

# TUTORIAL ON MADGRAPH5\_AMC@NLO:

## BASIC USAGES

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# INSTALL MADGRAPH 5



- Preinstall requirements *(you should receive an email before)*:
  - Unix system (Linux or Mac OS). For windows user, try a virtual machine
  - gcc and gfortran (version  $\geq 4.6$  and not 8.X)
  - python (version  $\geq 2.6$  and  $< 3.0$ )
- <https://launchpad.net/mg5amcnlo>
- untar it (`tar -zxvf MG5_aMC_v2.6.X.X.tar.gz`)
- launch it ( `$ ./bin/mg5_aMC` )
- learn it from tutorial !
  - ➔ Type **tutorial** and follow instructions

# INSTALL MADGRAPH 5



MadGraph5\_aMC@NLO In Launchpad

OS X Updates Available  
Your computer will restart to complete these updates.

Canonical Group Ltd launchpad.net/mg5amcnlo

Code : MadG...core2" team Itinéraires ... tramway bus 海外申請护照在线预约 EPS The 8th Wor...nuary 2015) Certificate ...FAQ < TWiki Text to ASCI...ator (TAAG) CERN Market - Category

MadGraph5\_aMC@NLO In Launchpad

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## 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, and 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](http://amcatnlo.web.cern.ch/amcatnlo/list_refs.htm)

Download:

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Downloads

Latest version is 2.6.x

- MG5\_aMC\_v2.6.4.tar.gz
- MG5\_aMC\_v2.6.3.2.tar.gz
- MG5\_aMC\_v3....beta.tar.gz

released on 2017-08-15

# FIND HELP ?



- Ask us (tutors and/or authors) or your experienced friends
- Use the command “**help**” or “**help XXX**”
  - ➔ “**help**” will guide you what to do next.
- From Launchpad:
  - ➔ First check: <https://answers.launchpad.net/mg5amcnlo/+faq>
  - ➔ Submit Q: <https://answers.launchpad.net/mg5amcnlo>

- My first example:

```
./bin/mg5_aMC  
> generate p p > t t~  
> output MyExample  
> exit  
cd MyExample/Cards
```

- Read the cards and understand what they are
  - ➔ **param\_card.dat**: model parameters
  - ➔ **run\_card.dat**: run parameters and kinematical cuts

Detail explanations: <https://answers.launchpad.net/mg5amcnlo/+faq/2014>

# EXERCISE: INPUTS



- Please change the following inputs
  - *top quark mass*
  - *top quark width*
  - *W boson mass*
  - *beam energy*
  - *number of events*
  - *min pt cut of the charged leptons*
  - *number of quark flavors in a jet*



# EXERCISES: GENERATION SYNTAX



- What's the meaning of the coupling order QED/QCD
- What's the difference between

```
> generate p p > t t~
```

```
> generate p p > t t~ QED=2
```

```
> generate p p > t t~ QED=0
```

```
> generate p p > z a > t t~
```

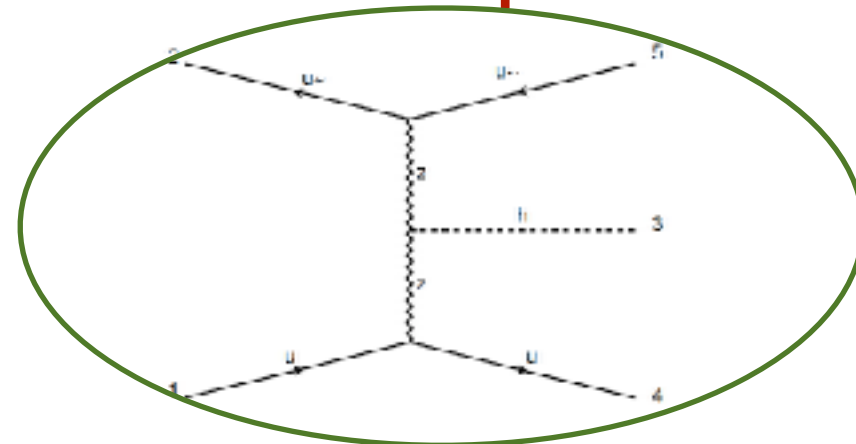
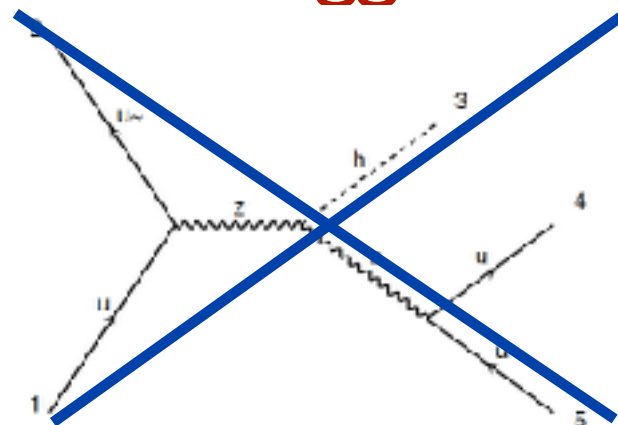
```
> generate p p > t t~ QCD=0
```

```
> generate p p > t t~ QCD<=2
```

```
> generate p p > t t~ QCD^2==2
```

```
> generate p p > t t~ $$ z QED=2
```

- Hint: Use 'display diagrams' to see the generated Feynman diagrams
- Compute the cross-section for each of them !
- Generate a Higgs from vector-boson fusion process



# EXERCISES: PLOT DISTRIBUTIONS



- Generate the invariant mass distribution for

```
> generate p p > e+ e-
```

```
> generate p p > z, z > e+ e-
```

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

```
> generate p p > e+ e- / z
```

- **Hint:** If you have installed MadAnalysis5 via ‘**install MadAnalysis5**’, you can find a few predefined plots in MA5\_report\_analysis I.
- Edit the **madanalysis5\_parton\_card.dat** to refine the bins.
- Understand the meaning from the invariant mass distribution



# EXERCISE SOLUTION: INPUTS



```
#####
# PARAM_CARD AUTOMATICALLY GENERATED BY MG5 FOLLOWING UFO MODEL  ###
#####
#
# Width set on Auto will be computed following the information
# present in the decay.py files of the model.
# See arXiv:1402.1178 for more details.
#
#####
#####
# INFORMATION FOR MASS
#####
Block mass
  5 4.700000e+02 # MT
  6 1.730000e+02 # MT
 15 1.777000e+02 # MTA
 23 9.118000e+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)))
#####
# INFORMATION FOR SMINPUTS
#####
Block sminputs
 1 1.325070e+02 # aEWM1
 2 1.166390e-05 # Gf
 3 1.180000e-01 # alphaS
#####
# INFORMATION FOR YUKAWA
#####
Block yukawa
 5 4.700000e+02 # ymb
 6 1.730000e+02 # ymt
15 1.777000e+02 # ymtau
#####
# INFORMATION FOR DECAY
#####
DECAY  6 1.491500e+00 # WT
DECAY 23 2.441404e+00 # WZ
DECAY 24 2.047500e+00 # WW
DECAY 25 6.382339e-03 # WH
# Dependent parameters, given by model restrictions.
# Those values should be edited following the
# analytical expression. MG5 ignores those values
```

**top quark mass**

**W boson mass**

Not allowed to change independently !  
Change MZ, aEWM1, Gf.

**top quark width**

# EXERCISE SOLUTION: INPUTS



```
#
# ModGraph5_aMCENLO Nov 19 01:32:32 on ttys003
#
# Hua-Shengs-MacBook-Pro:~ huasheng$ ls
# Desktop Documents Downloads Library Music Physics Pictures
#
# This file is used to set the parameters of the run.
#
# Some notation/conventions:
#
# Lines starting with a '#' are info or comments
#
# mind the format: #value = variable !comment
#
# To display more options, you can type the command:
# update full_run_card
#
#*****
#
#*****
# Some notation/conventions:
#
# Running parameters
#*****
#
# Lines starting with a '#' are info or comments
#
#*****
#
# Tag name for the run (one word)
#*****
#
# tag_1 = run_tag ! name of the run _run_card
#*****
#
# 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 = lseed ! 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
#*****
#
# Param Card
#
# 1 = lpp1 ! beam 1 type
#
# 1 = lpp2 ! beam 2 type
#
# 6500.0 = ebeam1 ! beam 1 total energy in GeV
#
# 6500.0 = ebeam2 ! beam 2 total energy in GeV
```

*number of events*

*beam energy*



# EXERCISE SOLUTION: INPUTS



```
#
# ModGraph5_aMCENLO Nov 19 01:32:32 on ttys003
#
# Hua-Sheng-MacBook-Pro:~ huasheng$ ls
# Desktop Documents Library Physics Pictures
#
# This file is used to set the parameters of the run.
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#
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# mind the format: # value = variable #! comment
#
# To display more options, you can type the command:
# update_full_run_card
#
#*****
# Some notation/conventions:
#
# Running parameters
#*****
# Lines starting with a '#' are info or comments
#
#*****
# Tag name for the run (one word)
#*****
tag_1 = run_tag ! name of the run _run_card
#*****
# 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 = lseed ! 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
6500.0 = ebeam1 ! beam 1 total energy in GeV
6500.0 = ebeam2 ! beam 2 total energy in GeV

#*****
# Standard Cuts
#*****
# Minimum and maximum pt's (for max, -1 means no cut)
#*****
20.0 = ptj ! minimum pt for the jets
0.0 = ptb ! minimum pt for the b
10.0 = pta ! minimum pt for the photons
10.0 = ptl ! minimum pt for the charged leptons
0. = miset ! minimum missing Et (sum of neutrino's momenta)
-1.0 = ptjmax ! maximum pt for the jets
-1.0 = ptbmax ! maximum pt for the b
-1.0 = ptamax ! maximum pt for the photons
-1.0 = ptlmax ! maximum pt for the charged leptons
-1.0 = misetmax ! maximum missing Et (sum of neutrino's momenta)
{} = pt_min_pdg ! pt cut for other particles (use pdg code). Applied on particle and anti-particle
{} = pt_max_pdg ! pt cut for other particles (syntax e.g. {6: 100, 25: 50})
```

*min pt cut of the charged leptons*

# EXERCISE SOLUTION: INPUTS



```
#
# ModGraph5_mCENLO Nov 19 01:32:32 on ttys003
#
# Hua-Sheng-MacBook-Pro:~ huasheng$ ls
# Desktop Downloads Dropbox Music
# Documents Library Physics
# This file is used to set the parameters of the run. Pictures
#
# Some notation/conventions:
#
# Lines starting with a '#' are info or comments
#
# mind the format: # value = variable #! comment MCBENLO
#
# To display more options, you can type the command:
# update full_run_card
#
#*****
# Some notation/conventions:
#
# Running parameters
#*****
# Lines starting with a '#' are info or comments
#
#*****
# Tag name for the run (one word)
#*****
tag_1 = run_tag ! name of the run _run_card
#*****
# 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 = lseed ! 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
6500.0 = ebeam1 ! beam 1 total energy in GeV
6500.0 = ebeam2 ! beam 2 total energy in GeV
```

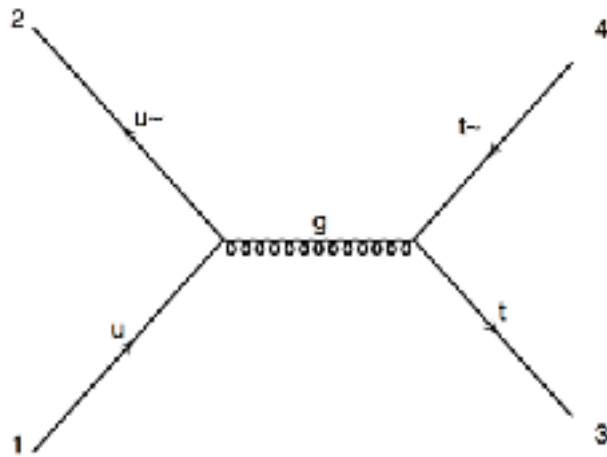
```
#*****
# Standard Cuts
#*****
# Minimum and maximum pt's (for max, -1 means no cut)
#*****
20.0 = ptj ! minimum pt for the jets
0.0 = ptb ! minimum pt for the b
10.0 = pta ! minimum pt for the photons
10.0 = ptl ! minimum pt for the charged leptons
0.0 = miset ! minimum missing Et (sum of neutrino's momenta)
-1.0 = ptjmax ! maximum pt for the jets
-1.0 = ptbmax ! maximum pt for the b
-1.0 = ptamax ! maximum pt for the photons
-1.0 = ptlmax ! maximum pt for the charged leptons
-1.0 = misetmax ! maximum missing Et (sum of neutrino's momenta)
{} = pt_min_pdg ! pt cut for other particles (use pdg code). Applied on particle and anti-particle
{} = pt_max_pdg ! pt cut for other particles (syntax e.g. {6: 100, 25: 50})
#*****
# maximal pdg code for quark to be considered as a light jet
# (otherwise b cuts are applied)
#*****
4 = maxjetflavor ! Maximum jet pdg code
```

*number of quark flavors in a jet*

# EXERCISE SOLUTION: GENERATION



- What's the meaning of the coupling order **QED/QCD**
  - ➔ By default, MG5 will guess the lowest order in **QED**
  - ➔ `> generate p p > t t~` = `> generate p p > t t~ QED=0`

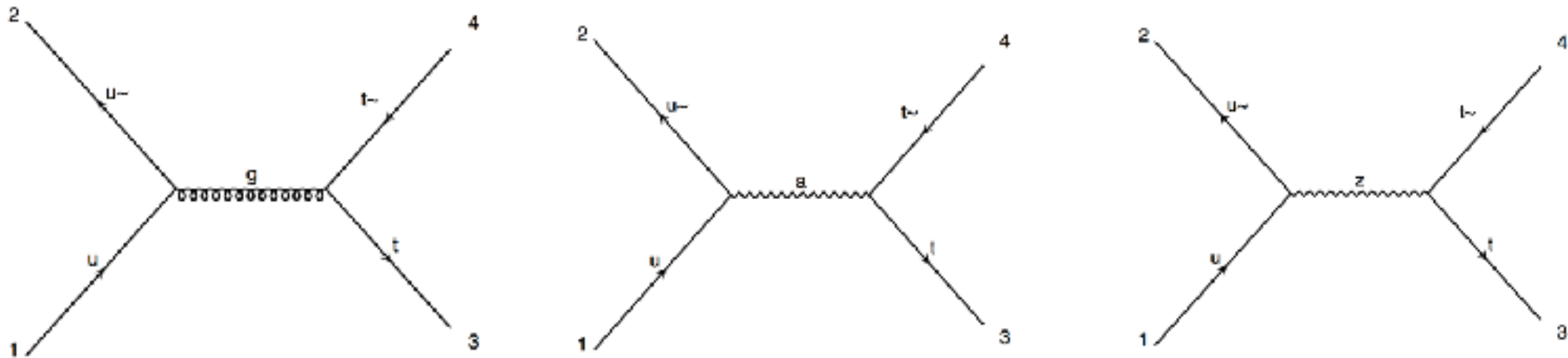




# EXERCISE SOLUTION: GENERATION



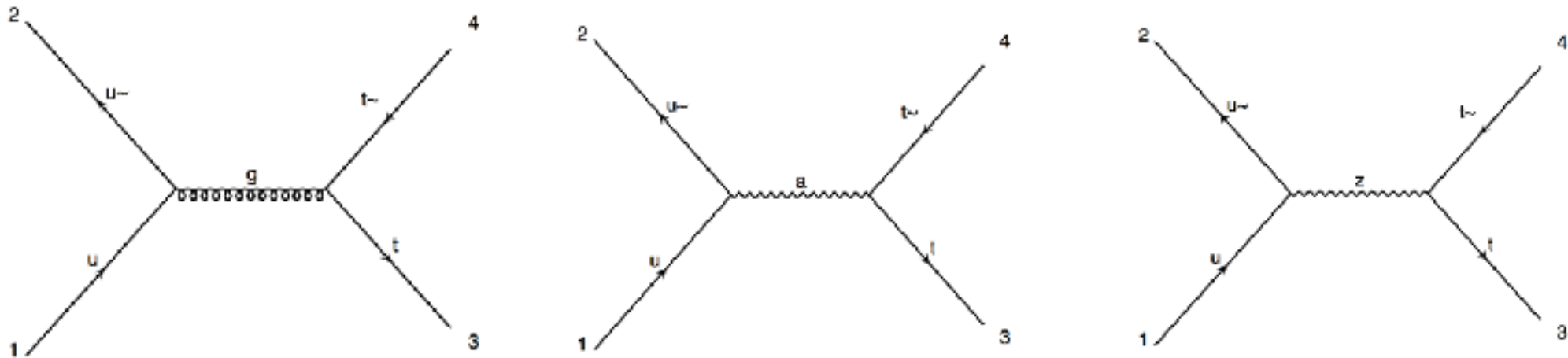
- What's the meaning of the coupling order **QED/QCD**
  - ➔ By default, MG5 will guess the lowest order in **QED**
  - ➔ `> generate p p > t t~` = `> generate p p > t t~ QED=0`
  - ➔ `> generate p p > t t~ QED=2`



# EXERCISE SOLUTION: GENERATION



- What's the meaning of the coupling order **QED/QCD**
  - ➔ By default, MG5 will guess the lowest order in **QED**
  - ➔ `> generate p p > t t~` = `> generate p p > t t~ QED=0`
  - ➔ `> generate p p > t t~ QED=2`



**Results in the sm for  $p p \rightarrow t \bar{t}$**

Run	Collider	Banner	Cross section (pb)
run_01	P P 6500.0 x 6500.0 GeV	<a href="#">tag_1</a>	<a href="#">505.7 ± 0.79</a>

**Results in the sm for  $p p \rightarrow t \bar{t}$  QED=2**

Run	Collider	Banner	Cross section (pb)
run_01	P P 6500.0 x 6500.0 GeV	<a href="#">tag_1</a>	<a href="#">505.8 ± 0.93</a>



# EXERCISE SOLUTION: GENERATION

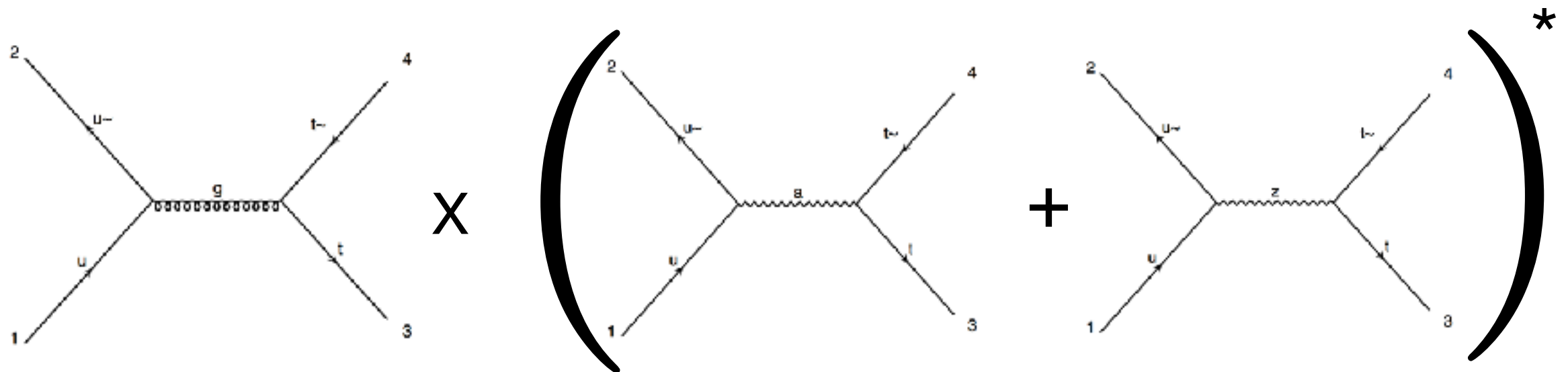


- What's the meaning of the coupling order QED/QCD

➡ 'QED $\leq$ 2' is the same as 'QED=2'

➡ `> generate p p > t t~ QCD^2==2`

- Returns the interference between the QCD and QED diagrams

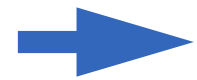


*Zero in this case due to the colour !*

# EXERCISE SOLUTION: GENERATION



- Generate a Higgs from vector-boson fusion process



```
> generate p p > h j j $$ w+ w- z a
```

- '\$\$' excludes diagrams with the particles in s-channel

# EXERCISES: PLOT DISTRIBUTIONS



- Generate the invariant mass distribution for  
➔ Refine the bins in `madanalysis5_parton_card.dat`

```
# Uncomment the line below to skip this analysis altogether
# @MG5aMC skip_analysis

@MG5aMC stdout_lvl=INFO

@MG5aMC inputs = *.lhe
@MG5aMC analysis_name = analysis1

# Multiparticle definition
define vl = 12 14 16
define vl~ = -16 -14 -12
define invisible = ve ve~ vm vm~ vt vt~ vl vl~

# Histogram drawer (options: matplotlib or root)
set main.graphic_render = matplotlib

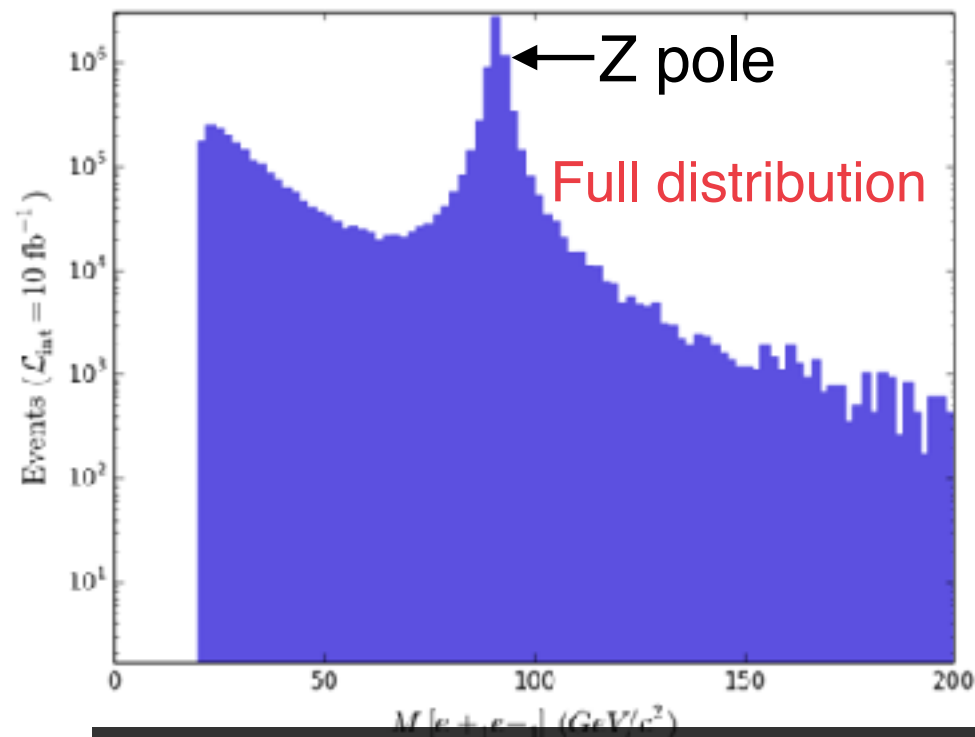
# Global event variables
plot THT 40 0 500 [logY]
plot MET 40 0 500 [logY]
plot SQRTS 40 0 500 [logY]
# PT and ETA distributions of all particles
plot PT(e-[1]) 40 0 500 [logY]
plot ETA(e-[1]) 40 -10 10 [logY]
plot PT(e+[1]) 40 0 500 [logY]
plot ETA(e+[1]) 40 -10 10 [logY]
# Invariant-mass distributions
plot M(e-[1],e+[1]) 40 0 500 [logY]
# Angular distance distributions
plot DELTAR(e-[1],e+[1]) 40 0 10 [logY]
```

*Invariant mass of the lepton pair*

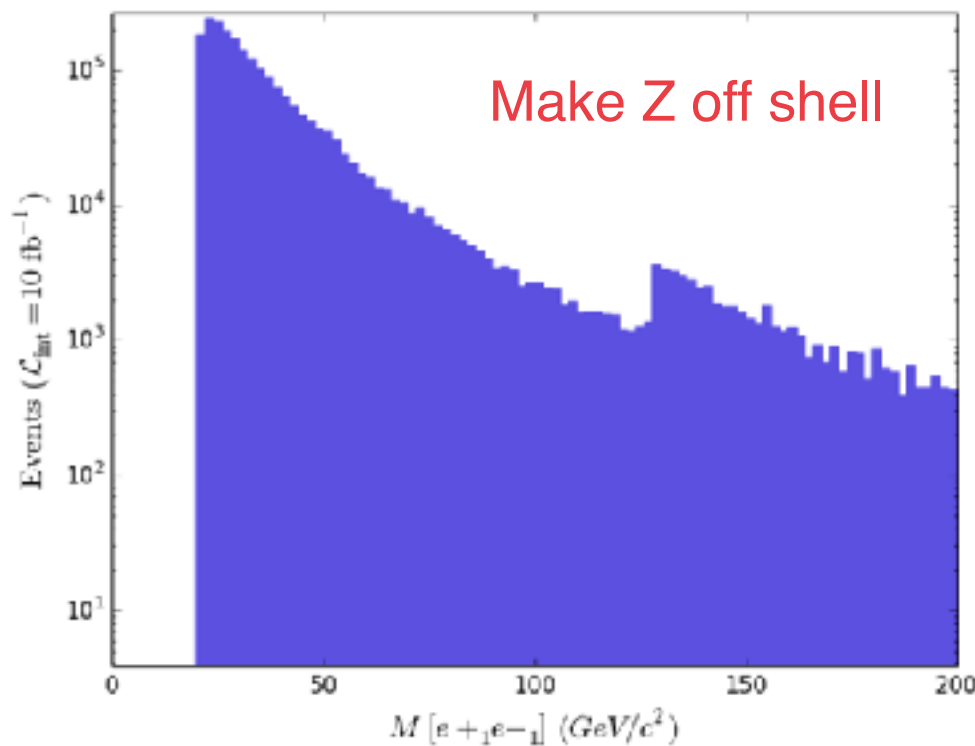
# EXERCISES: PLOT DISTRIBUTIONS



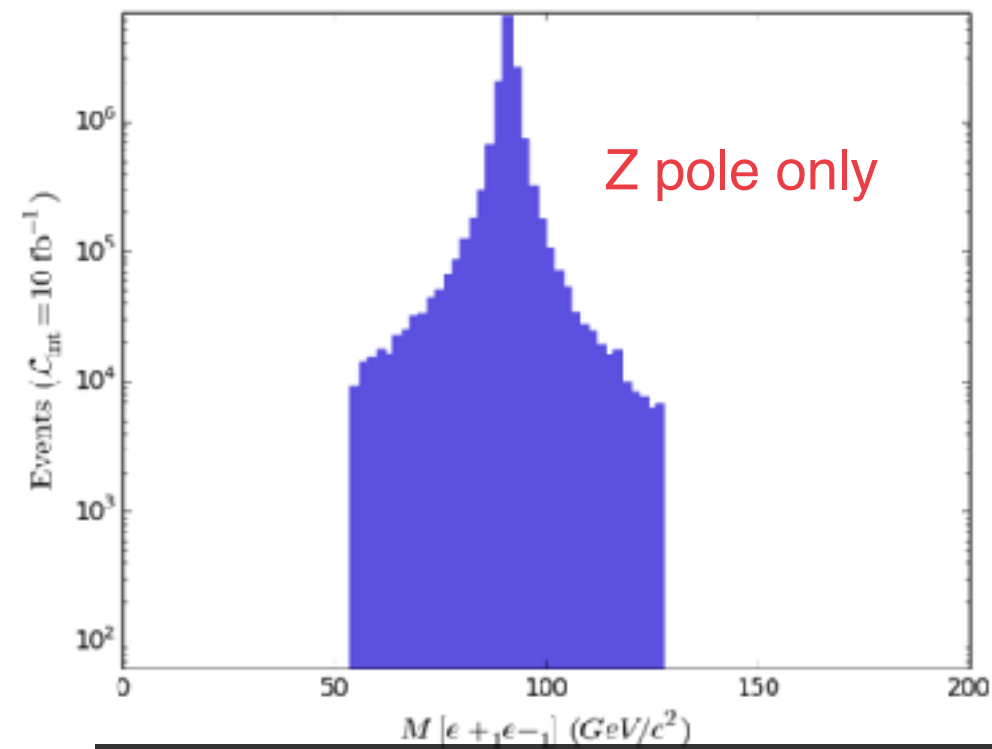
```
> generate p p > e+ e-
```



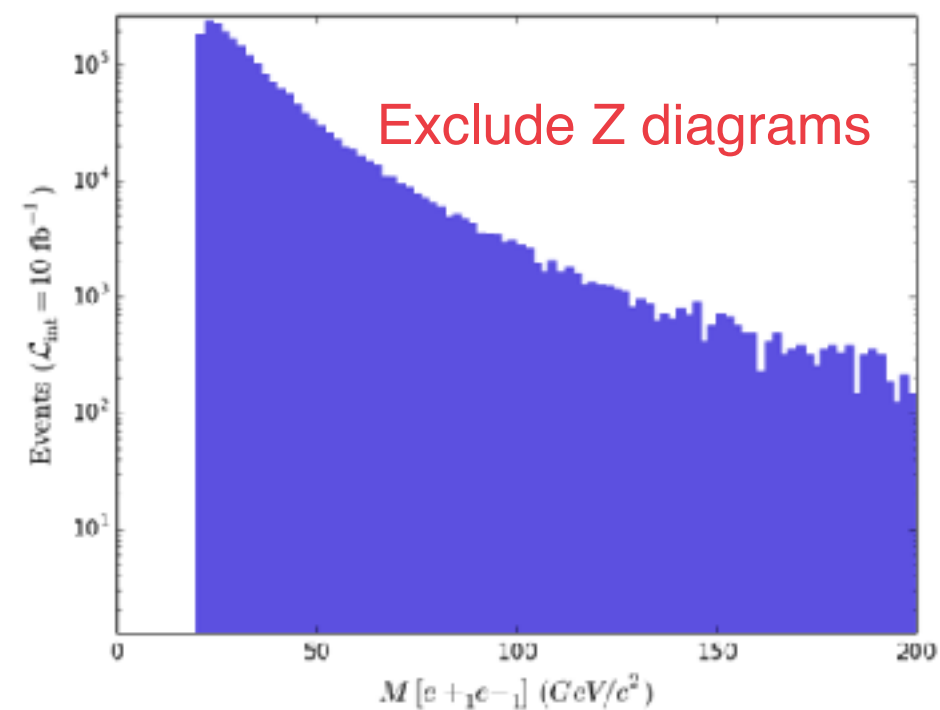
```
> generate p p > e+ e- $ z
```



```
> generate p p > z, z > e+ e-
```



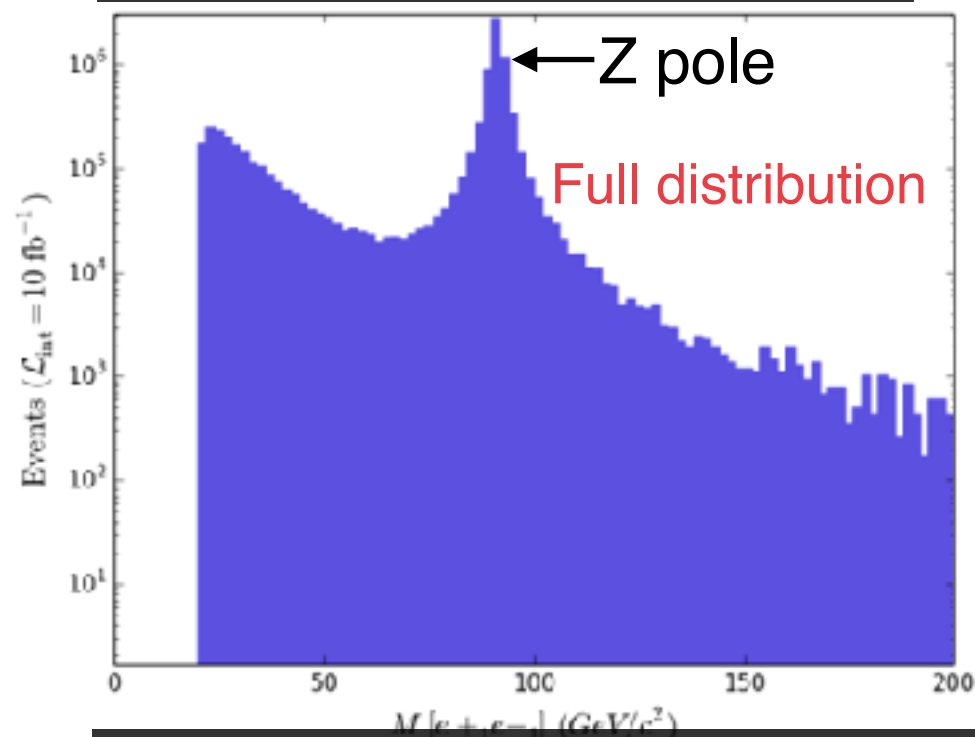
```
> generate p p > e+ e- / z
```



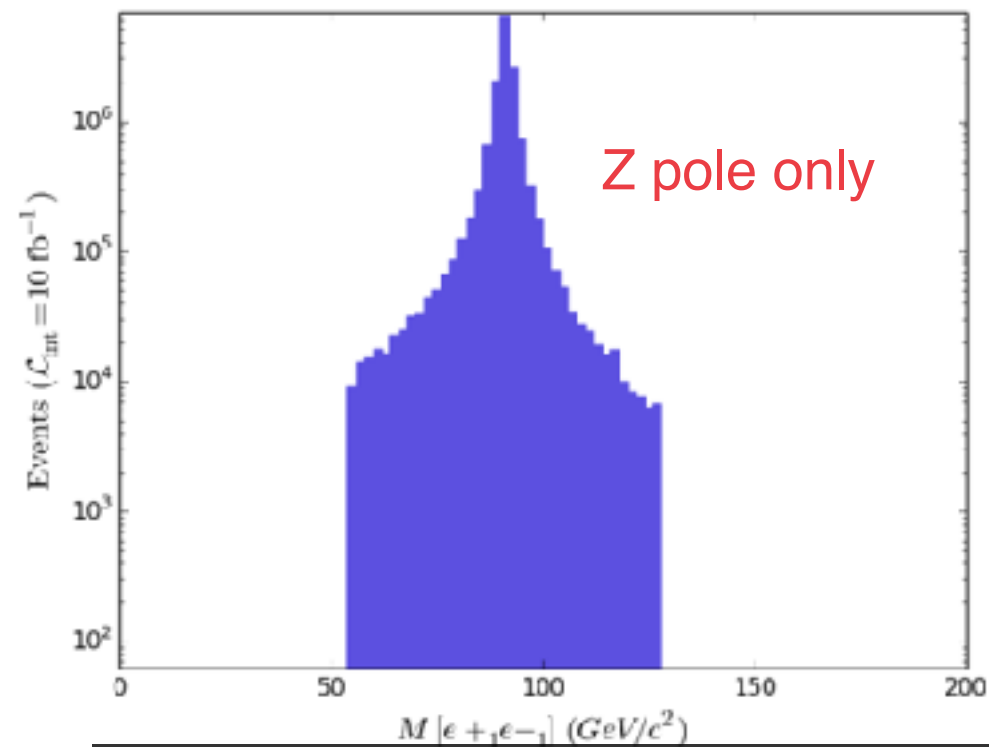
# EXERCISES: PLOT DISTRIBUTIONS



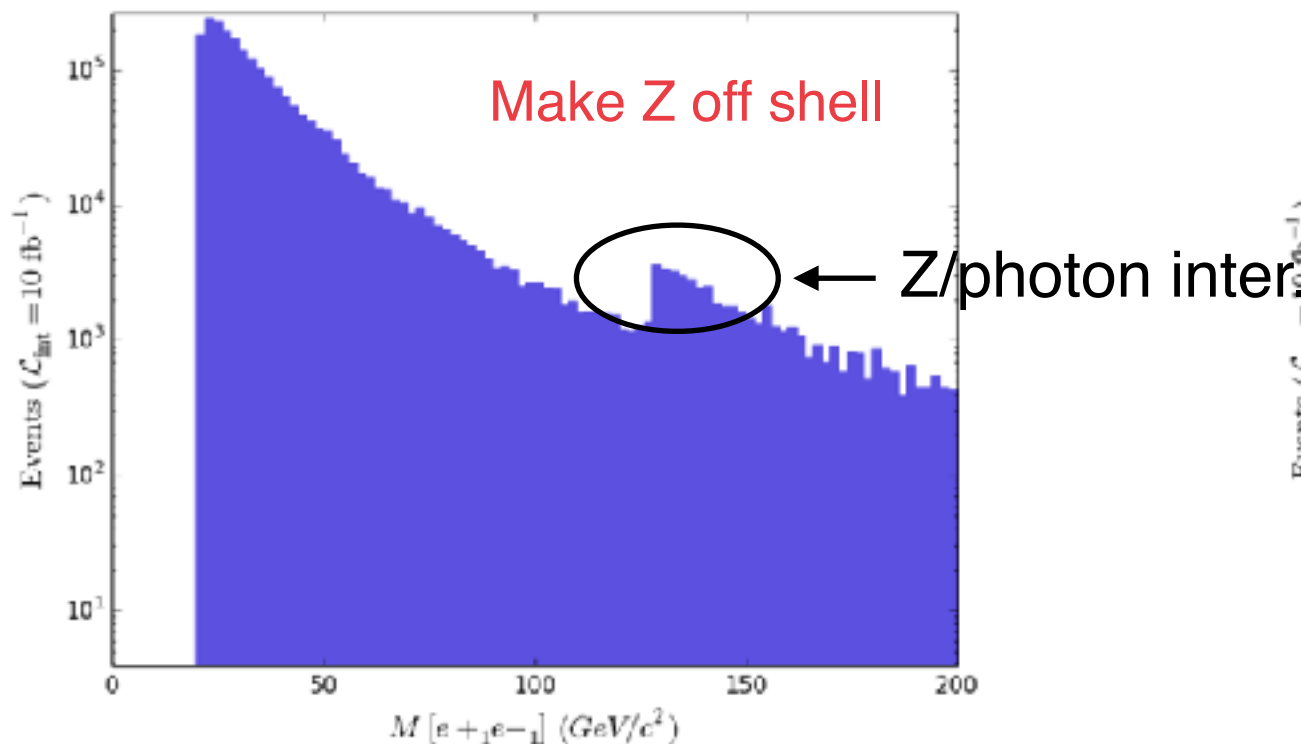
```
> generate p p > e+ e-
```



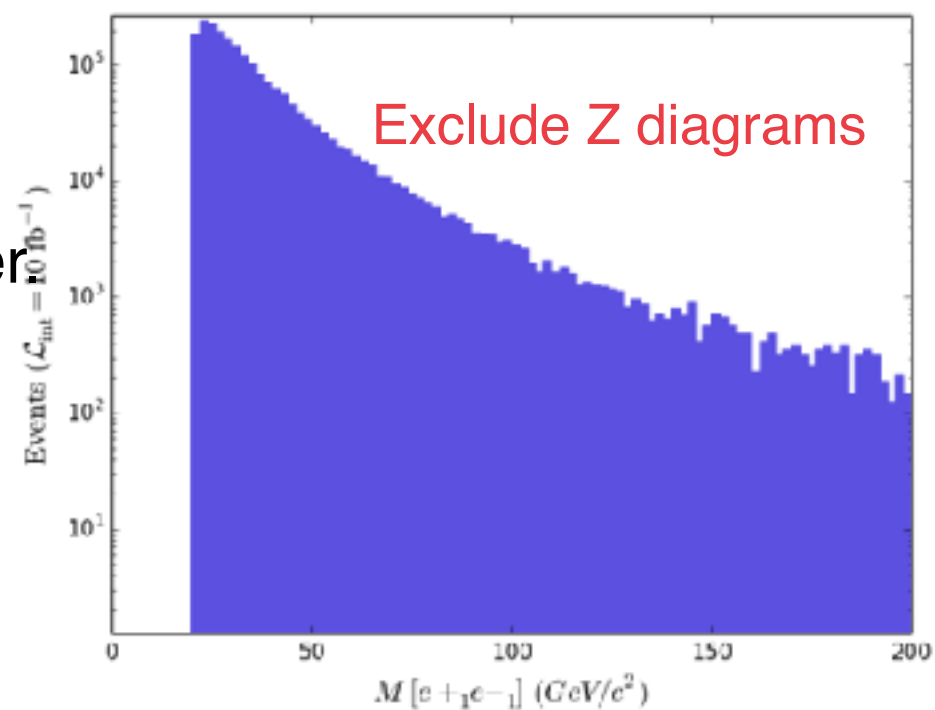
```
> generate p p > z, z > e+ e-
```



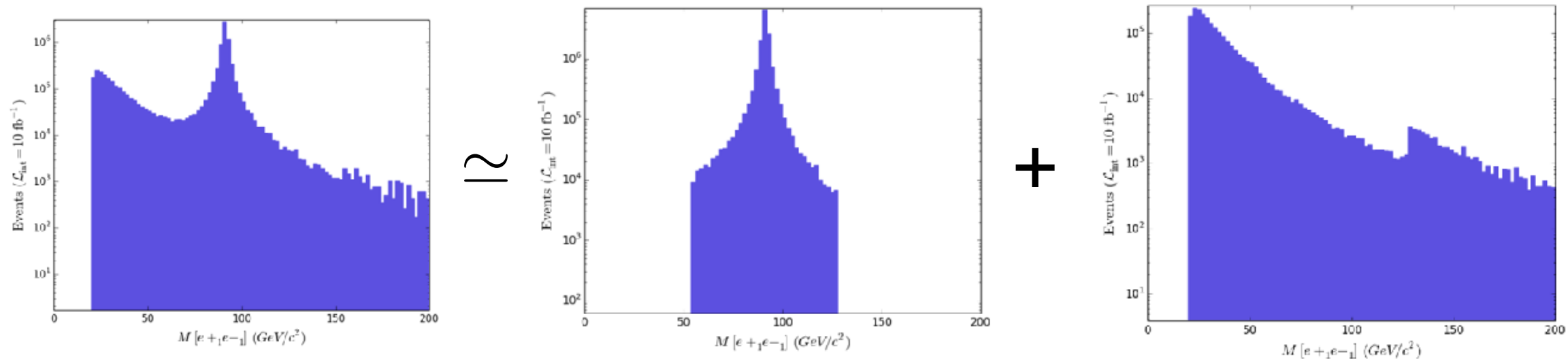
```
> generate p p > e+ e- $ z
```



```
> generate p p > e+ e- / z
```



# EXERCISES: PLOT DISTRIBUTIONS



On-shell cut in `run_card.dat`

```
#####
# BW_cutoff (M+/-bw cutoff*Gamma) ! Define on/off-shell for "$" and decay
#
# 15.0 = bw cutoff ! (M+/-bw cutoff*Gamma)
#####
```

$$|M(e^+e^-) - M_Z| < \text{bw cutoff} \times \Gamma_Z$$

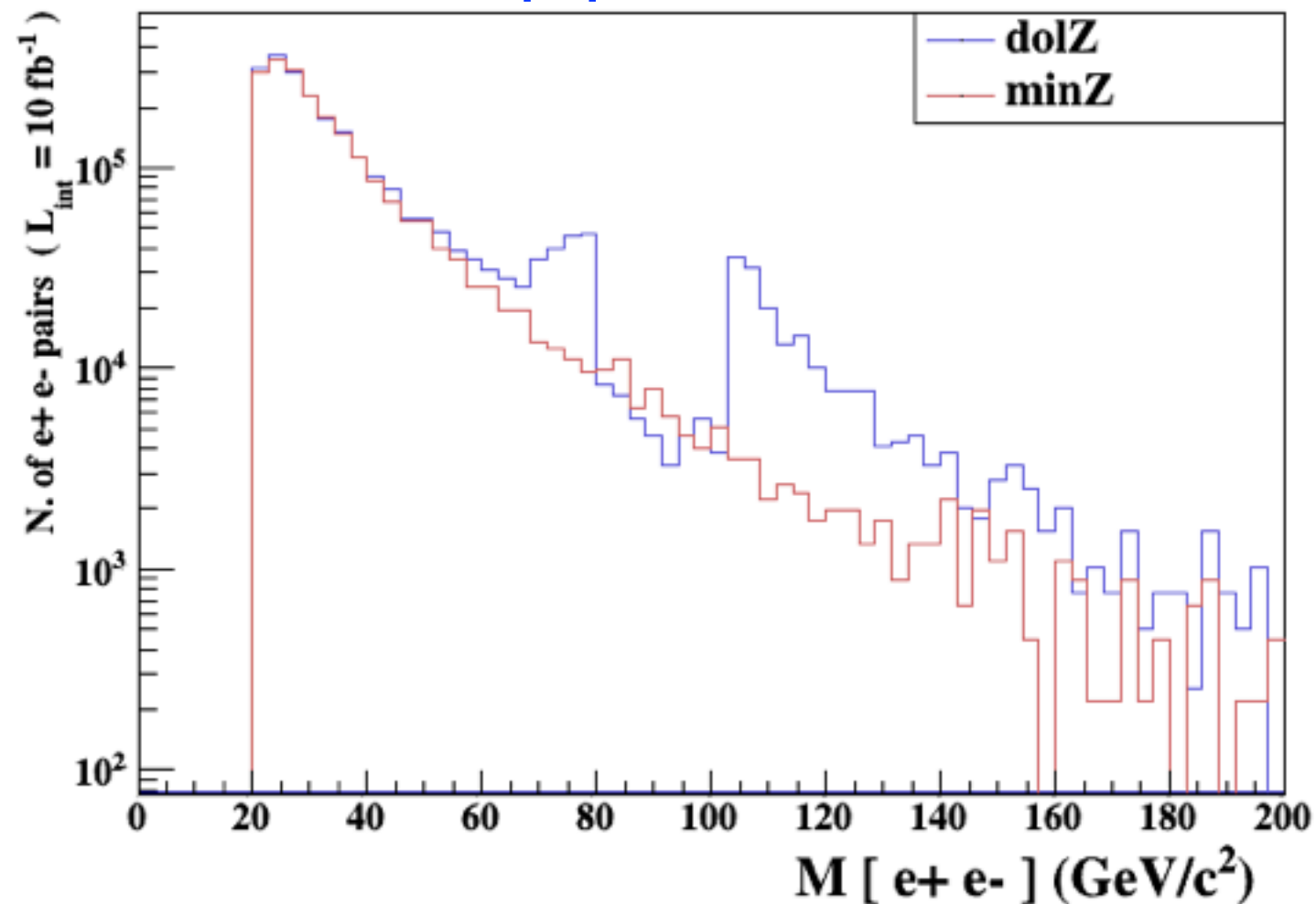
- Full (physical) distribution is very close the sum of the two.
- The '\$' forbids the Z to be on shell but the photon invariant mass can be at  $M_Z$  (i.e. on-shell subtraction).
- The '/' is to be avoid if possible since this may lead to (unphysical) gauge dependent.

# EXERCISES: PLOT DISTRIBUTIONS



- Next slides are generated with bwcutoff=5, which is **TOO SMALL** from the physical viewpoint in practice.

Red curve  $p p \rightarrow e^+ e^- / z$   
Blue curve  $p p \rightarrow e^+ e^- \gamma z$



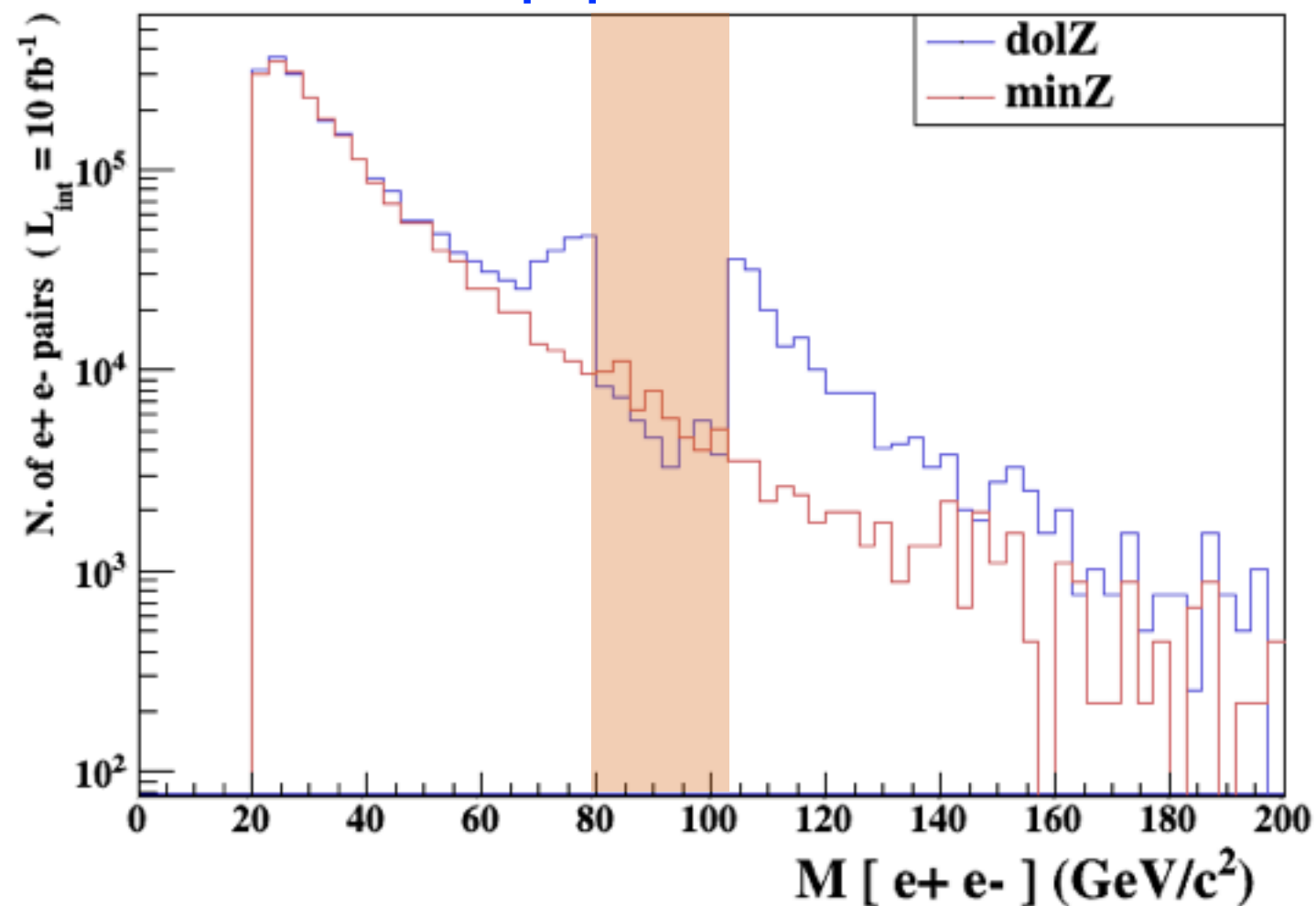


# EXERCISES: PLOT DISTRIBUTIONS



- Next slides are generated with bwcutoff=5, which is **TOO SMALL** from the physical viewpoint in practice.

Red curve  $p p \rightarrow e^+ e^- / Z$   
Blue curve  $p p \rightarrow e^+ e^- \otimes Z$



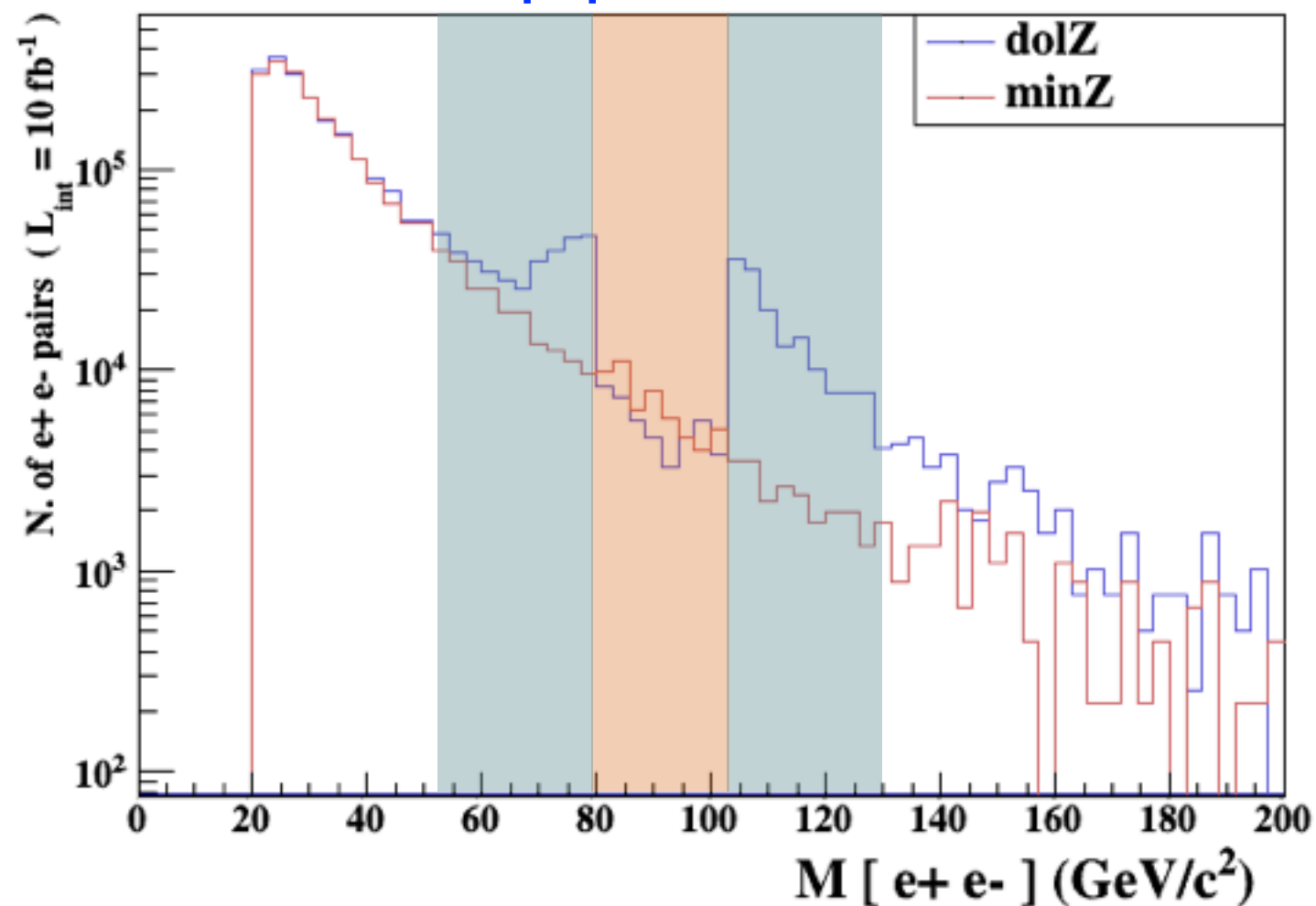
The on-shell region of Z is vetoed  
Photon contribution is still there.

# EXERCISES: PLOT DISTRIBUTIONS



- Next slides are generated with bwcutoff=5, which is **TOO SMALL** from the physical viewpoint in practice.

Red curve  $pp \rightarrow e^+e^-/\gamma$   
Blue curve  $pp \rightarrow e^+e^-Z$



The on-shell region of Z is vetoed  
Photon contribution is still there.

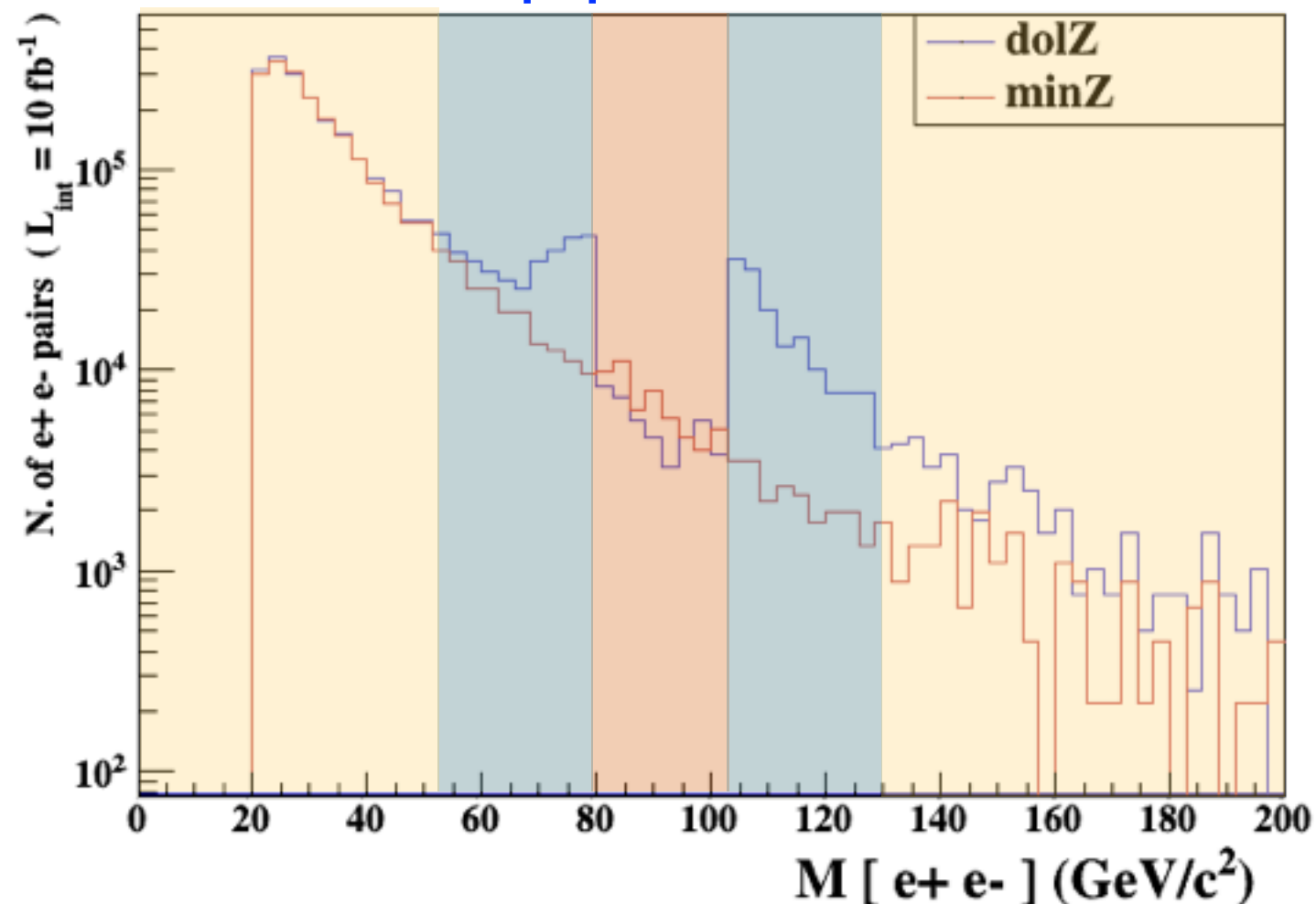
Area sensitive to Z peak  
bwcutoff=15 will cover this region

# EXERCISES: PLOT DISTRIBUTIONS



- Next slides are generated with bwcutoff=5, which is **TOO SMALL** from the physical viewpoint in practice.

Red curve  $pp \rightarrow e^+e^- / Z$   
Blue curve  $pp \rightarrow e^+e^- \otimes Z$



The on-shell region of Z is vetoed  
Photon contribution is still there.

Area sensitive to Z peak

bwcutoff=15 will cover this region

The very off-shell Z region, the difference between the two curves is due to the interference between Z and photon diagrams