FeynRules/Madgraph School on Collider Phenomenology 2018

Tutorial On MadGraph5_aMC@NLO:

Basic Usages

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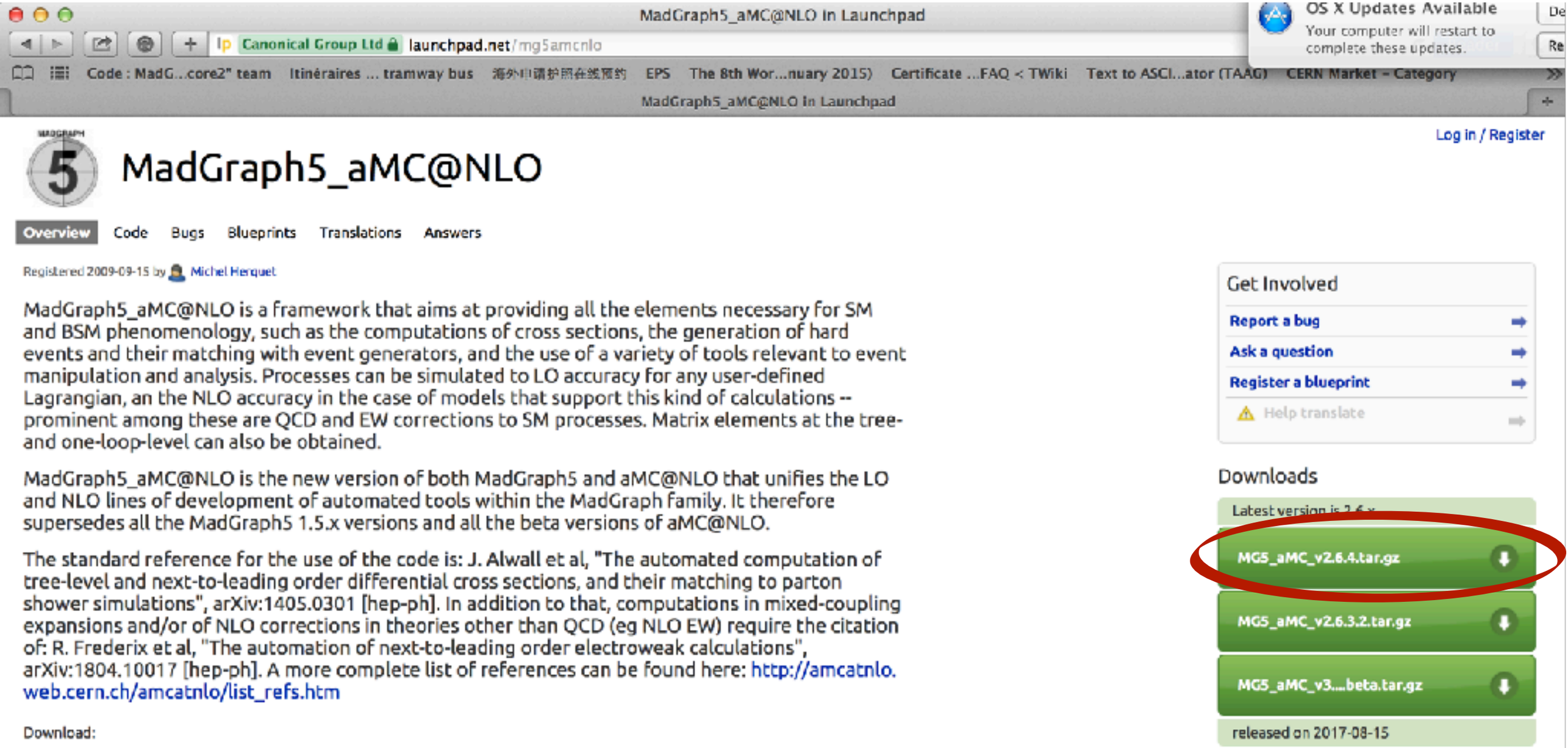
INSTALL MADGRAPH 5

- 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 >= 4.6 and not 8.X)
  - python (version >= 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



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/+faqs

  → Submit Q: https://answers.launchpad.net/mg5amcnlo

INPUTS

- 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 explainations: 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 > t t~ QCD=0
```

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

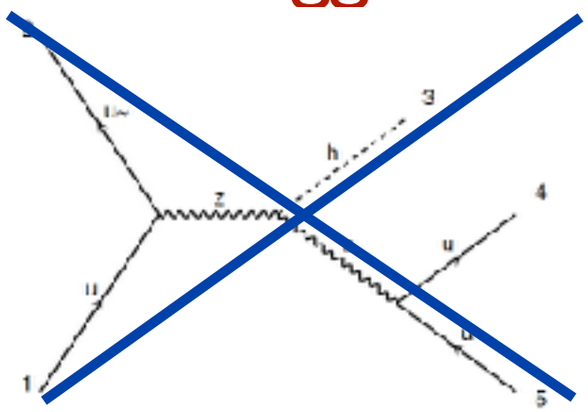
```
> generate p p > t t~ QCD^2==2
```

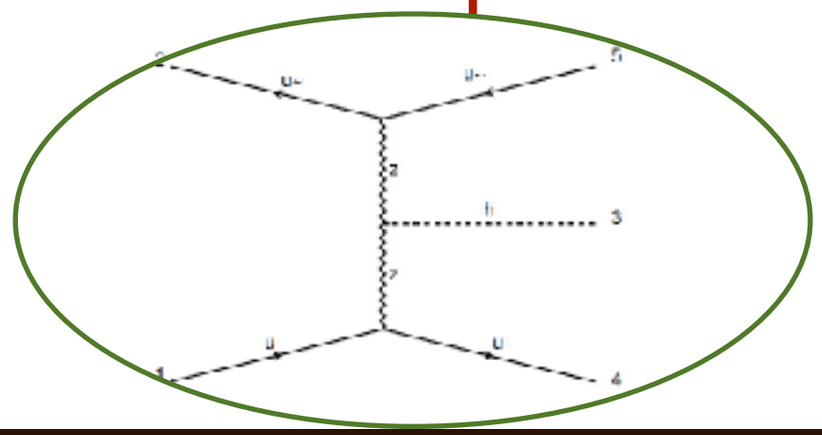
```
> generate p p > z a > t t~
```

```
> 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_analysis1.

- Edit the madanalysis5_parton_card.dat to refine the bins.

- Understand the meaning from the invariant mass distribution

EXERCISE SOLUTION: INPUTS

```
#*********************************************************************
#* PARAM_CARD AUTOMATICALY 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+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)))

###################################
## INFORMATION FOR SMINPUTS
###################################
Block sminputs
    1 1.325070e+02 # aEWM1
    2 1.166390e-05 # Gf
    3 1.180000e-01 # aS

###################################
## INFORMATION FOR YUKAWA
###################################
Block yukawa
    5 4.700000e+00 # ymb
    6 1.730000e+02 # ymt
   15 1.777000e+00 # ymtau

###################################
## INFORMATION FOR DECAY
###################################
DECAY   6 1.491500e+00 # WT
DECAY  23 2.441404e+00 # WZ
DECAY  24 2.047600e+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

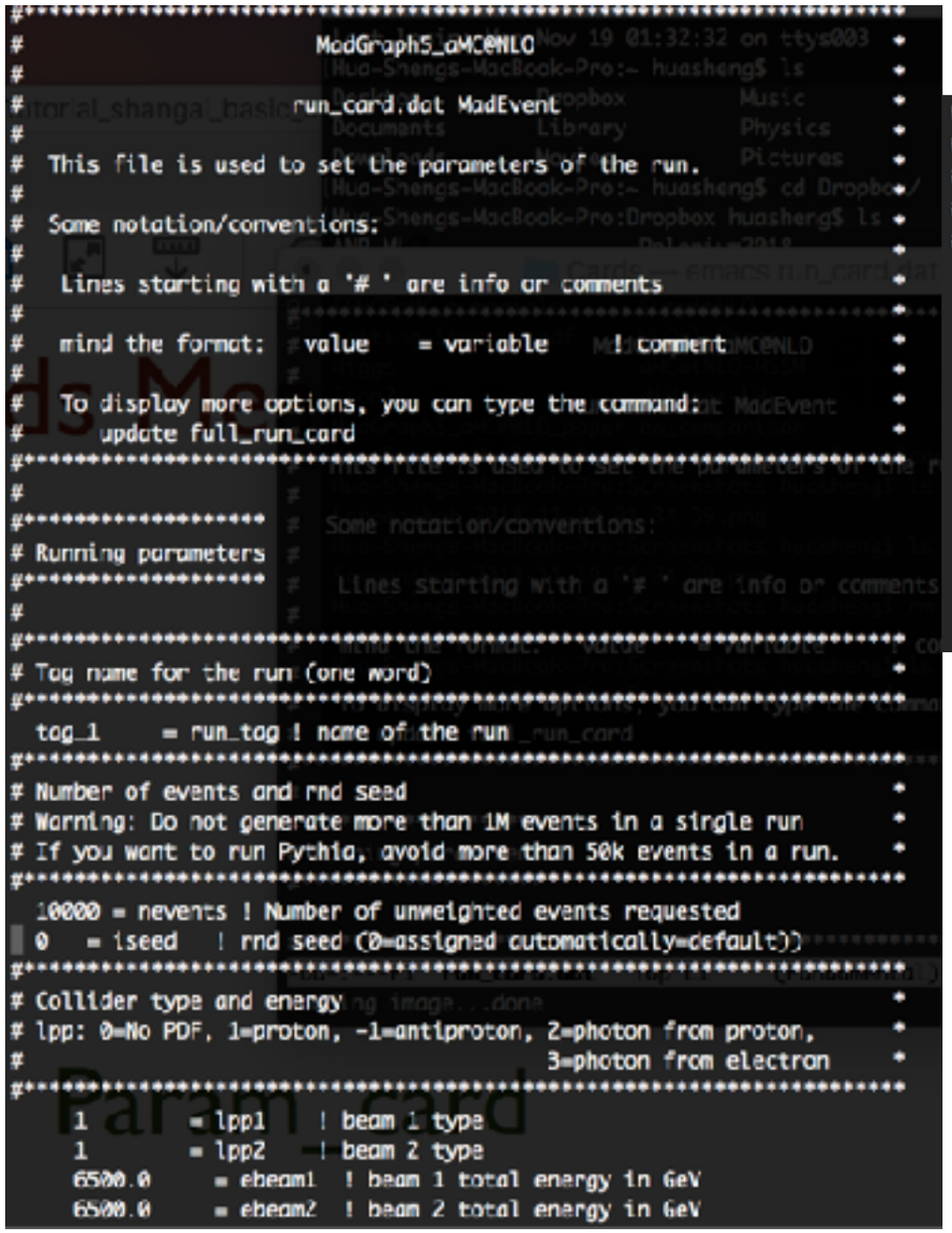
EXERCISE SOLUTION: INPUTS

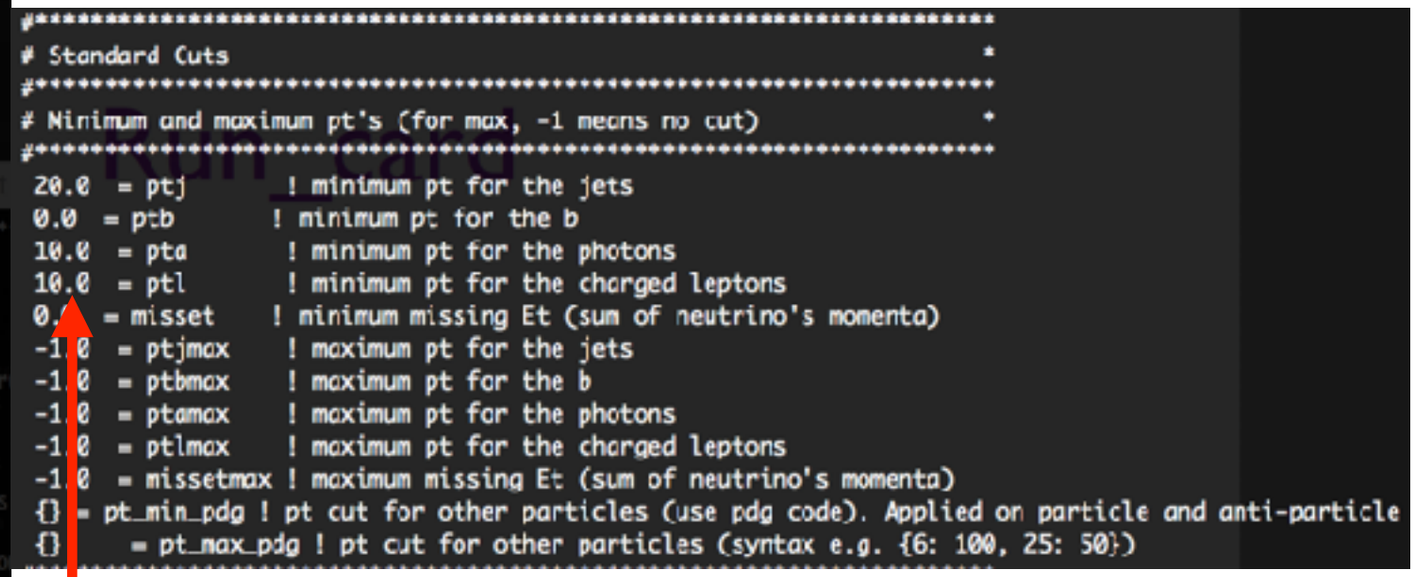
```
#*********************************************************************
#                        MadGraph5_aMC@NLO                           *
#                                                                    *
#                      run_card.dat MadEvent                         *
#                                                                    *
#  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                                           *
#*********************************************************************
#
#*********************
# Running parameters
#*********************
#
#*********************************************************************
# Tag name for the run (one word)                                    *
#*********************************************************************
  tag_1     = run_tag ! name of the run
#*********************************************************************
# 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
     6500.0     = ebeam1  ! beam 1 total energy in GeV
     6500.0     = ebeam2  ! beam 2 total energy in GeV
```

number of events

beam energy

EXERCISE SOLUTION: INPUTS





min pt cut of the charged leptons

EXERCISE SOLUTION: INPUTS

```
#*********************************************************************
#                    MadGraph5_aMC@NLO                               *
#                                                                    *
#                  run_card.dat MadEvent                             *
#                                                                    *
#  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:                *
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#*********************************************************************
  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
    6500.0     = 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   = misset    ! 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  = missetmax ! 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
```

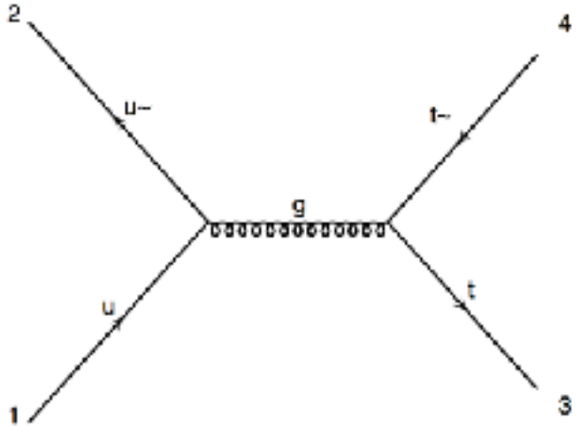
number of quark flavors in a jet

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`



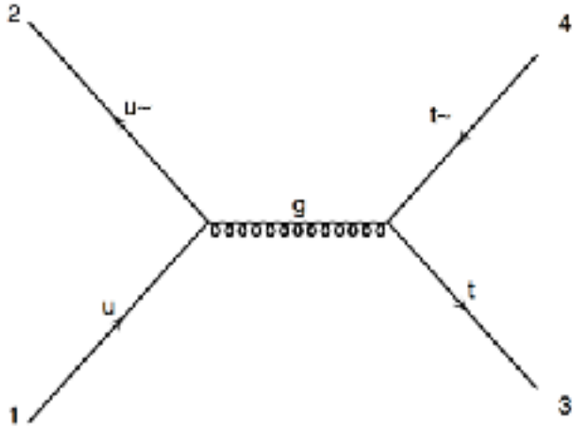
EXERCISE SOLUTION: GENERATION

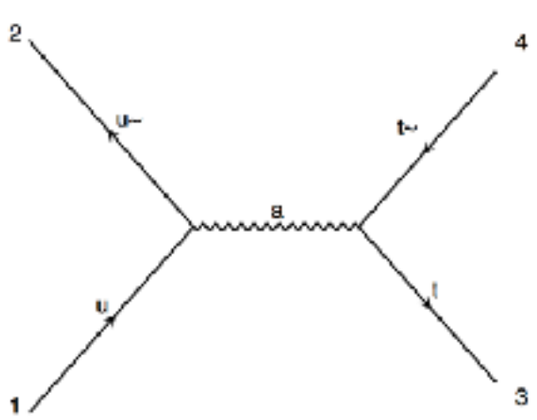
- What's the meaning of the coupling order QED/QCD

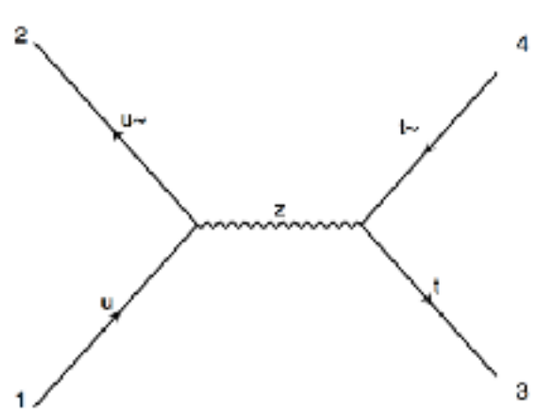
  → By default, MG5 will guess the lowest order in QED

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

  → `> generate p p > t t~ QED=2`







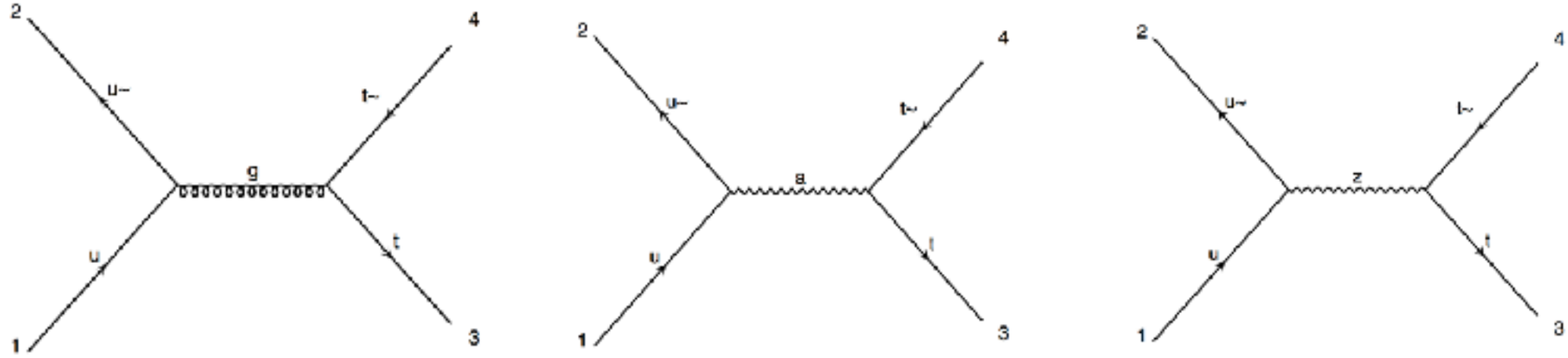
EXERCISE SOLUTION: GENERATION

- 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 > t t~

Run	Collider	Banner	Cross section (pb)
run_01	p p 6500.0 x 6500.0 GeV	tag_1	505.7 ± 0.79

Results in the sm for p p > t t~ QED=2

Run	Collider	Banner	Cross section (pb)
run_01	p p 6500.0 x 6500.0 GeV	tag_1	505.8 ± 0.93

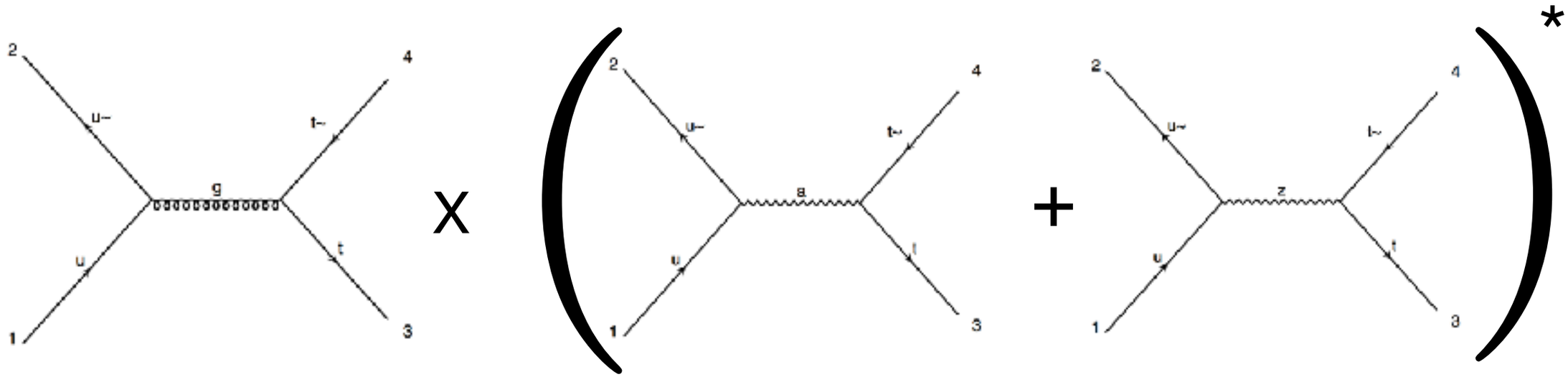
EXERCISE SOLUTION: GENERATION

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

  → 'QED<=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

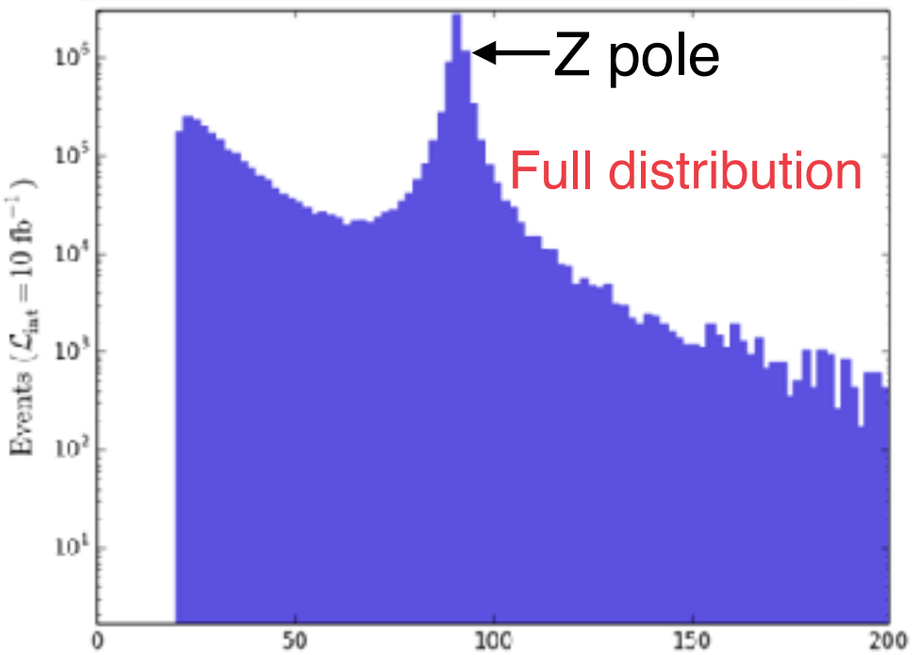
  → Refine the bins in madanalysis5_parton_card.dat

```
# 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 ]
```

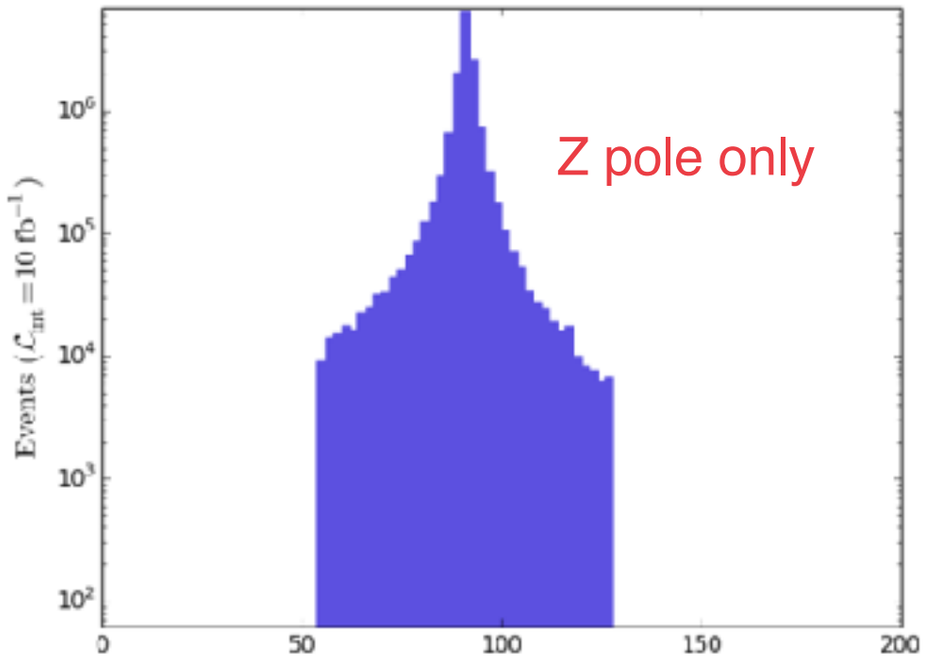
Invariant mass of the lepton pair

EXERCISES: PLOT DISTRIBUTIONS

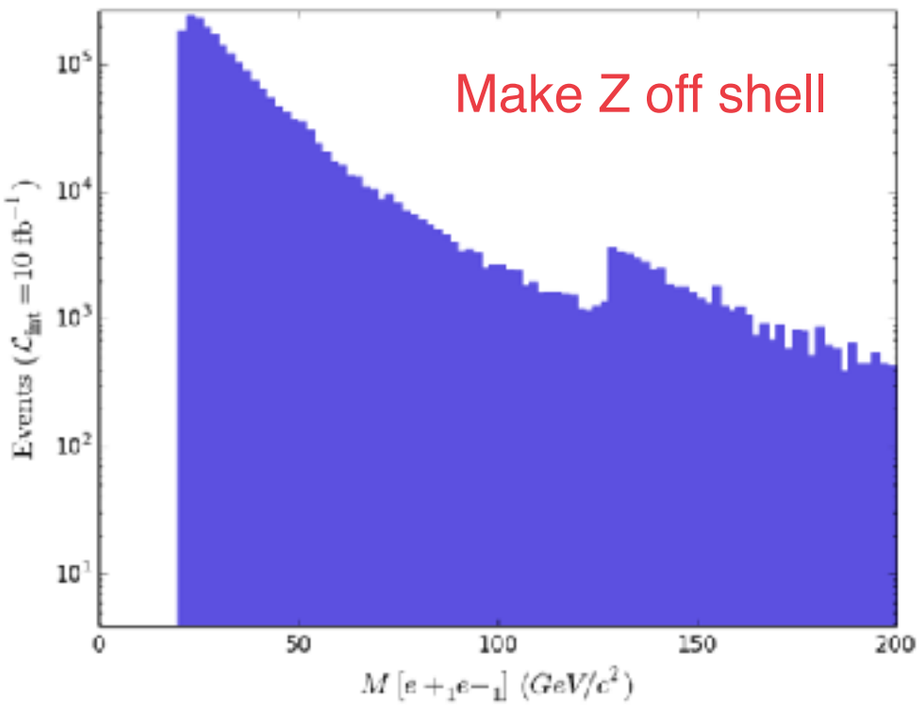
```
> generate p p > e+ e-
```



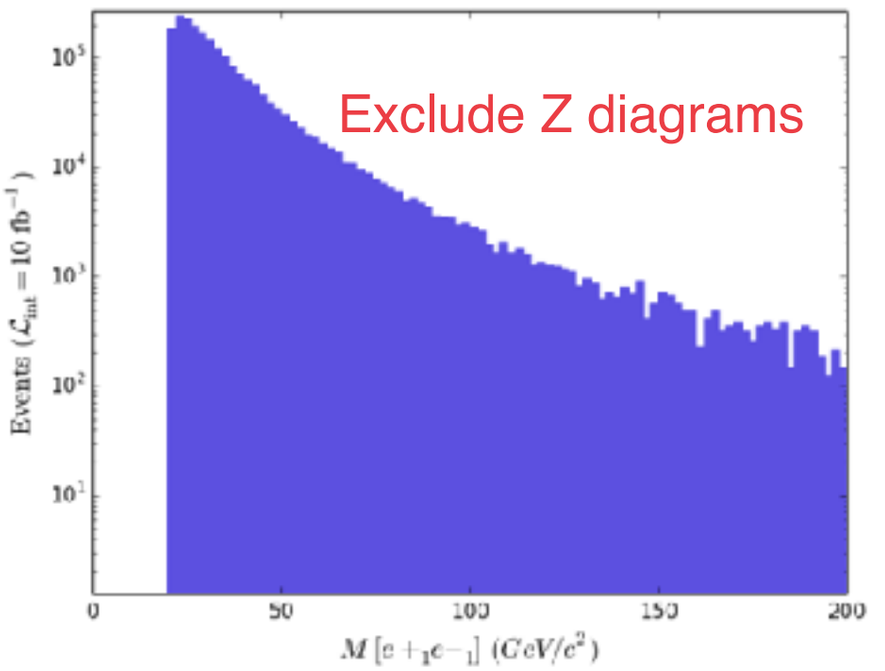

```
> generate p p > z, z > e+ e-
```




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

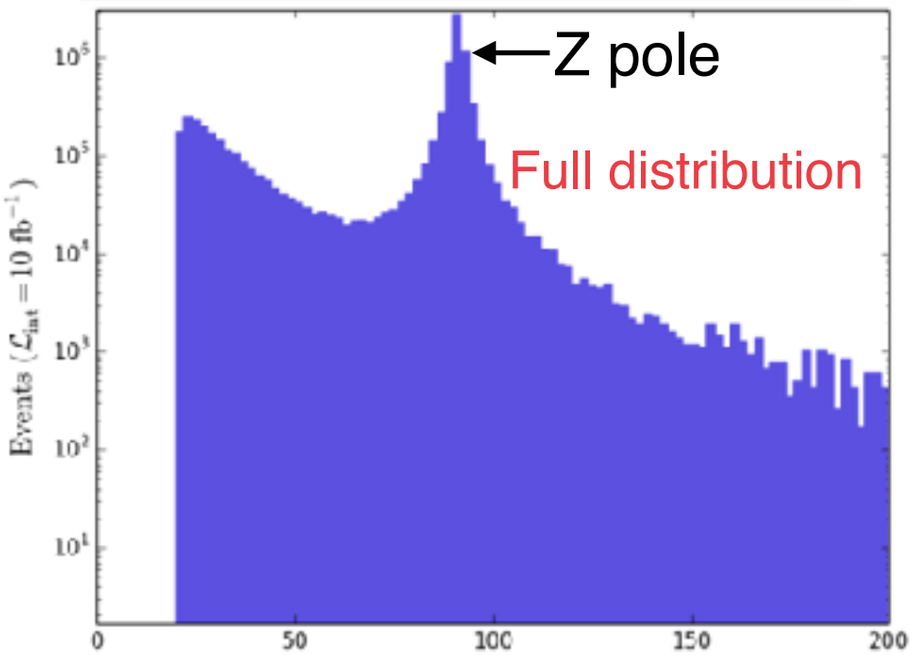



```
> generate p p > e+ e- / z
```



EXERCISES: PLOT DISTRIBUTIONS


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

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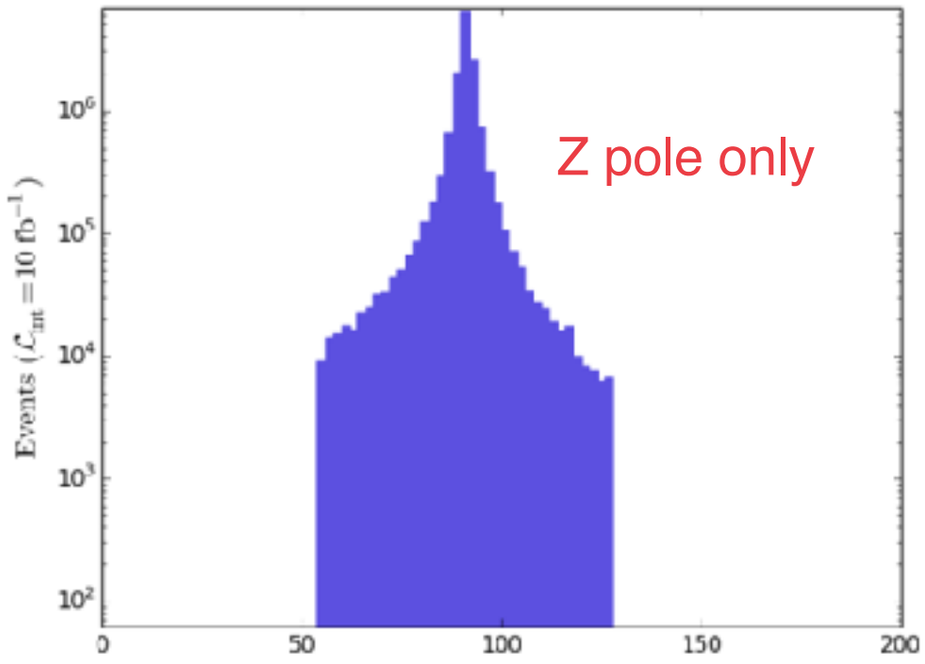


```
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```
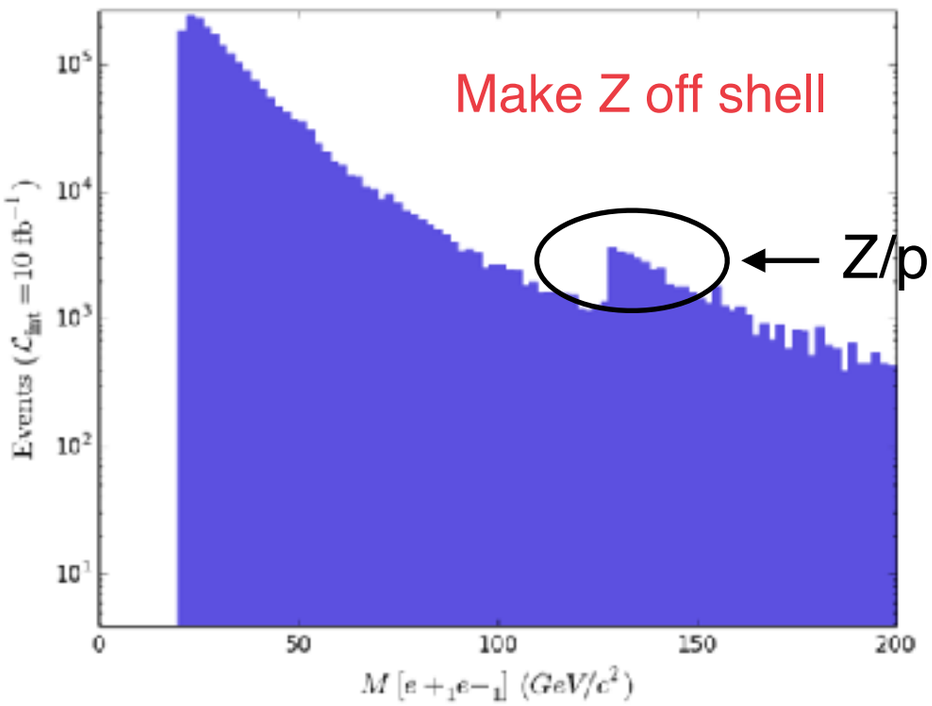
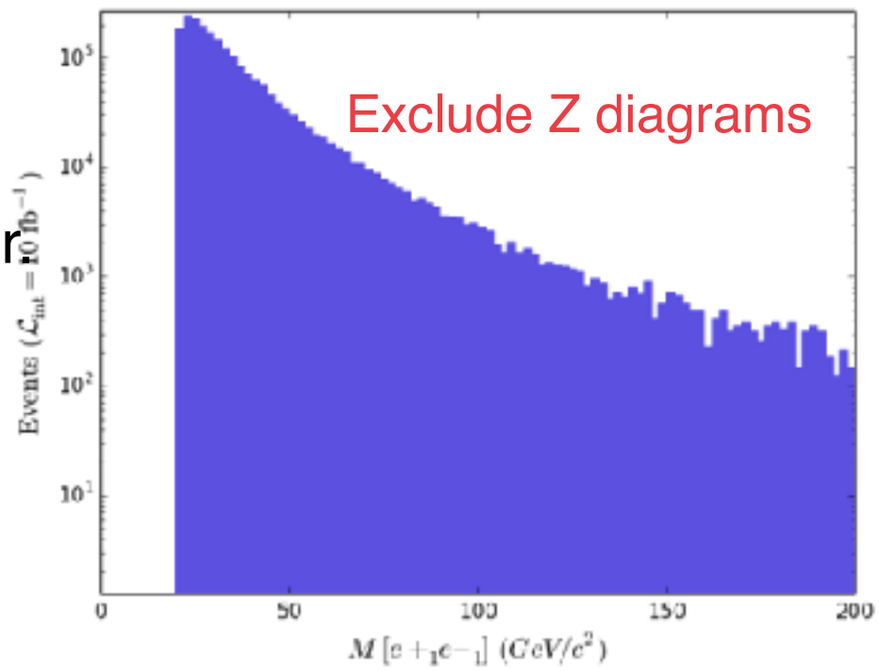
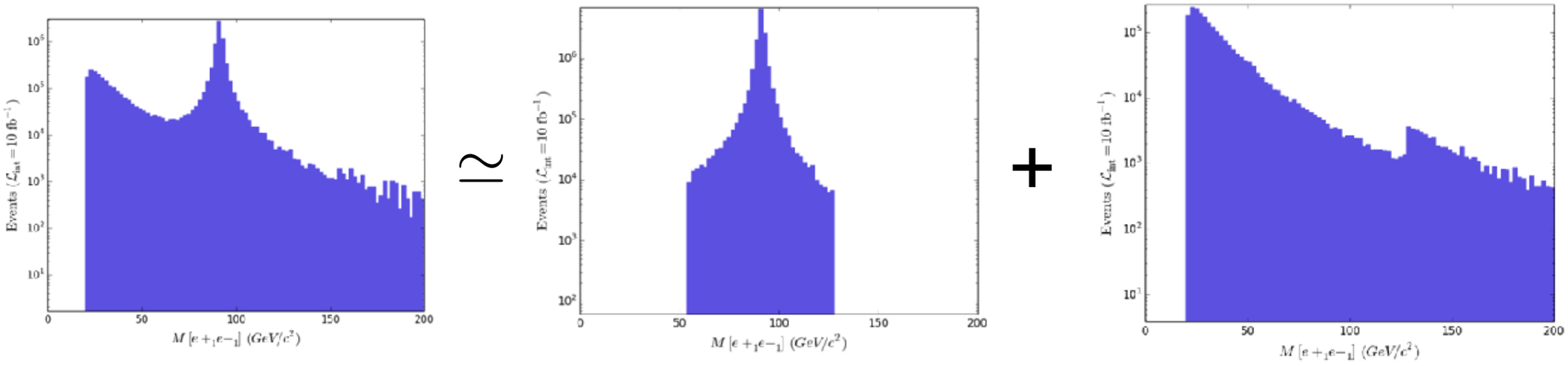




```
> generate p p > e+ e- / z
```



EXERCISES: PLOT DISTRIBUTIONS



On-shell cut in run_card.dat

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

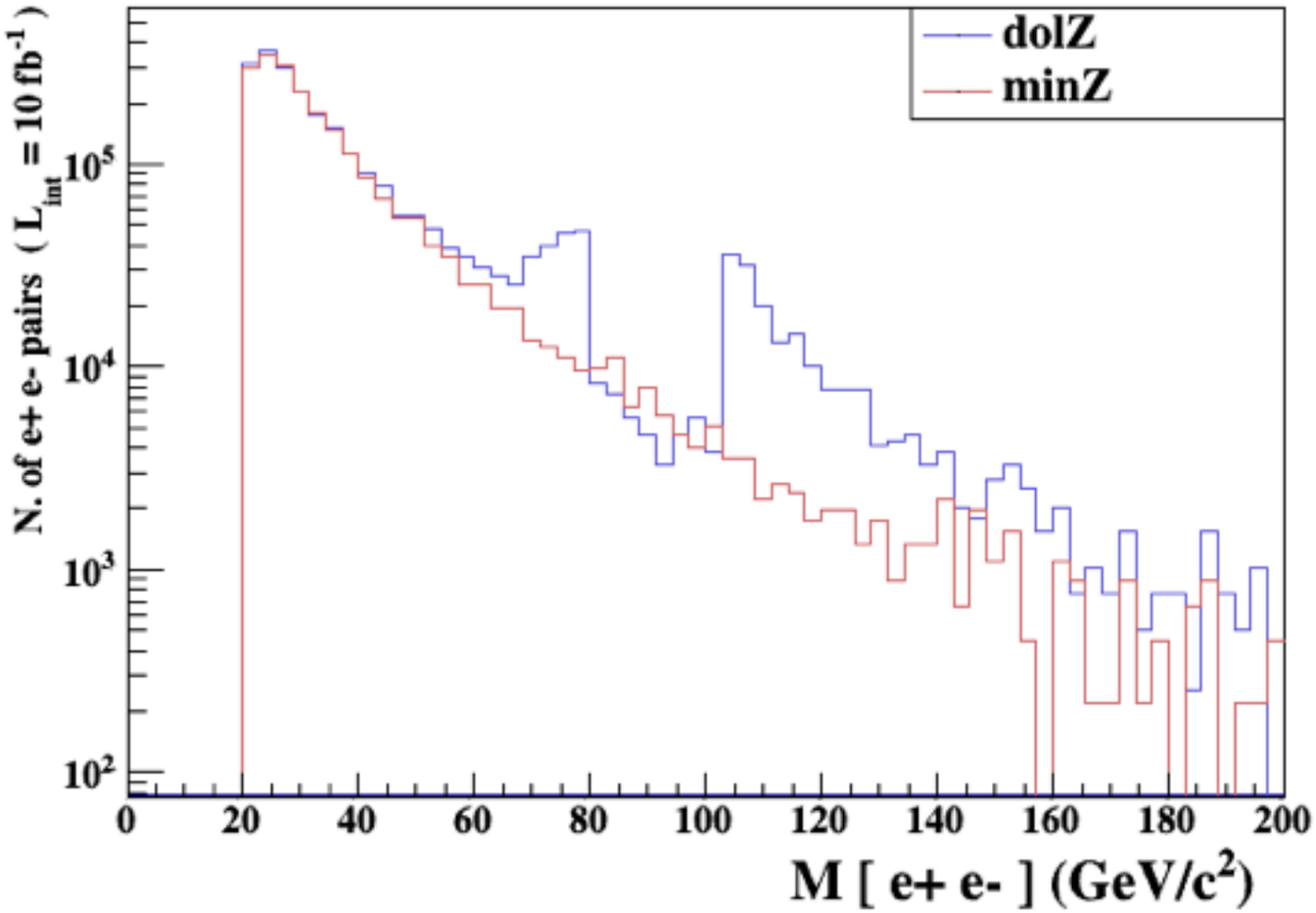
$$|M(e^+e^-) - M_Z| < \text{bwcutoff} \times \Gamma_Z$$

- 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 > e+ e- / z`
Blue curve `p p > e+ e- $ z`



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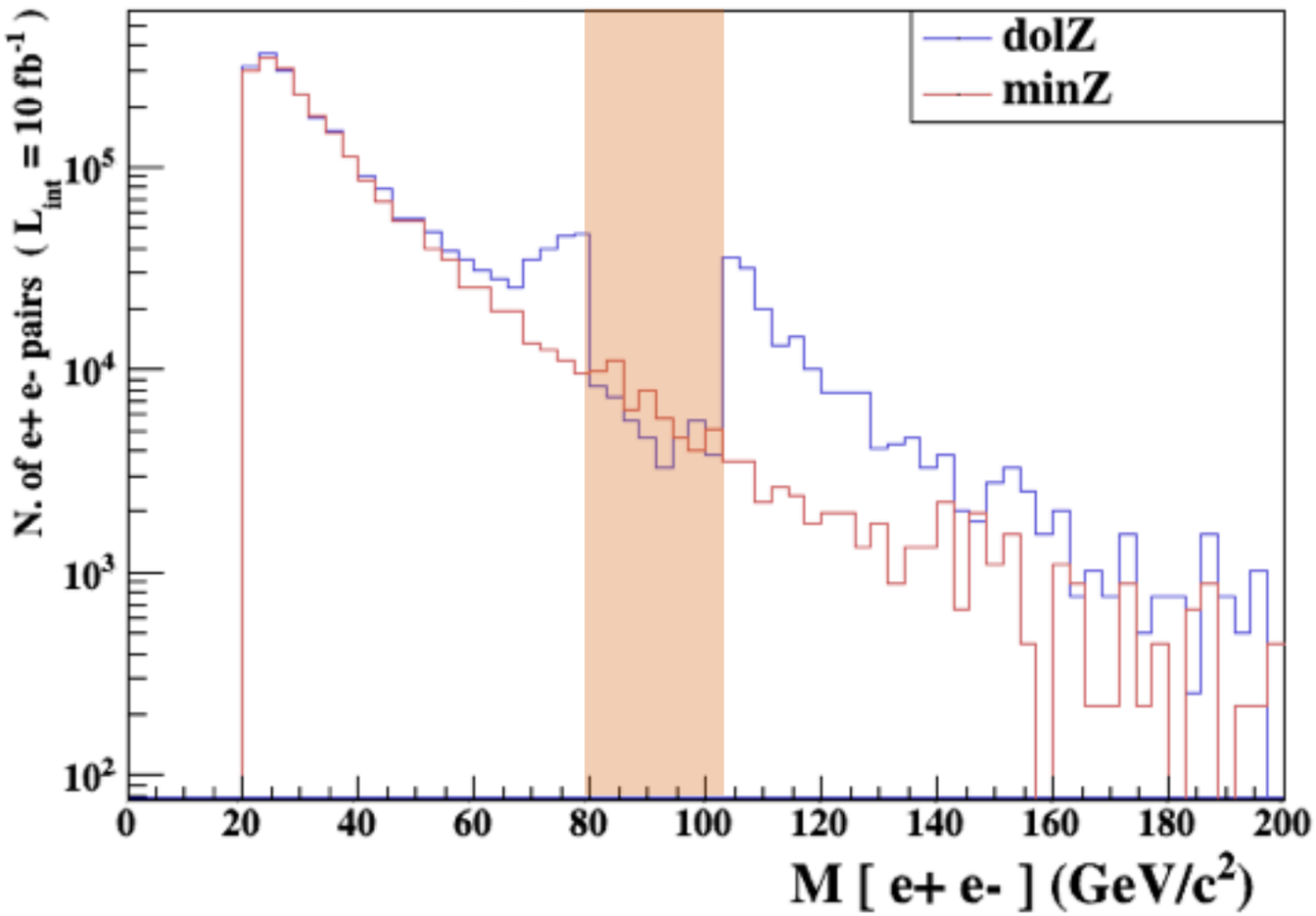

The on-shell region of Z is vetoed

Photon contribution is still there.

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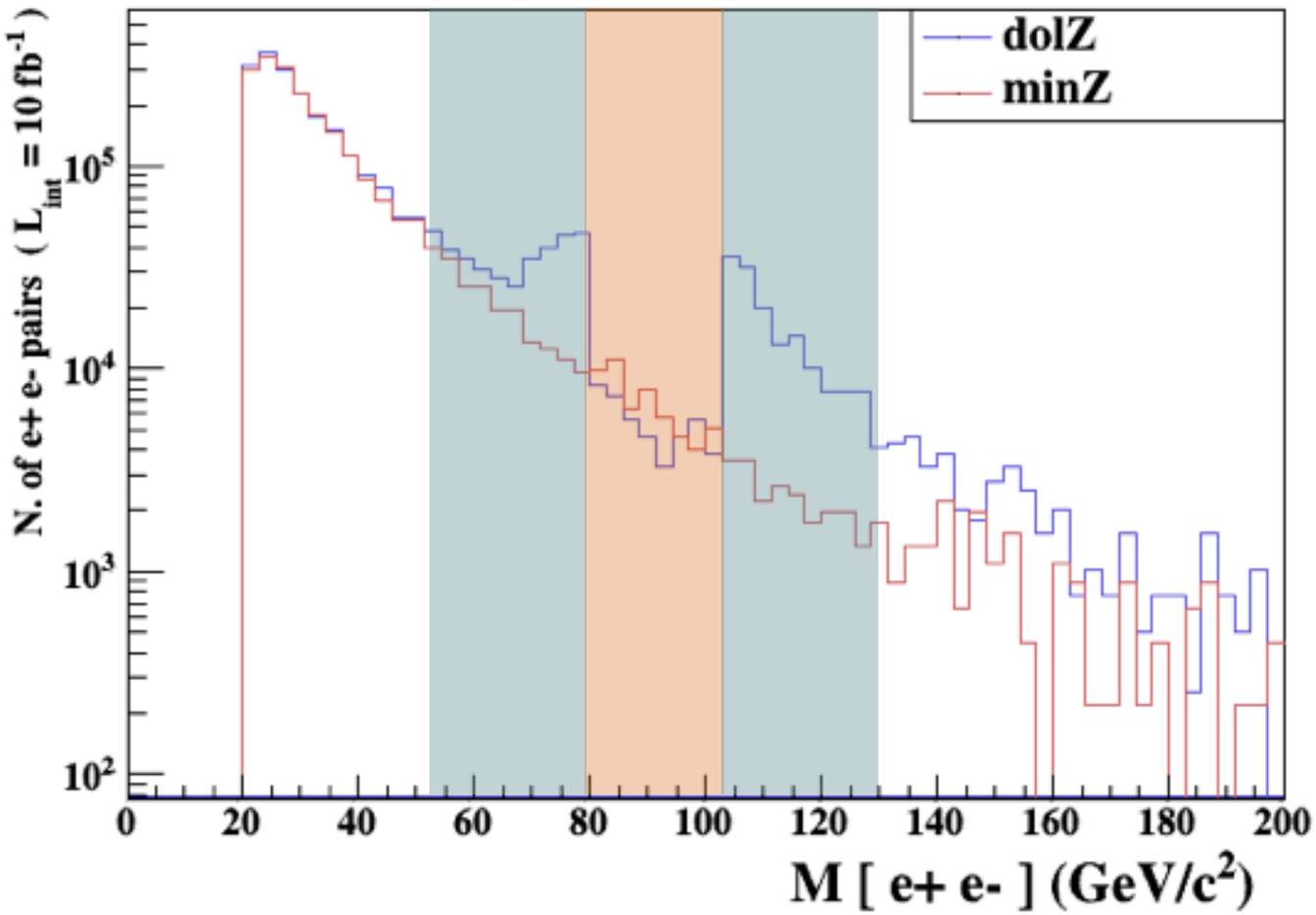

The on-shell region of Z is vetoed

Photon contribution is still there.

Area sensitive to Z peak

bwcutoff=15 will cover this region

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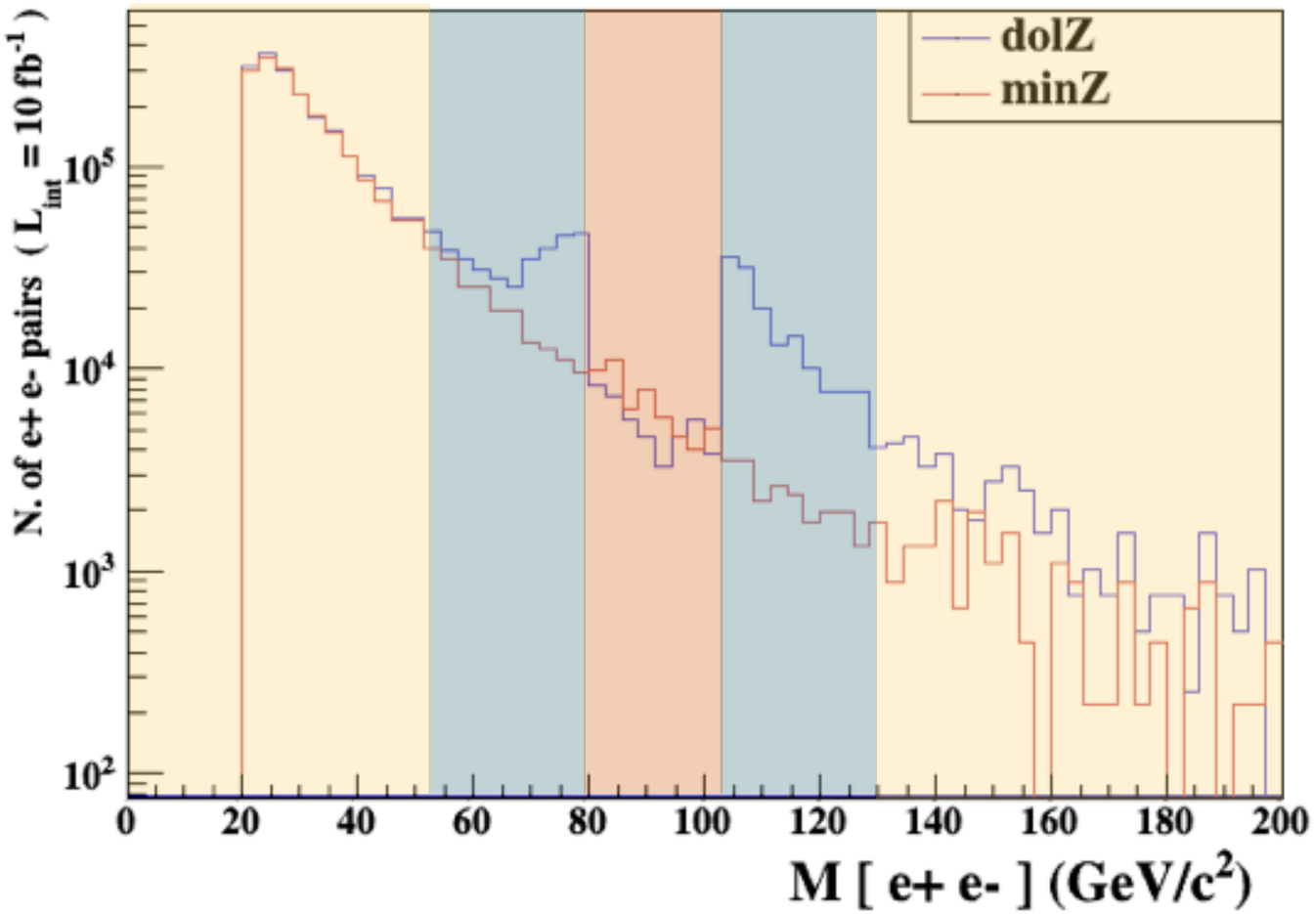

The on-shell region of Z is vetoed

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