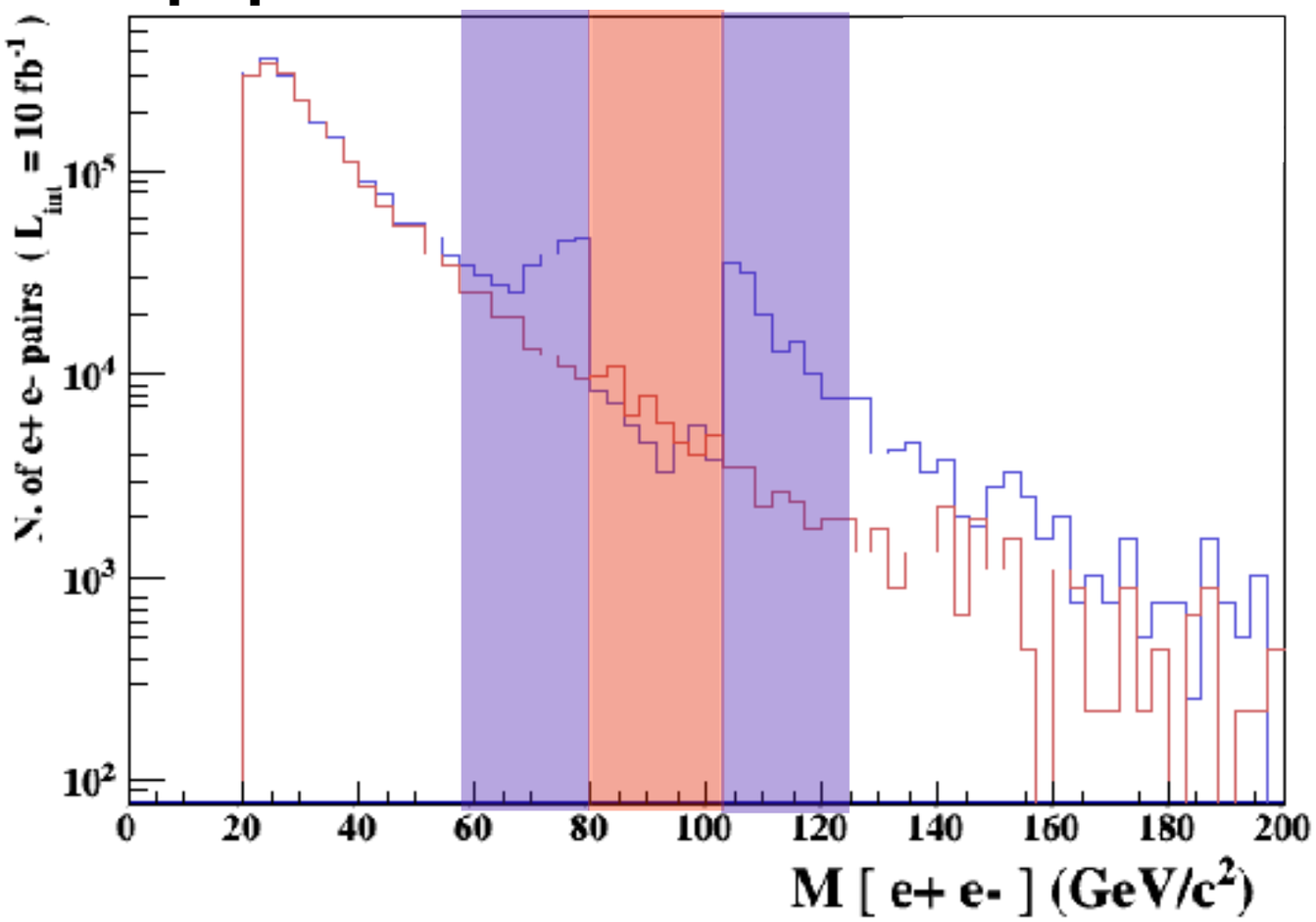


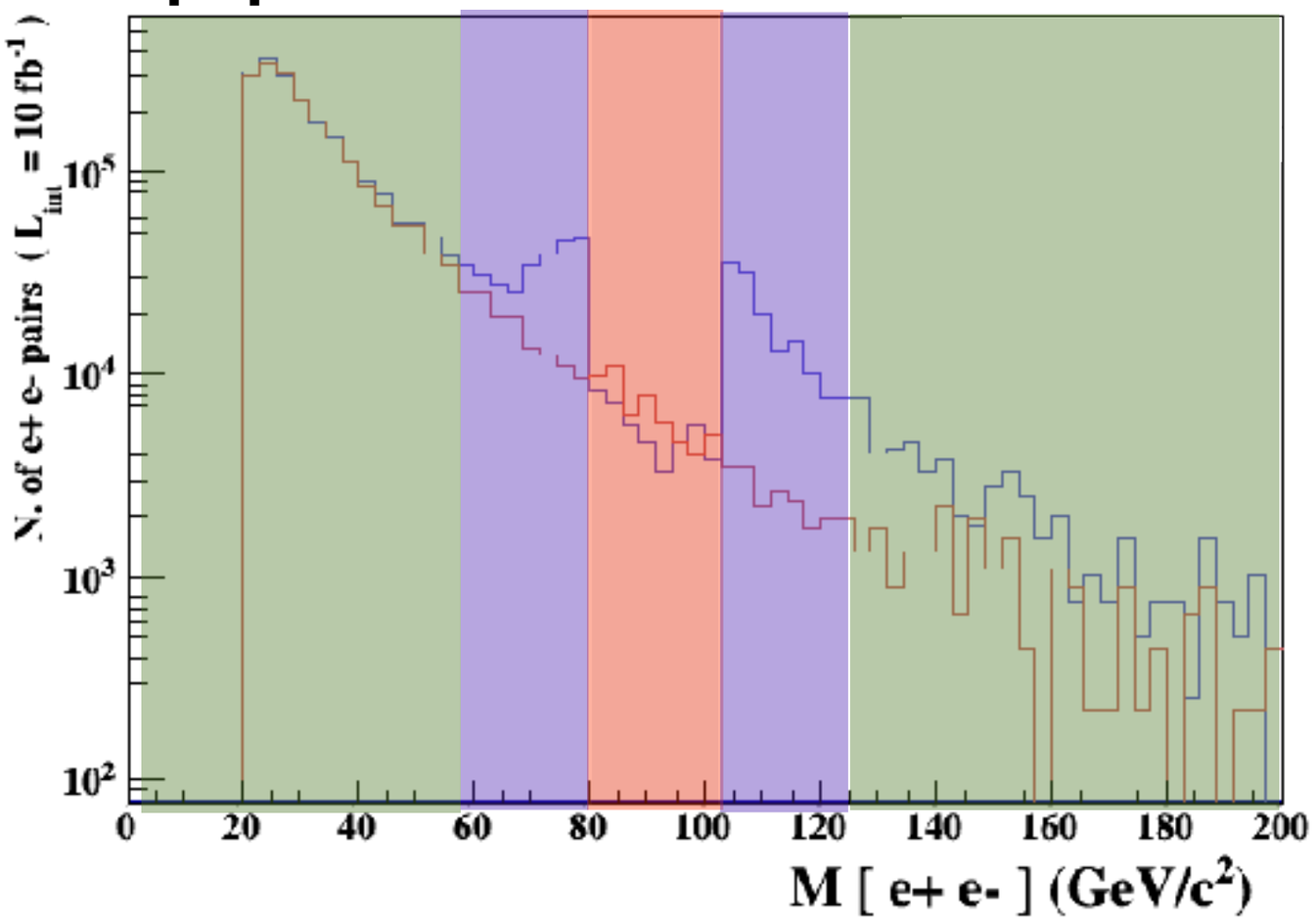
- Z onshell veto
- In veto area only photon contribution
- area sensitive to z-peak

5 times width area

15 times width area

$ explanation

p p > e+ e- / Z (red curve) adding p p > e+ e- $ Z (blue curve)



- Z onshell veto
- In veto area only photon contribution
- area sensitive to z-peak
- very off-shell Z, the difference between the curve is due to interference which are need to be KEPT in simulation.

5 times width area

15 times width area

>15 times width area

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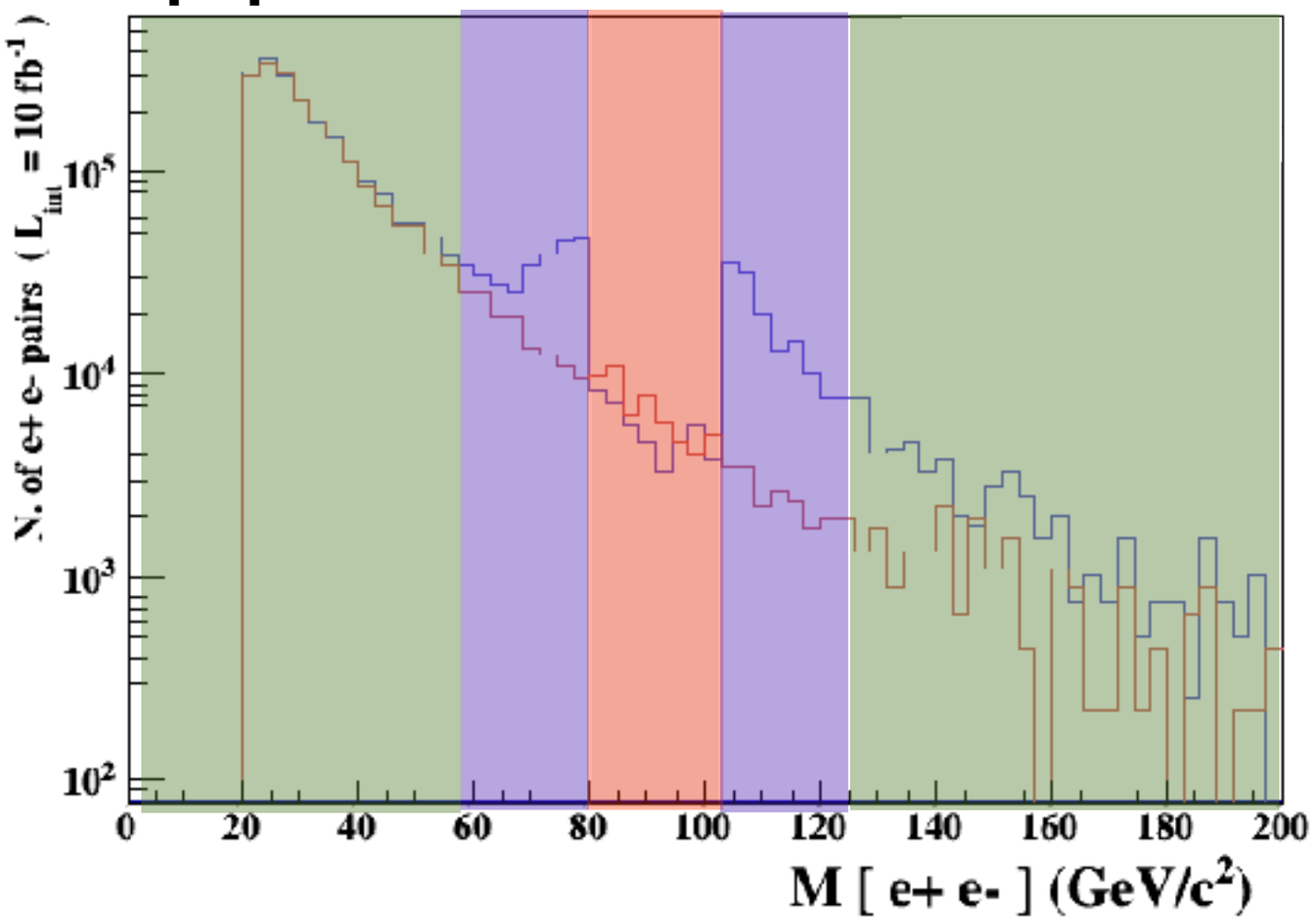

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- In veto area only photon contribution
- area sensitive to z-peak
- very off-shell Z, the difference between the curve is due to interference which are need to be KEPT in simulation.

5 times width area

15 times width area

>15 times width area

The "$" can be use to split the sample in BG/SG area

- Syntax Like
  - ➡ p p > z > e+ e- (ask one S-channel z)
  - ➡ p p > e+ e- / z (forbids any z)
  - ➡ p p > e+ e- $$ z (forbids any z in s-channel)
- ARE NOT GAUGE INVARIANT !
- forgets diagram interference.
- can provides un-physical distributions.

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Avoid Those as much as possible!

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- ARE NOT GAUGE INVARIANT !
  - forgets diagram interference.
  - can provides un-physical distributions.

Avoid Those as much as possible!

check physical meaning and gauge/Lorentz invariance if you do.

- Syntax like
  - p p > z, z > e+ e- (on-shell z decaying)
  - p p > e+ e- $ z (forbids s-channel z to be on-shell)

- Are linked to cut $|M^* - M| < BW_{cut} * \Gamma$
- Are more safer to use
- Prefer those syntax to the previous slides one

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 that 'WEIGHTED'?
  - > `display diagrams`
- No photon/z appear.
- Are we missing anything important?

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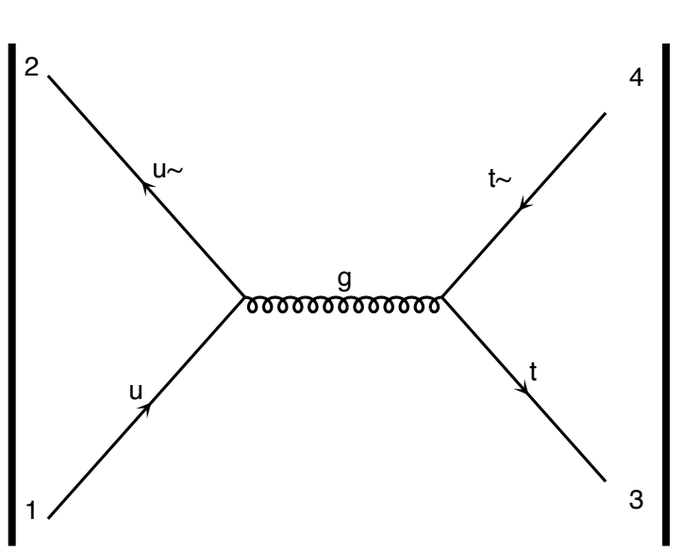
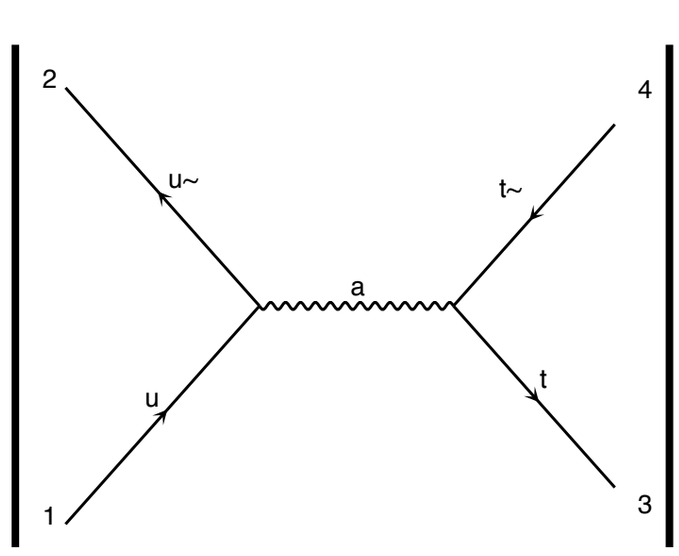


$$\left| \quad \right|^2 \sim \alpha_s^2$$



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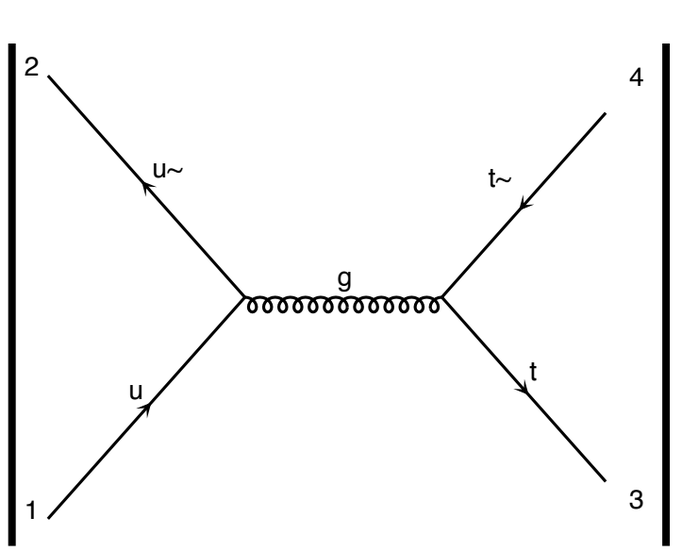
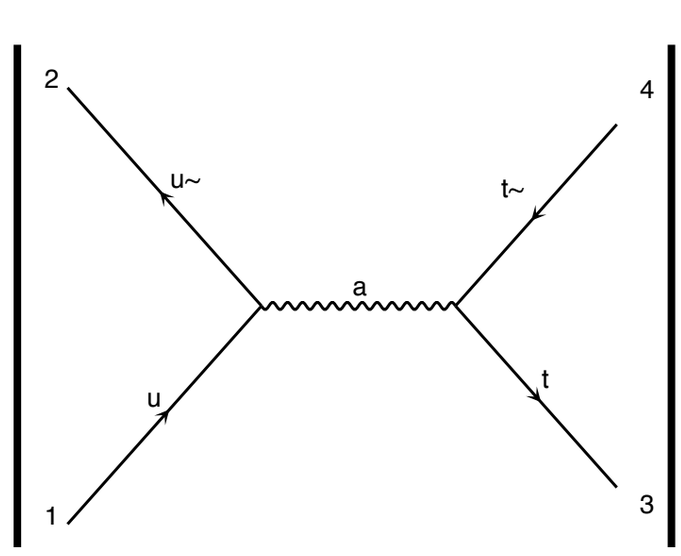


$$\sim \alpha_s^2$$



$$\sim \alpha_e^2 \, \frac{\alpha_e}{\alpha_s} \lesssim 0.1$$

Exercise 1:
Extra questions:

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  What is that 'WEIGHTED'?
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- 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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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`
  - > `output …`

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 …`

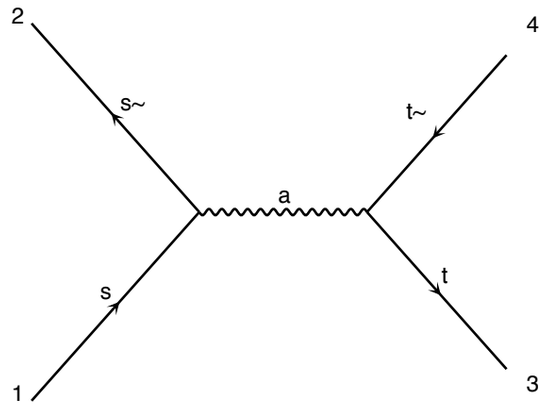

diagram 1 QCD=0, QED=2

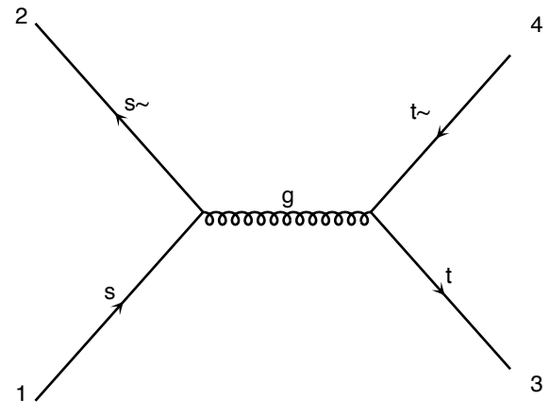

diagram 2 QCD=2, QED=0

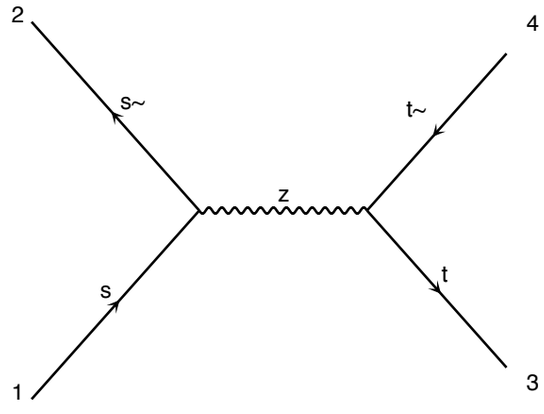

diagram 3 QCD=0, QED=2

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`
  - > …

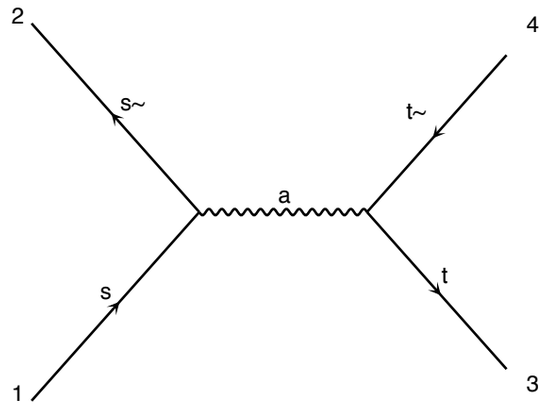

diagram 1 QCD=0, QED=2

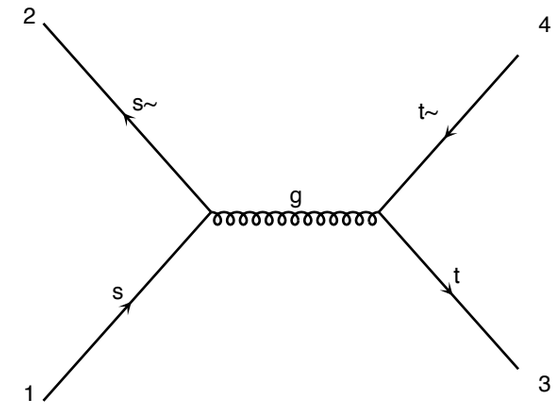

diagram 2 QCD=2, QED=0

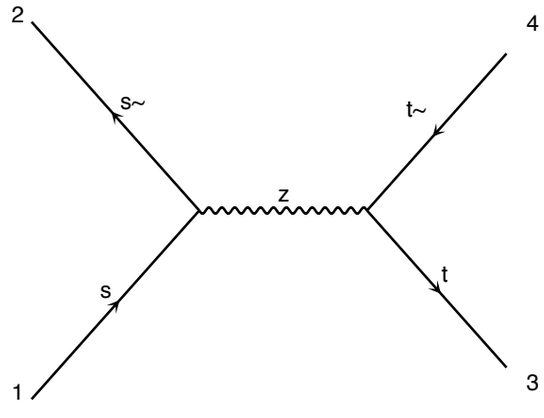

diagram 3 QCD=0, QED=2

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`
  - > …

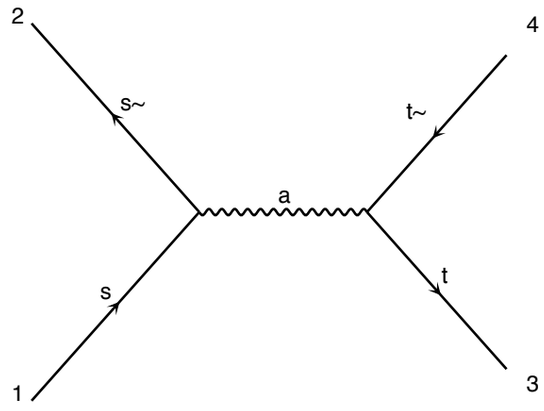

diagram 1 QCD=0, QED=2

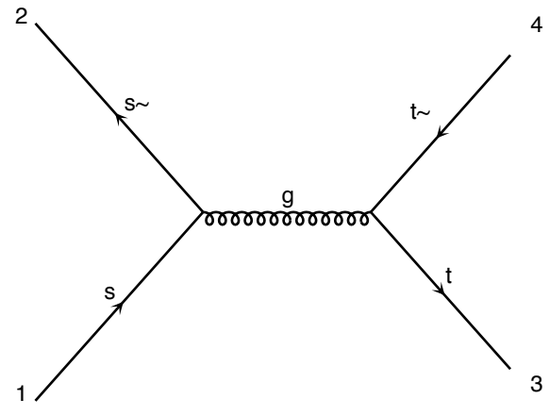

diagram 2 QCD=2, QED=0

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

WEIGHTED=2

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

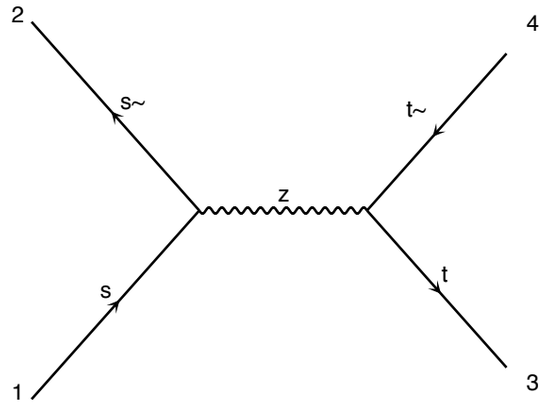

diagram 3 QCD=0, QED=2

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~

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
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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

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:

- Since recently, multiple values can be specified for parameters. Just set in the `param_card`, instead of the top mass

```
6 scan:[170,172,174,176,178]
```

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_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
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

Main Page

Add the decay

MadSpin

- generate p p > t t~

MadSpin Card

➡ decay t > w+ b, w+ > e+ ve

➡ decay t~ >w- b~, w- > e- ve~

MadGraph

- generate p p > t t~ h, (t > w+ b, w+ > e+ ve), (t~ >w- b~, w- > e- ve~)

By default cut does not apply to particle originated from an on shell decay

Mass-Scan (with decay)

- Generate p p > t t~, t > w+ b, t~ > w- b~
- Output
- Launch
- Set mt scan:range(170,181,2)

Scan

Available Results

Run	Collider	Banner	Cross section (pb)	Events	Data	Output	Action
run_01	p p 6500.0 x 6500.0 GeV	tag_1	462.6 ± 0.72 ± systematics	10000	parton madevent	LHE plots	remove run launch detector simulation
run_02	p p 6500.0 x 6500.0 GeV	tag_1	476.2 ± 0.72 ± systematics	10000	parton madevent	LHE plots	remove run launch detector simulation
run_03	p p 6500.0 x 6500.0 GeV	tag_1	488.2 ± 0.86 ± systematics	10000	parton madevent	LHE plots	remove run launch detector simulation
run_04	p p 6500.0 x 6500.0 GeV	tag_1	502.5 ± 0.8 ± systematics	10000	parton madevent	LHE plots	remove run launch detector simulation
run_05	p p 6500.0 x 6500.0 GeV	tag_1	514 ± 0.78 ± systematics	10000	parton madevent	LHE plots	remove run launch detector simulation
run_06	p p 6500.0 x 6500.0 GeV	tag_1	528.6 ± 0.87 ± systematics	10000	parton madevent	LHE plots	remove run launch detector simulation

Main Page

- What's wrong?
  - ➡ Why the cross-section increase?

Mass-Scan (with decay)

- The width was not updated. Let's fix it:
  - ➡Generate p p > t t~, t > w+ b, t~ > w- b~
  - ➡Output
  - ➡Launch
  - ➡Set mt scan:range(170,181,2)
  - ➡Set wt auto

- With the LO width

run_07	p p 6500.0 x 6500.0 GeV	tag_1	524.4 ± 0.89 ± systematics	10000	parton madevent	LHE plots	remove run launch detector simulation
run_08	p p 6500.0 x 6500.0 GeV	tag_1	496.6 ± 0.9 ± systematics	10000	parton madevent	LHE plots	remove run launch detector simulation
run_09	p p 6500.0 x 6500.0 GeV	tag_1	468.5 ± 0.79 ± systematics	10000	parton madevent	LHE plots	remove run launch detector simulation
run_10	p p 6500.0 x 6500.0 GeV	tag_1	446 ± 0.79 ± systematics	10000	parton madevent	LHE plots	remove run launch detector simulation
run_11	p p 6500.0 x 6500.0 GeV	tag_1	421.8 ± 0.81 ± systematics	10000	parton madevent	LHE plots	remove run launch detector simulation
run_12	p p 6500.0 x 6500.0 GeV	tag_1	400.3 ± 0.63 ± systematics	10000	parton madevent	LHE plots	remove run launch detector simulation

Main Page