

MadGraph Tutorial

Olivier Mattelaer
UIUC

I. Plan of this tutorial

- Install MadGraph 5
- Generate events.
- Install / optimize new model.
 - width computation
- Scan in mass
- Matching
- NLO

Madgraph 5

J. Alwall, M. Herquet, F. Maltoni, OM, T. Stelzer

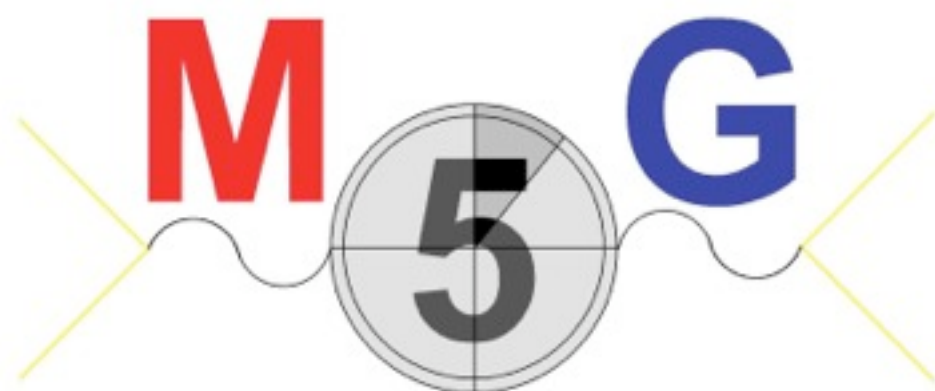


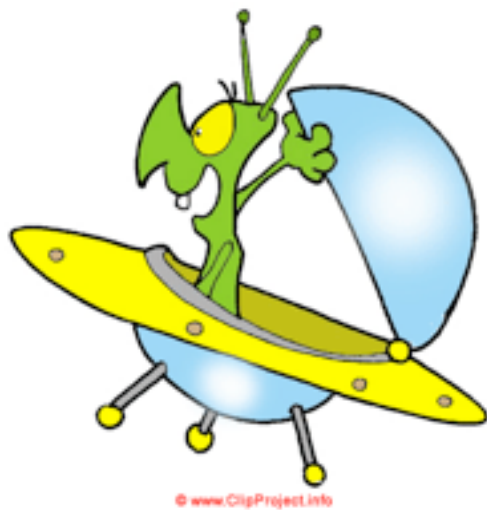
Diagram Generation
Matrix - Element
Cross -section
Events Generation

Suite of Program:

MadEvent / MadLoop / MadFKS /
aMC@NLO / MadSpin / ALOHA /
MadWeight / Madonia

BSM

UFO



Model Information

FeynRules Output

Basically **No limitation**

C. Degrande, C. Duhr, B. Fucks, D. Grellscheid, OM, T.Reiter

ALOHA



Automatic Creation of **HELAS** routines
for **ANY BSM** theory

- MadGraph building block

P.Aquino, W. Link, F. Maltoni, OM, T. Stelzer

Install MadGraph 5!

- <https://launchpad.net/madgraph5>
 - 1.5.7
 - 2.0.0.beta2 -> (NLO available !)
- untar it (`tar -xzipvf TUTO_model.tgz`)
- launch it (`$./bin/mg5`)
- learn it!
 - Type tutorial and follow instructions

Where to find help?

- Ask me !
- 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>

What are those cards?

- **param_card**: model parameters
- **run_card**: beam/run parameters and cuts
- <https://answers.launchpad.net/madgraph5/+faq/2014>

Exercise I : Syntax

- What's the meaning of the order QED/QCD
- What's the difference between
 - $p p > t t^{\sim}$
 - $p p > t t^{\sim} \text{ QED}=2$
 - $p p > t t^{\sim} \text{ QED}=0$

Solution I : Syntax

- What's the meaning of the order QED/QCD
 - By default MG5 takes the lowest order in QED!
 - $pp \rightarrow tt \Rightarrow pp \rightarrow tt$ **QED=0**

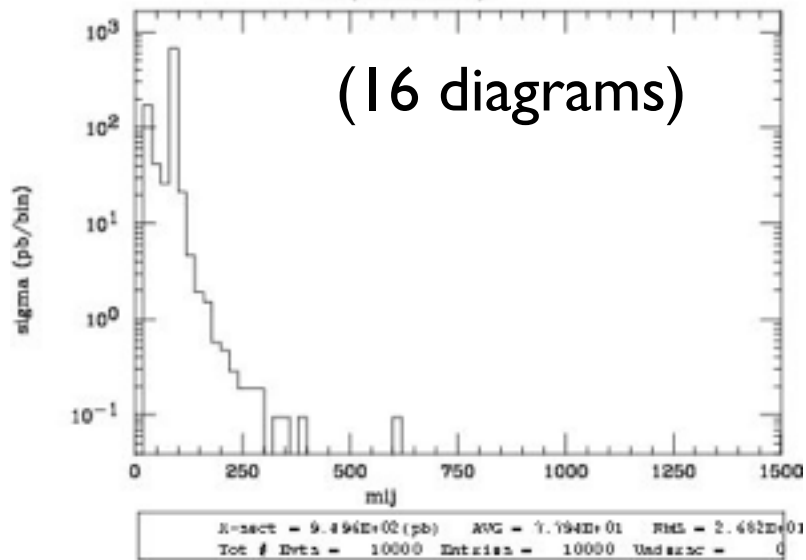
Exercise II: Syntax

- Generate the cross-section and the distribution (invariant mass) for
 - $pp \rightarrow e^+ e^-$
 - $pp \rightarrow z, z \rightarrow e^+ e^-$
 - $pp \rightarrow e^+ e^- \gamma z$
 - $pp \rightarrow e^+ e^- / z$

Hint : To have automatic distributions:
`mg5> install MadAnalysis`

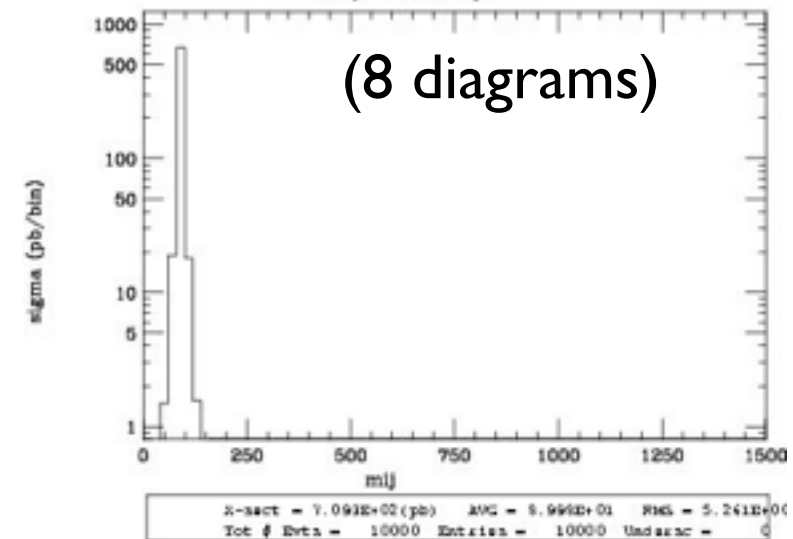
$pp \rightarrow e^+ e^-$
 $m(e^+, e^-)$

(16 diagrams)



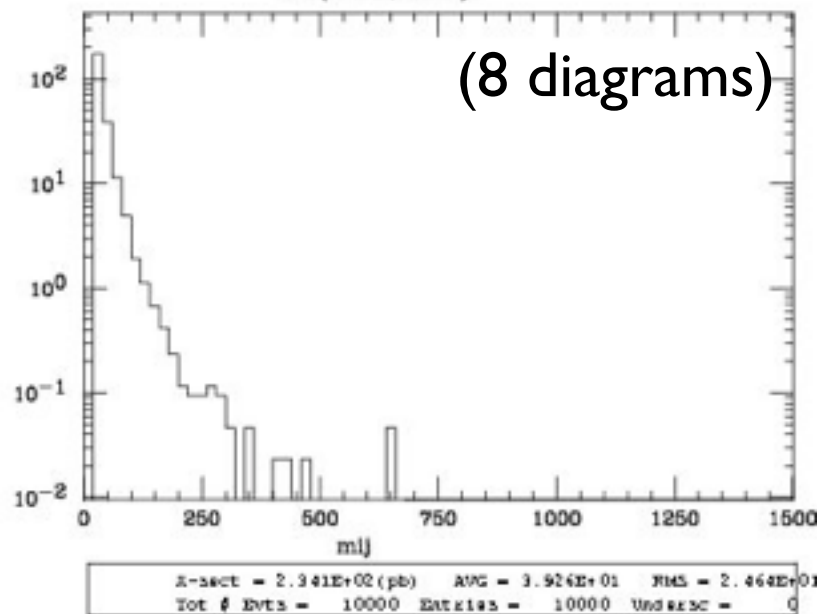
$pp \rightarrow Z, Z \rightarrow e^+ e^-$
 $m(e^+, e^-)$

(8 diagrams)



$pp \rightarrow e^+ e^- / Z$
 $m(e^+, e^-)$

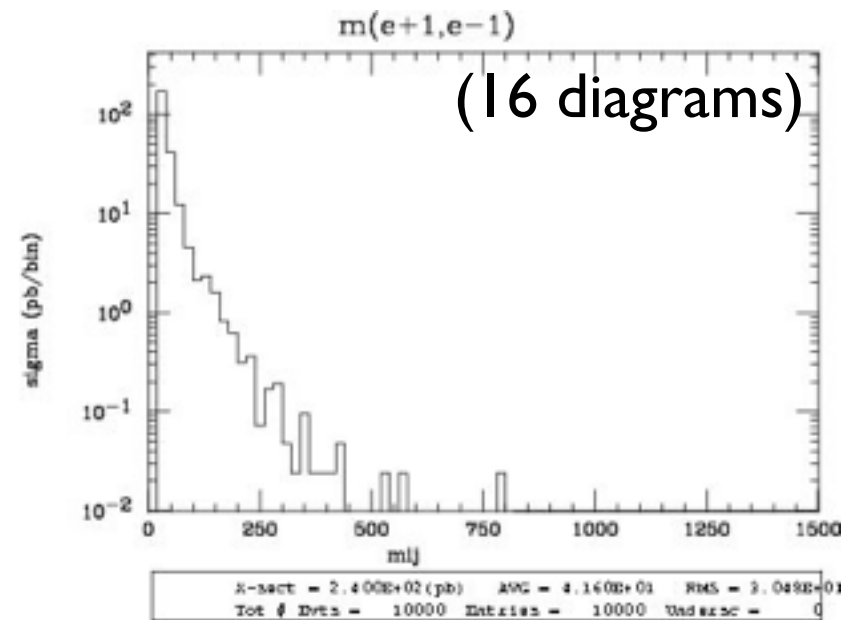
(8 diagrams)



No Z

$pp \rightarrow e^+ e^- \cancel{Z}$

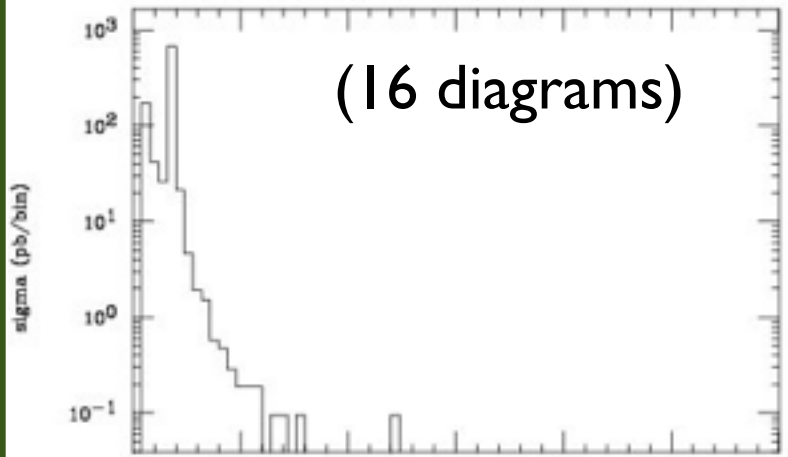
(16 diagrams)



Z- onshell veto

$pp \rightarrow e^+ e^-$
 $m(e^+, e^-)$

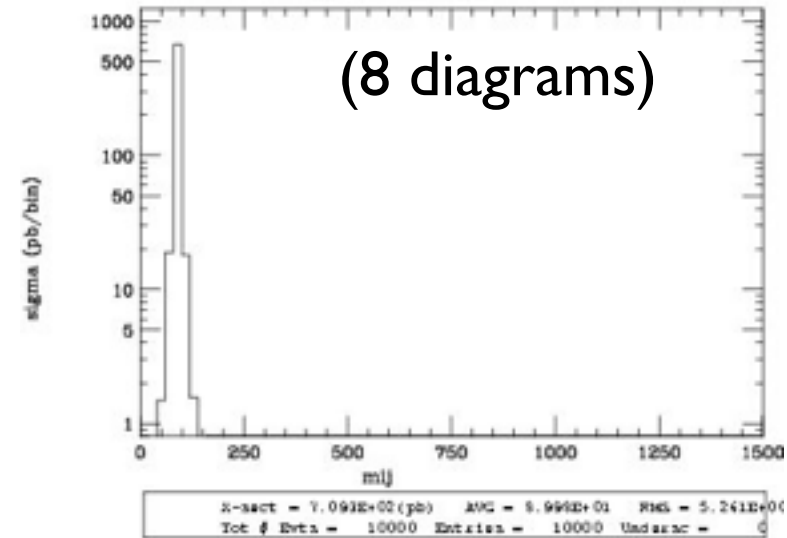
(16 diagrams)



Correct Distribution

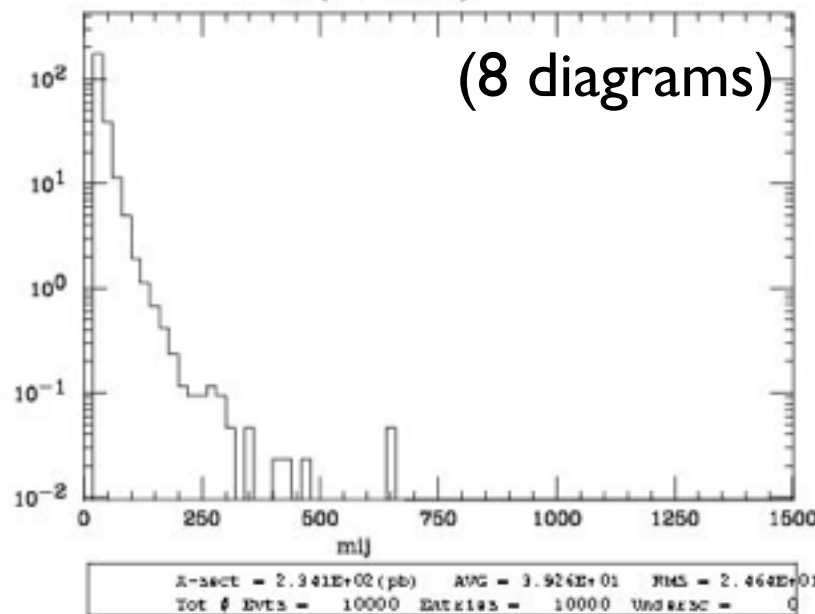
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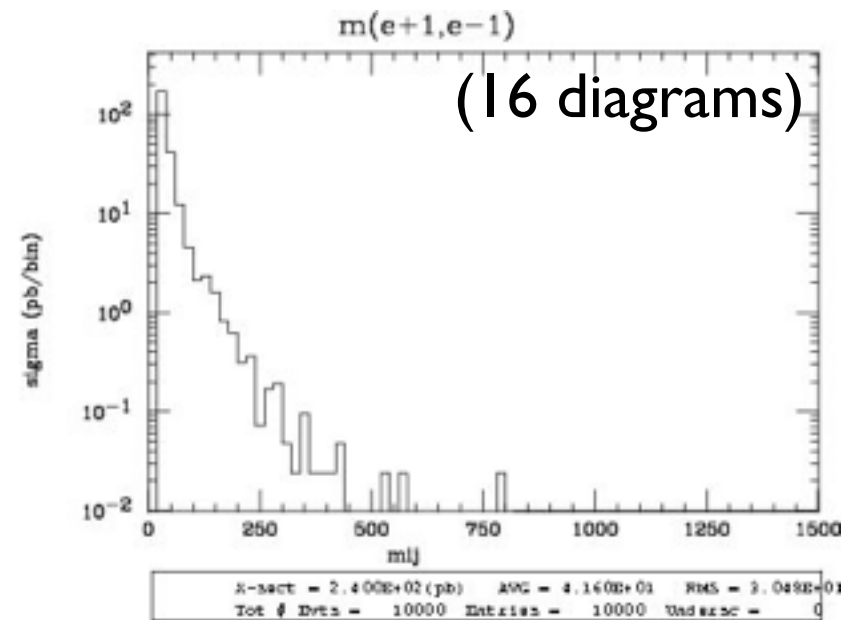
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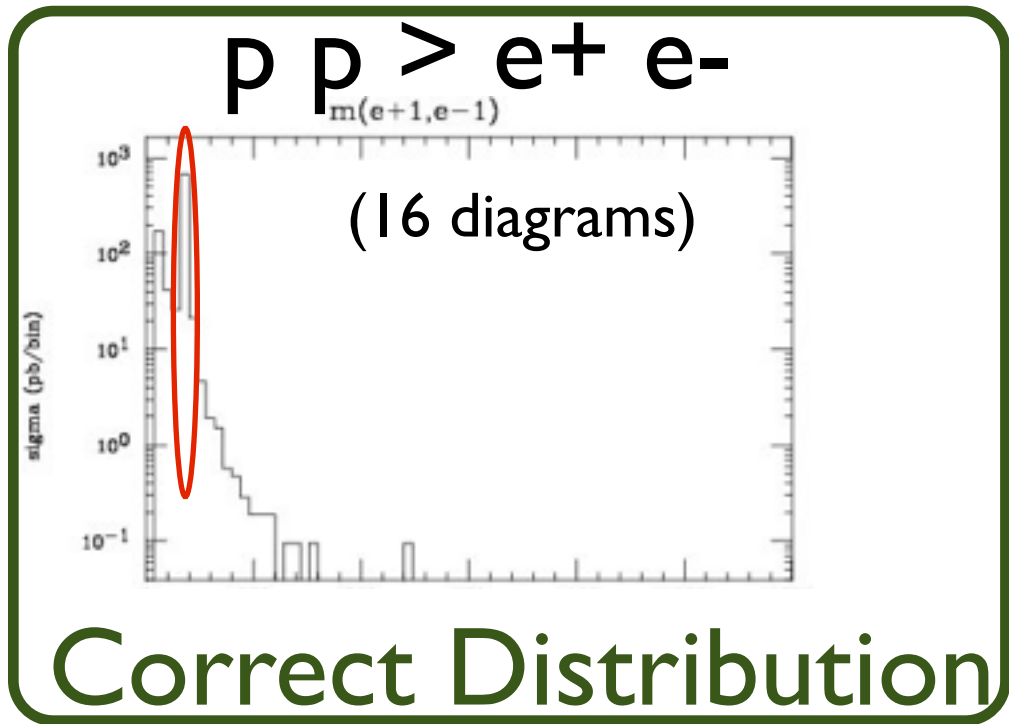
No Z

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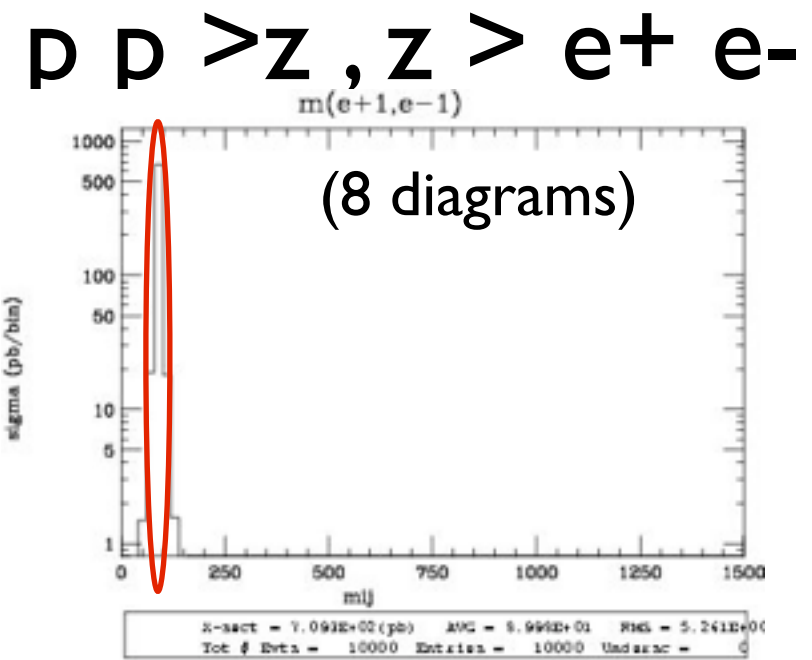
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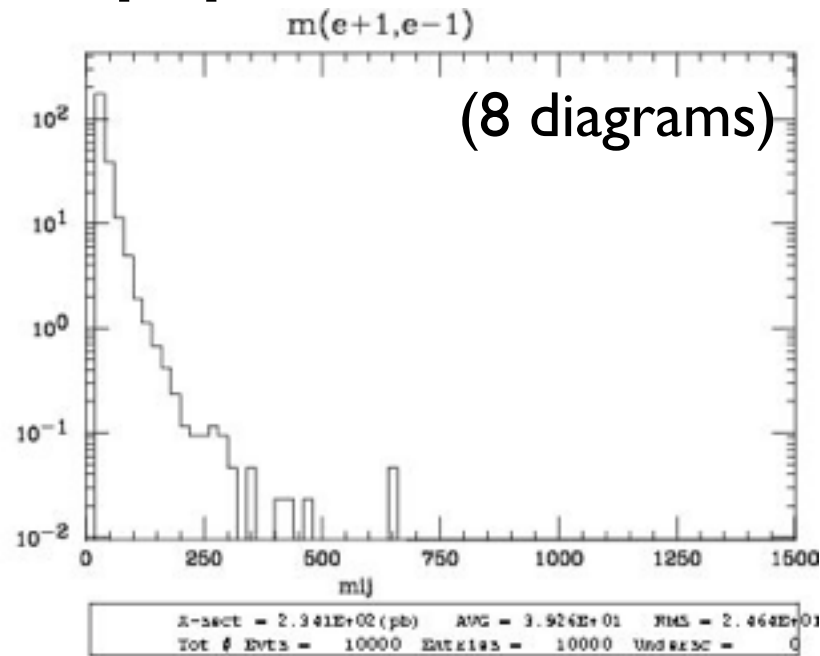
Z- onshell veto



Z Peak



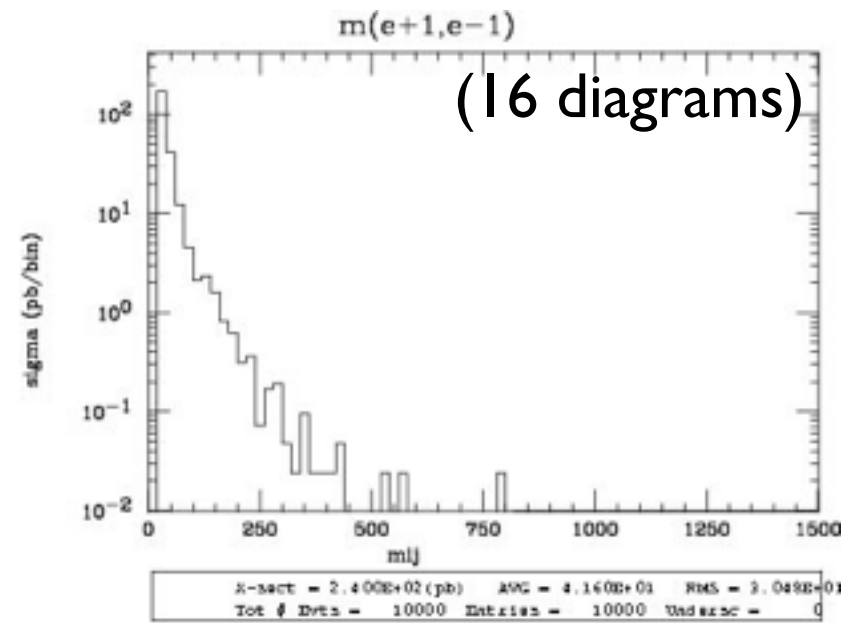
$pp \rightarrow e^+ e^- / z$
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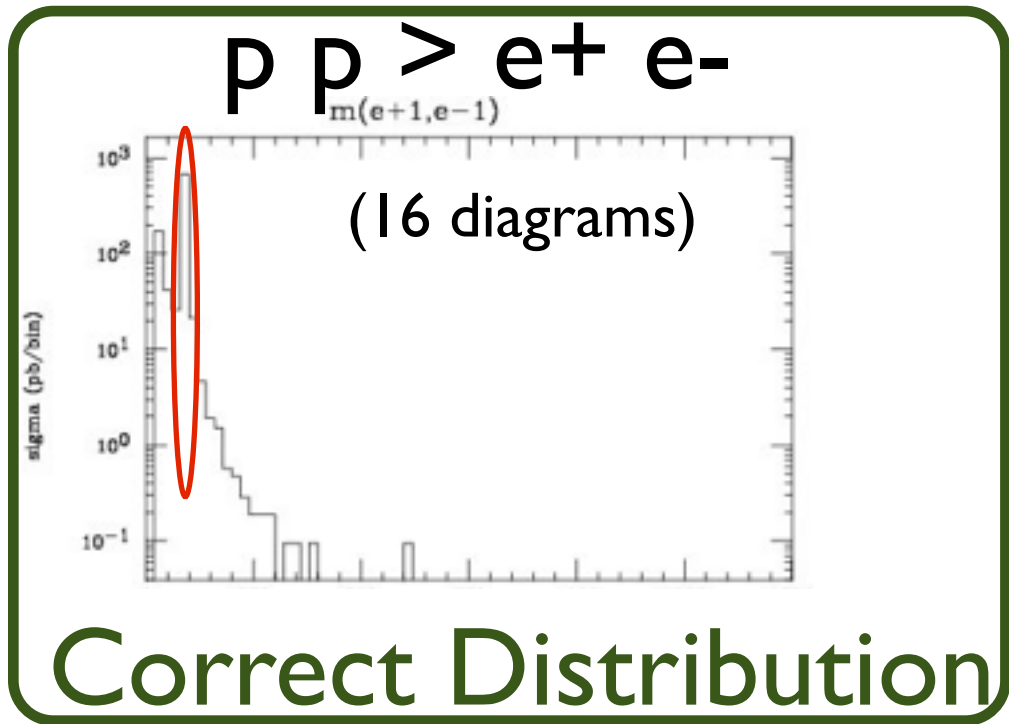
NO Z Peak

No Z

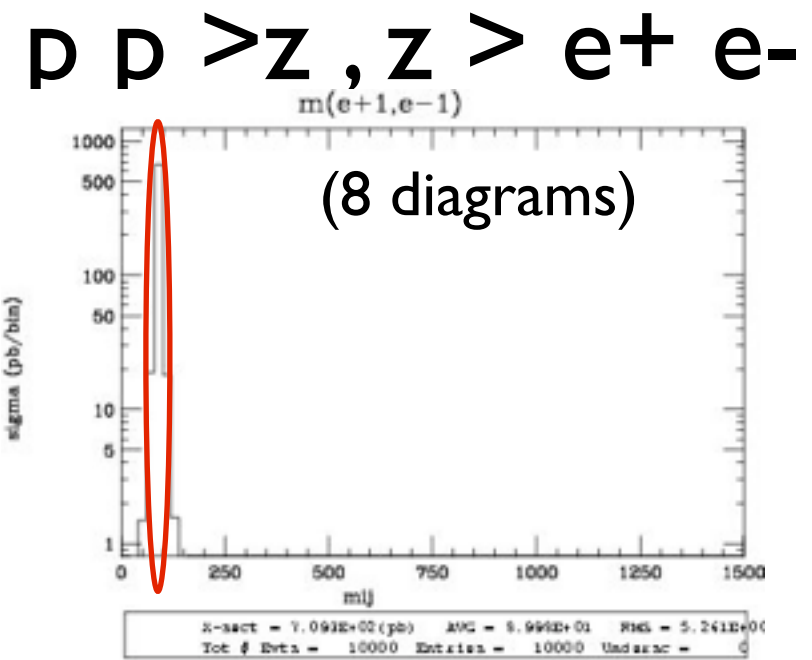
$pp \rightarrow e^+ e^- \cancel{z}$



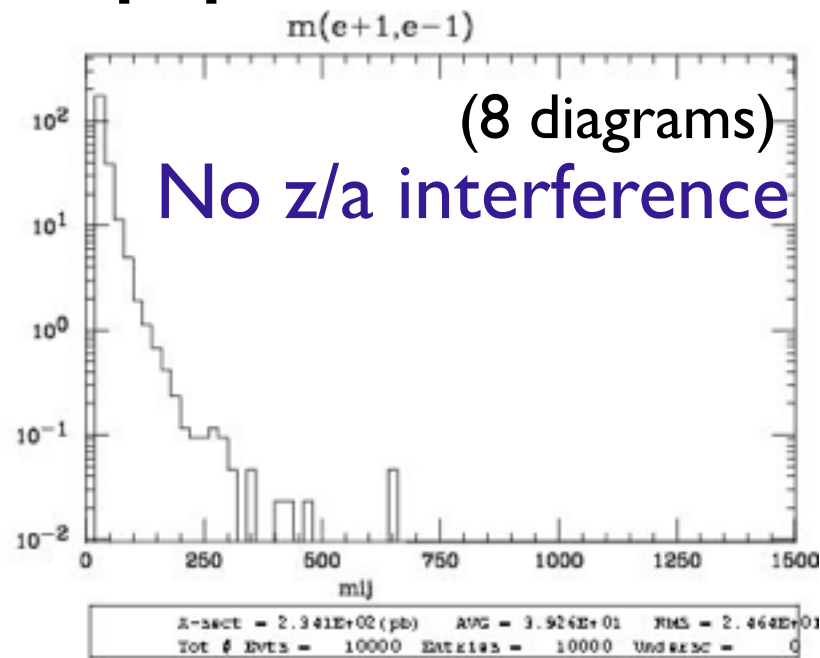
Z- onshell veto



Z Peak



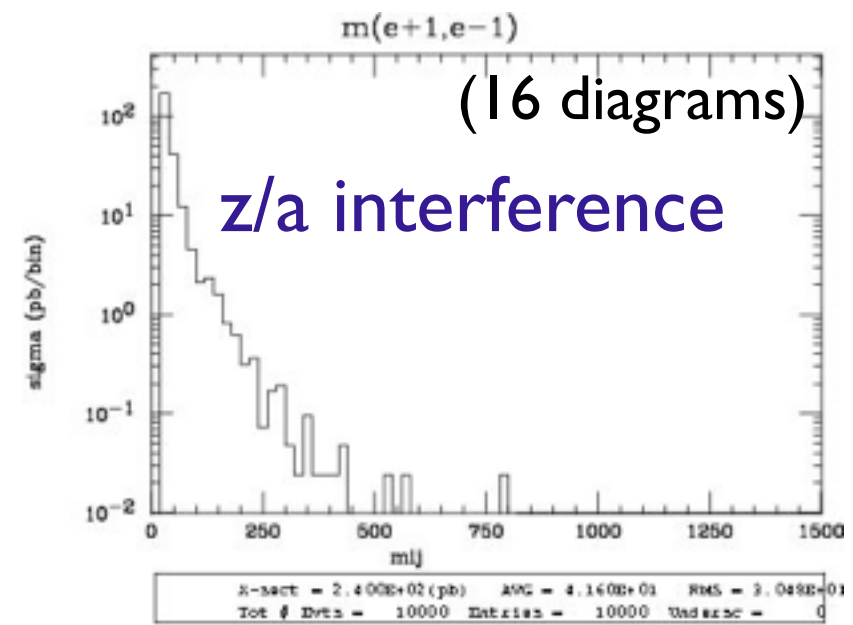
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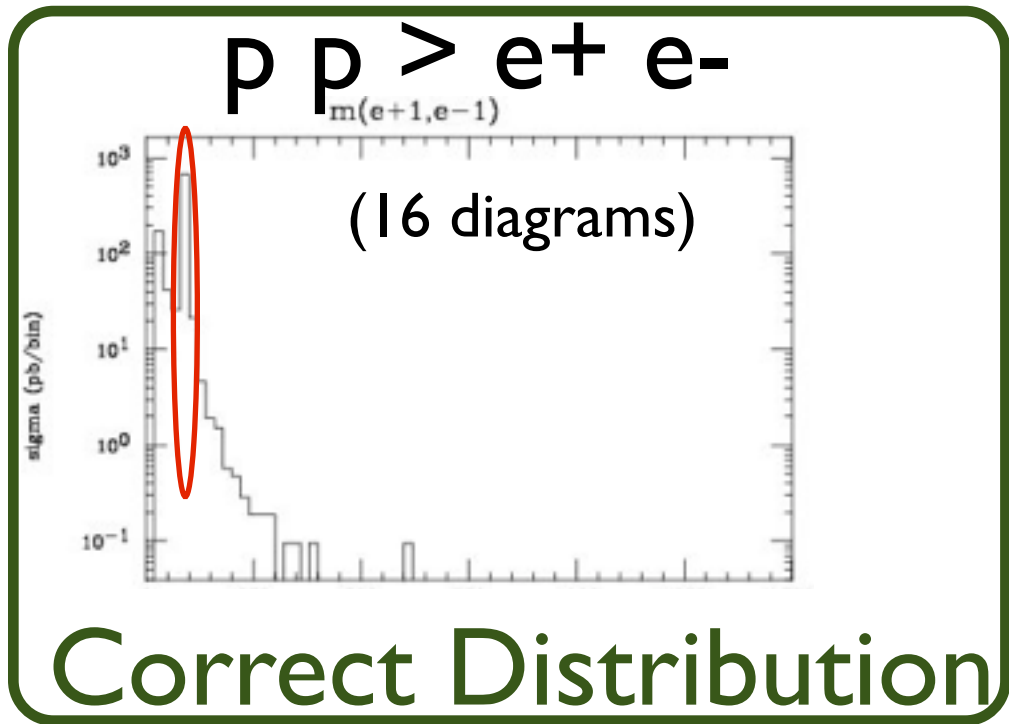
NO Z Peak

No Z

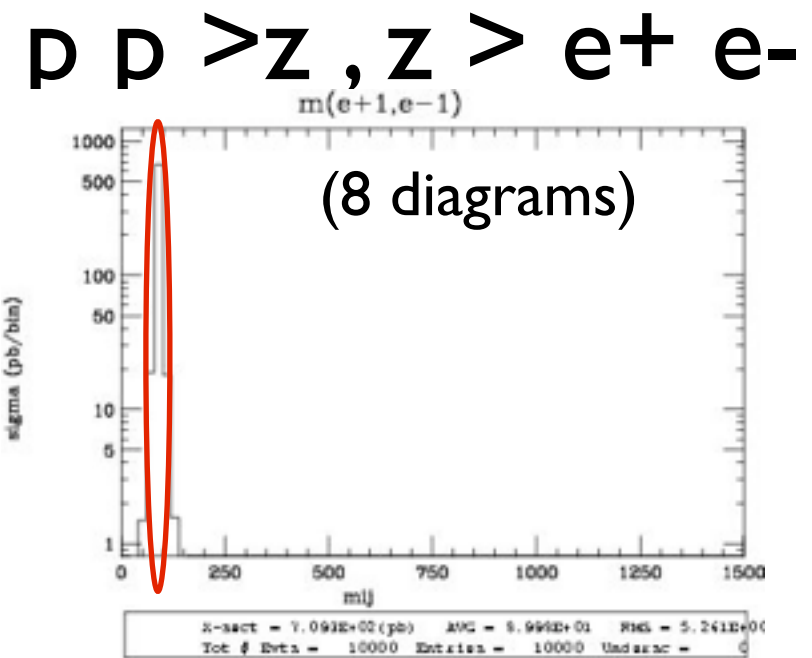
$pp \rightarrow e^+e^- \cancel{z}$



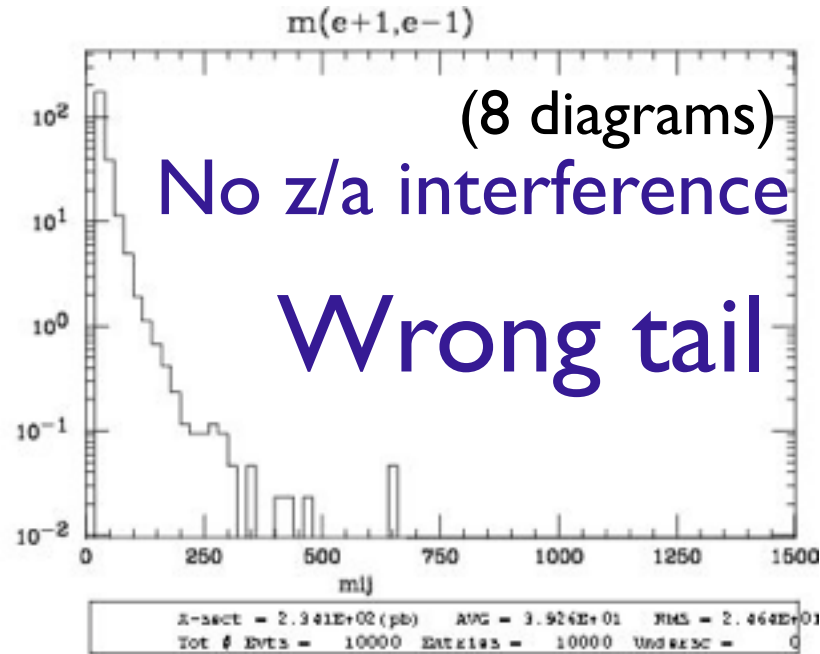
Z- onshell veto



Z Peak

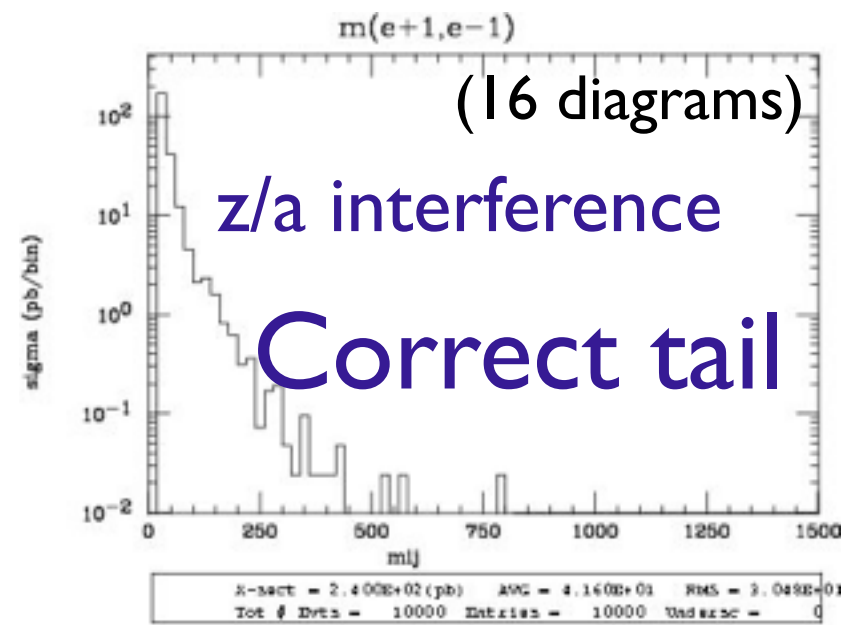


$pp \rightarrow e^+e^- / z$
 $m(e^+e^-)$



NO Z Peak

$pp \rightarrow e^+e^- \text{ } z$
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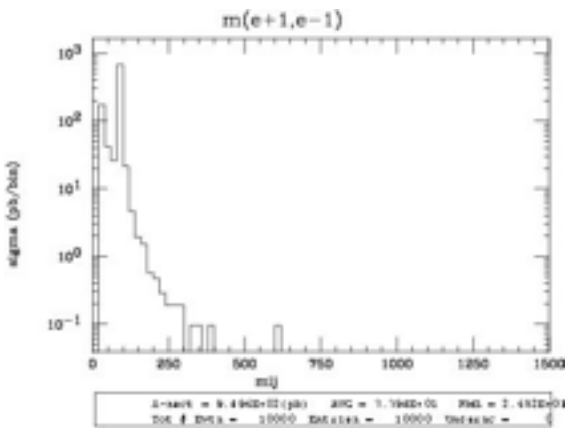
No Z

Z- onshell veto

$p p \rightarrow e^+ e^-$

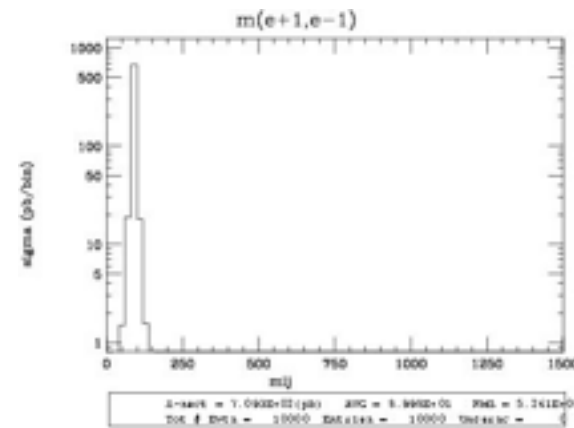
$p p \rightarrow z, z \rightarrow e^+ e^-$

$p p \rightarrow e^+ e^- \$ z$



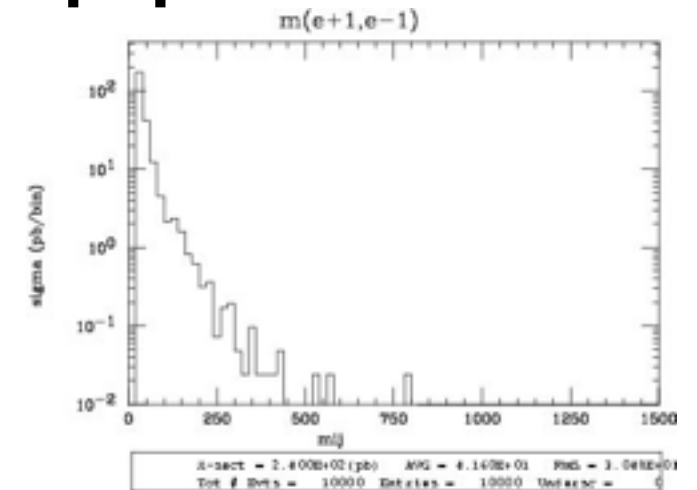
(16 diagrams)

=



(8 diagrams)

+



(16 diagrams)

Onshell cut: BW_cut

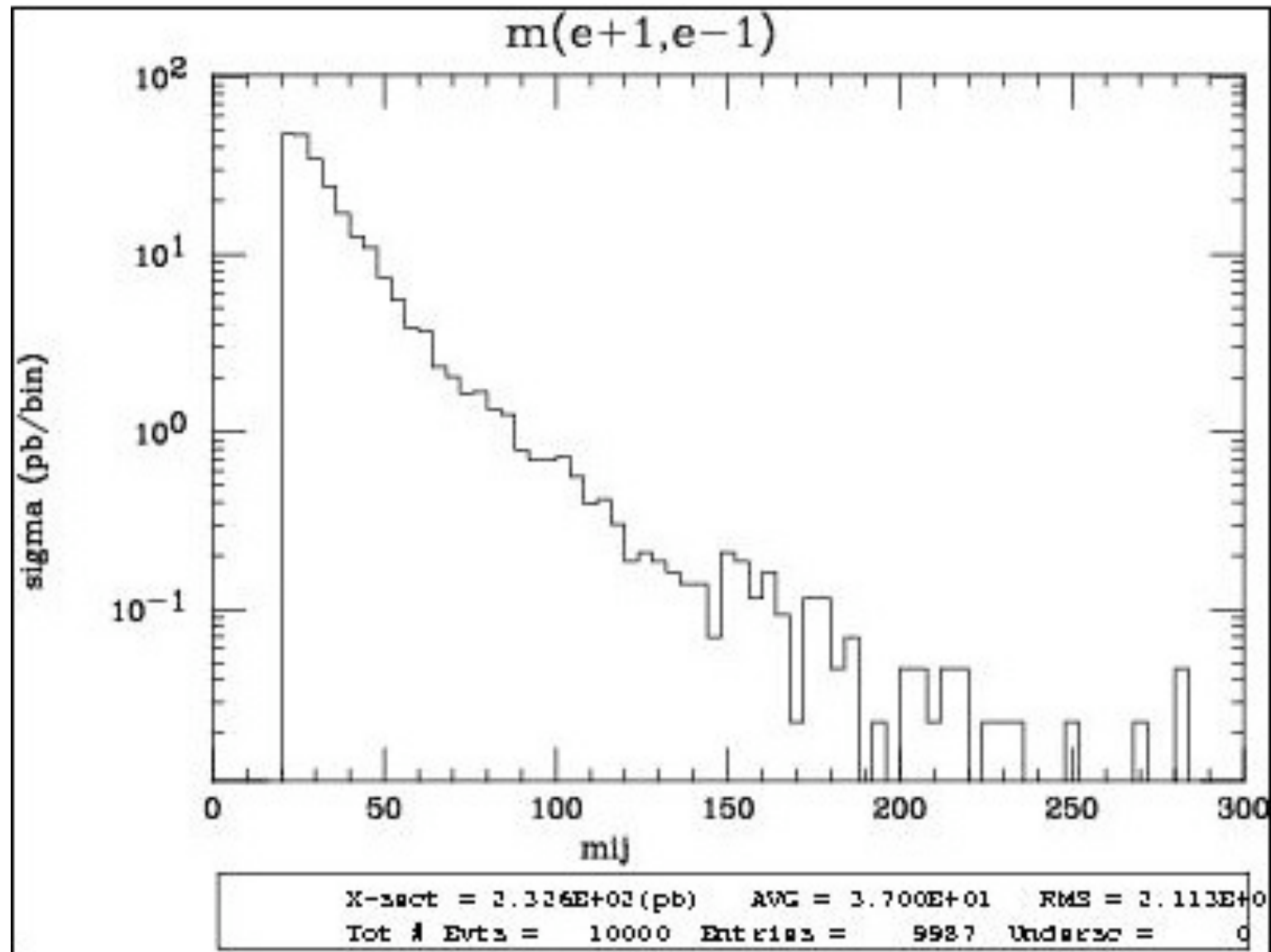
$$|M^* - M| < BW_{cut} * \Gamma$$

- 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.
- The “/” is to be avoid if possible since this leads to violation of gauge invariance.

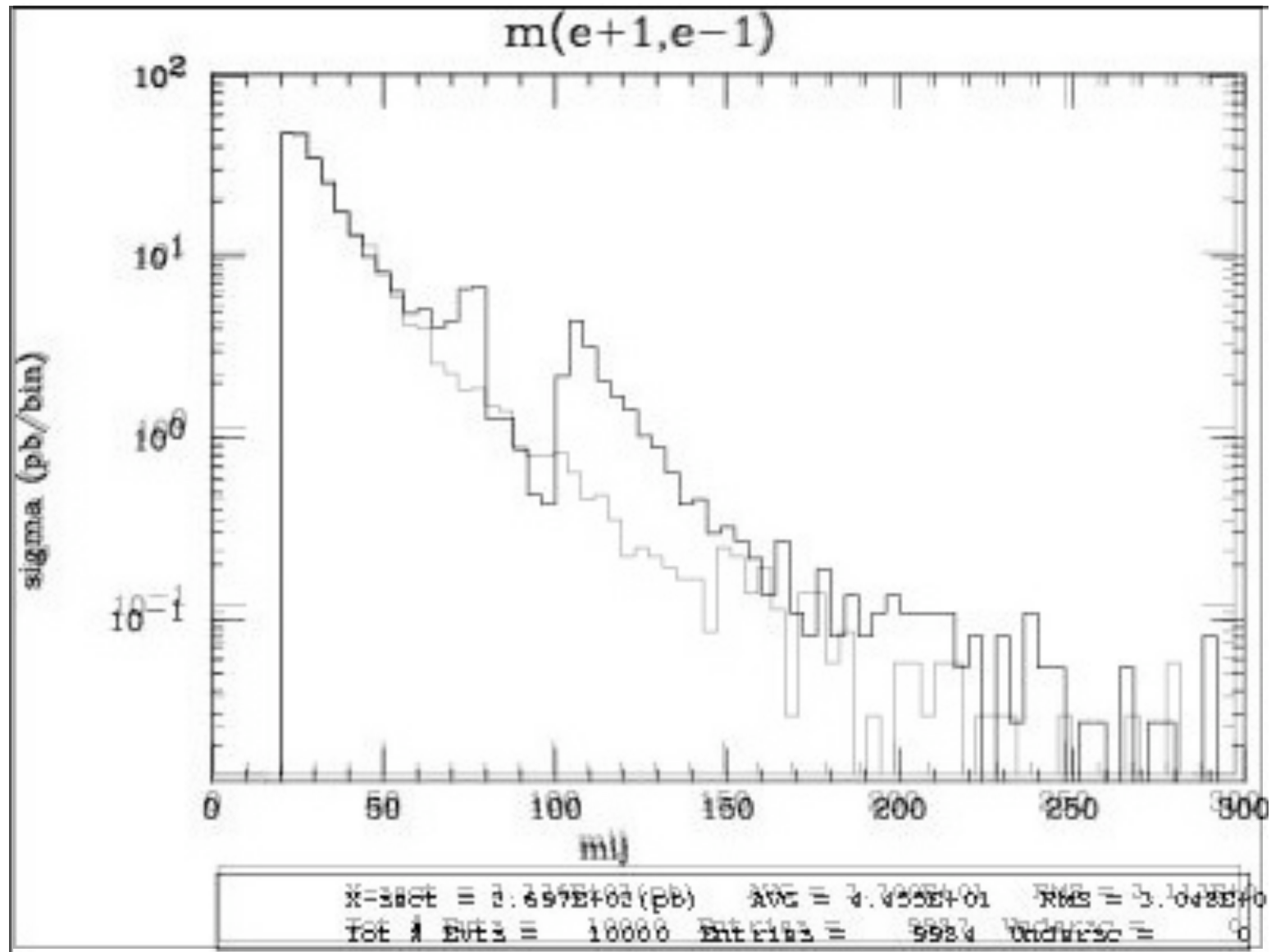
WARNING

- 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.

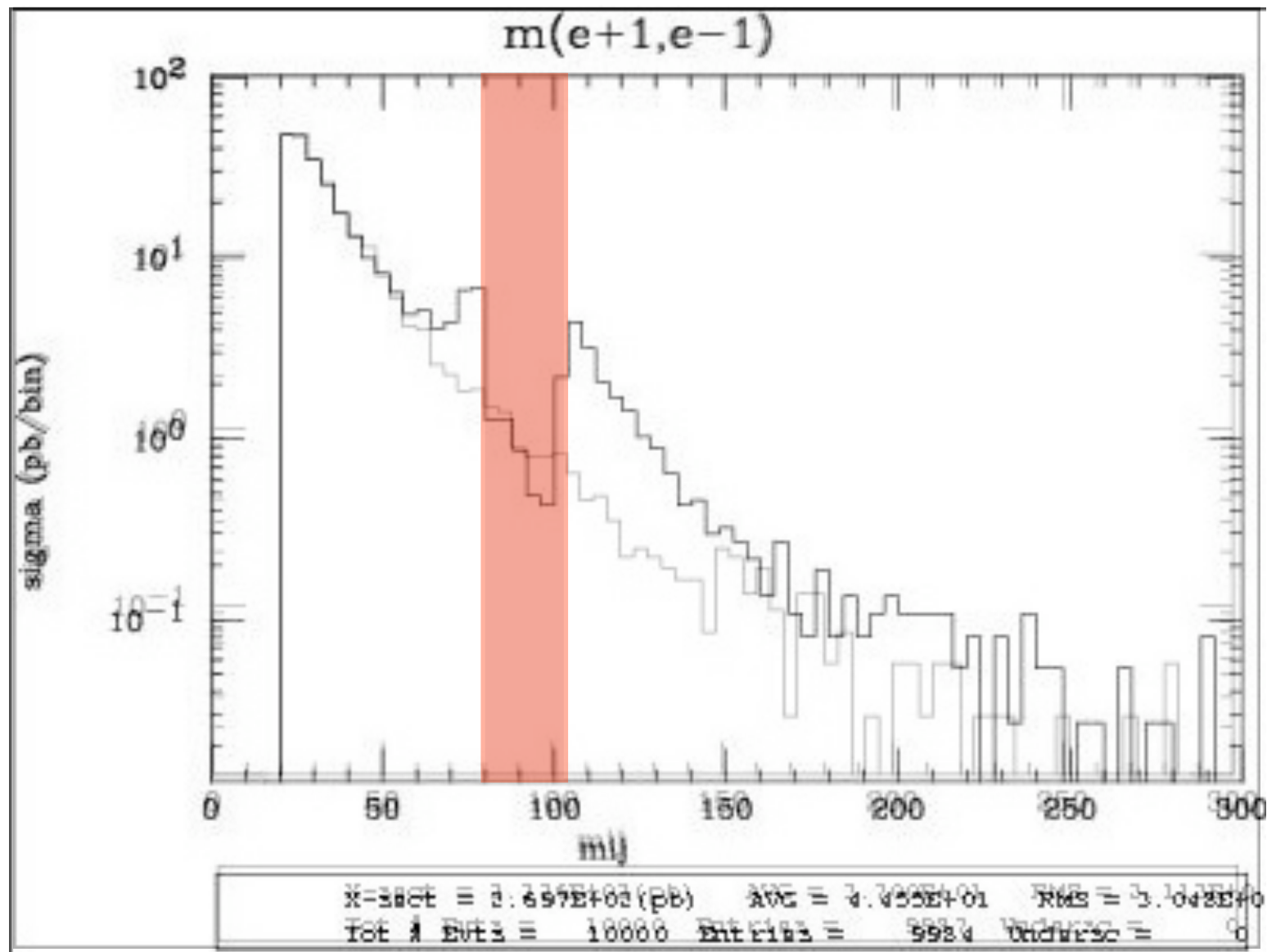
$$p p > e^+ e^- / Z$$



$$p p > e^+ e^- / Z$$

$$\text{adding } p p > e^+ e^- \text{ } Z$$


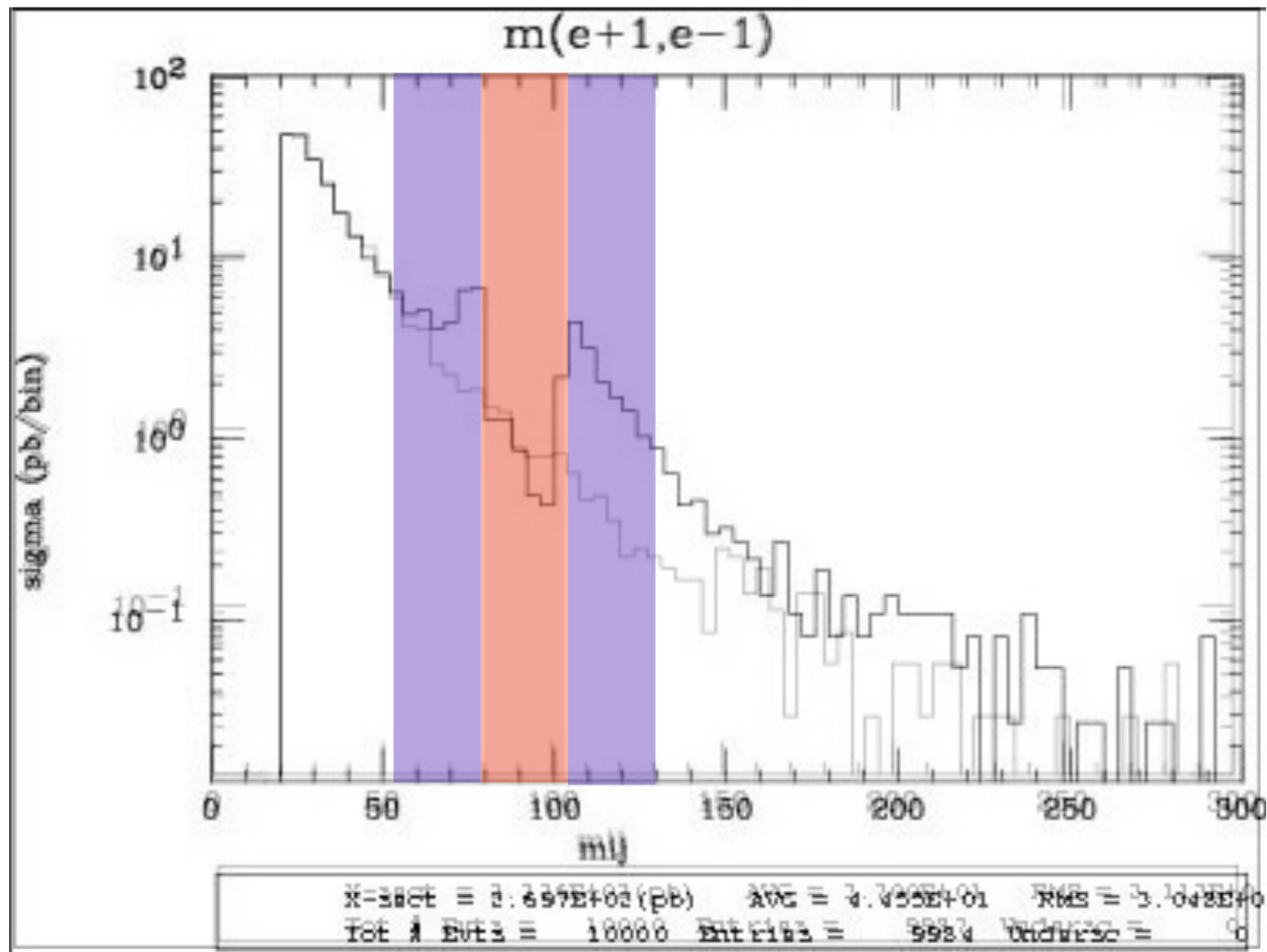
$$p p > e^+ e^- / Z$$

$$\text{adding } p p > e^+ e^- \text{ } \$ Z$$


5 times width area

- Z onshell veto
- In veto area only photon contribution

$$p p > e^+ e^- / Z$$

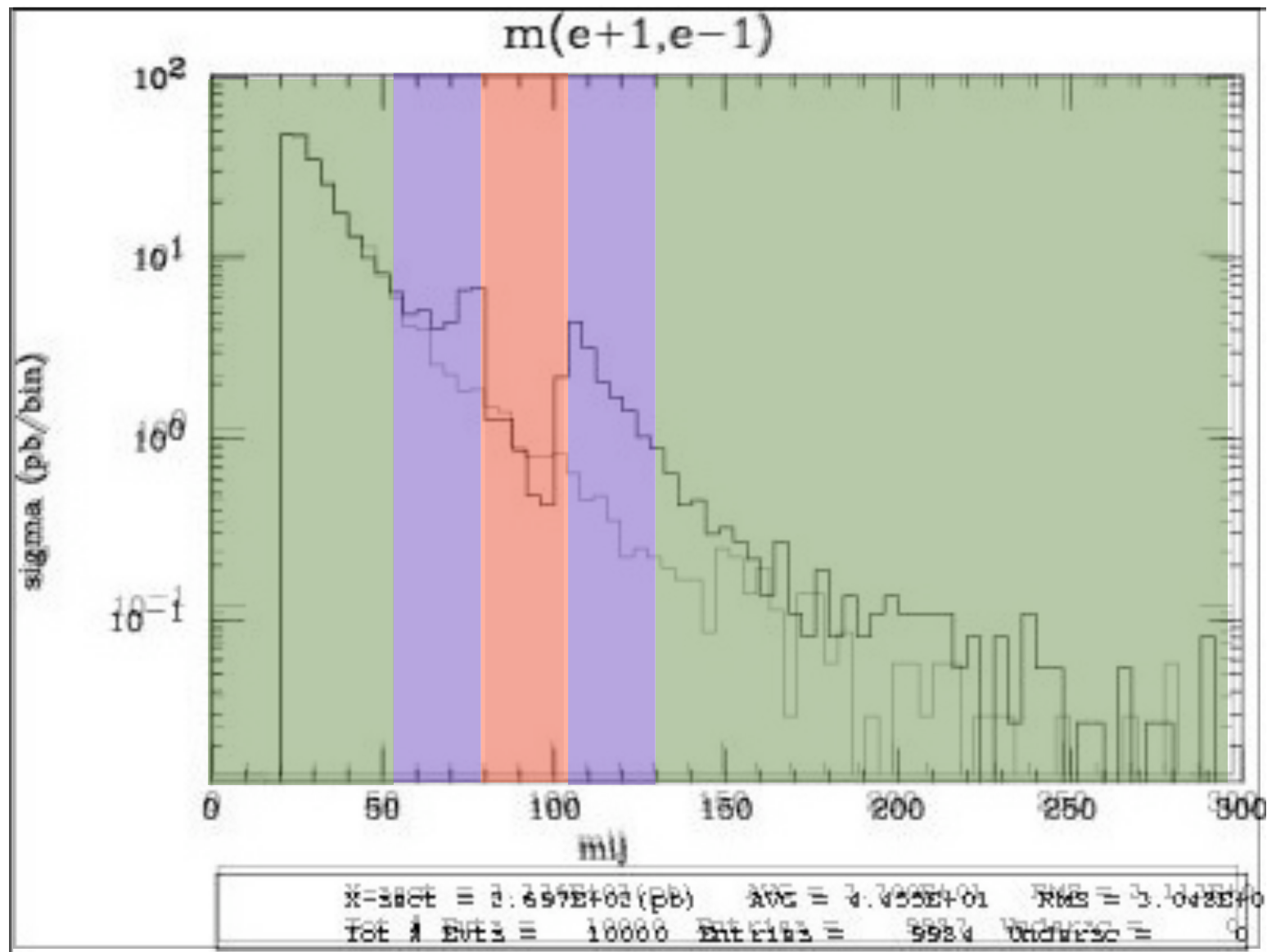
$$\text{adding } p p > e^+ e^- \text{ } \$ Z$$


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

5 times width area

15 times width area

$$p p > e^+ e^- / Z$$

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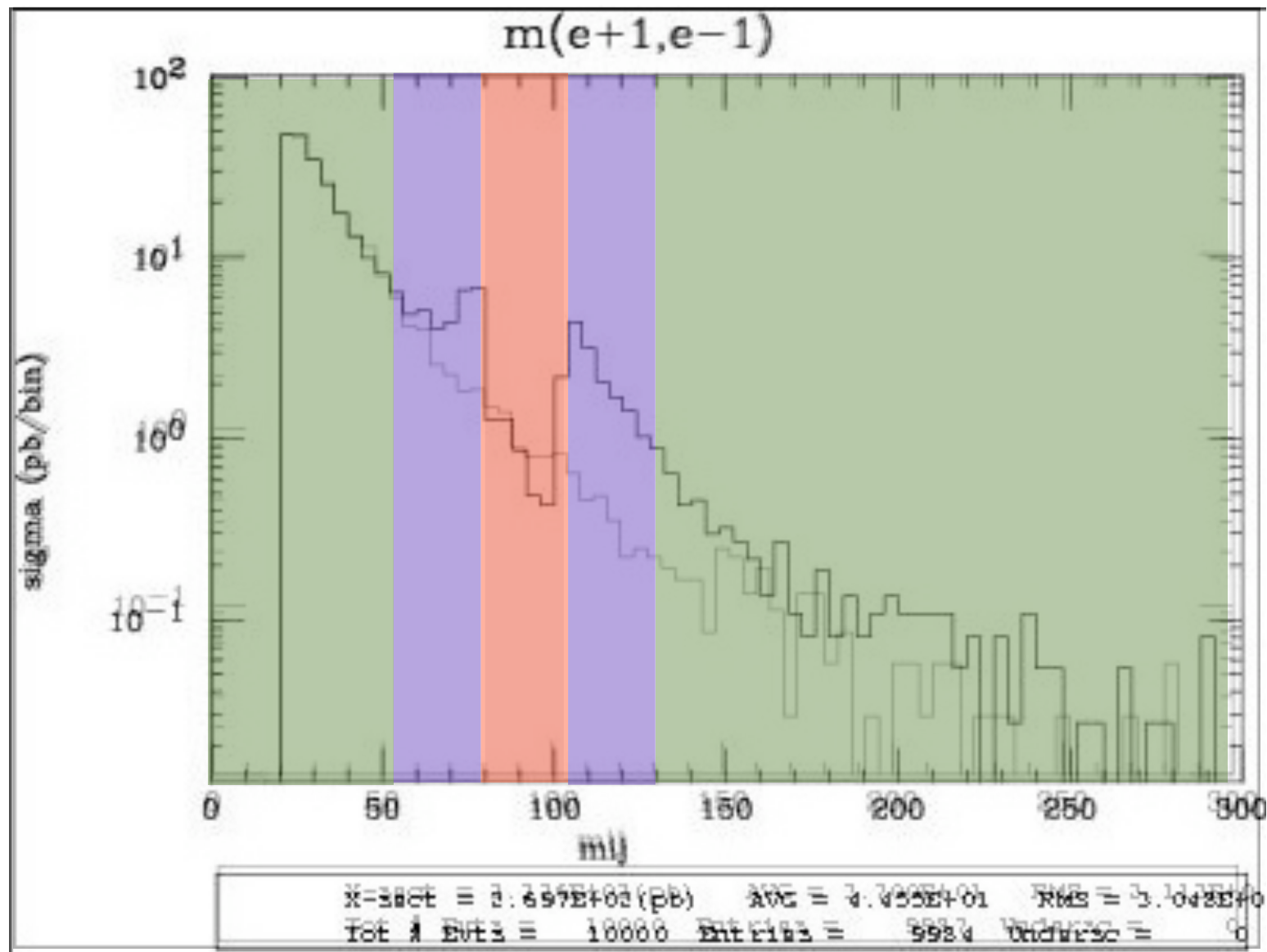
5 times width area

15 times width area

>15 times width area

- 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.

$p p > e^+ e^- / Z$

 adding $p p > e^+ e^- \$ Z$


5 times width area

15 times width area

>15 times width area

The “\$” can be use to split the sample in BG/SG area

- 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.

- Syntax Like
 - $p p \rightarrow z \rightarrow e^+ e^-$ (ask one S-channel z)
 - $p p \rightarrow e^+ e^- / z$ (forbids any z)
 - $p p \rightarrow e^+ e^- \$\$ z$ (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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 - $p p \rightarrow z \rightarrow e^+ e^-$ (ask one S-channel z)
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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
 - $p p \rightarrow z, z \rightarrow e^+ e^-$ (on-shell z decaying)
 - $p p \rightarrow e^+ e^- \cancel{z}$ (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 III: BSM

We will follow tutorial:
arxiv 1209:0297

- Download UFO model (on indico)
- Place it under models directory (That's it)

$$\mathcal{L}_{\text{s.m.}} = -\frac{m_1^2}{2}\phi_1^2 - \frac{m_2^2}{2}\phi_2^2 - m_{12}^2\phi_1\phi_2.$$

$$\mathcal{L}_{\text{f.m.}} = M_U\bar{U}U + M_E\bar{E}E.$$

$$\mathcal{L}_{Y_{uk}} = \lambda_1\phi_1\bar{U}P_Ru + \lambda_2\phi_2\bar{U}P_Ru + \lambda'_1\phi_1\bar{E}P_Re + \lambda'_2\phi_2\bar{E}P_Re$$

Exercise III:

- Check the validity of the model
- **Hint:** use the check command (use “help check” to learn the syntax)
- Compute cross-section for:
$$pp \rightarrow U\bar{U} \quad U \rightarrow u\phi_1 \quad \bar{U} \rightarrow \bar{u}\phi_1$$
- **Hint:** The width of the U needs to be computed first. (see next slide)

Width Computation

- **Old Way:**
 - generate $uv > \text{all all}$
 - output; launch
- **New Way** (some model only)
 - In `param_card` enter “Auto”
 - It use Analytical width formula provided by FeynRules

Comment: This is only two body decay.
The new method will support 3 body
in a couple of months (numerically)

Exercise IV: scripting

- Look at the cross-section for the previous process for 3 different mass points.
- **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.

Exercise V: scripting

- File content:

```
import model TUT0
generate p p > uv uv~, uv > p1 u
output
launch
set Muv 250
set width 9000006 Auto
set width 9000007 Auto
set width 9000008 Auto
set width 9000009 Auto
done
launch
set Muv 300
set width 9000008 Auto
launch
set Muv 400
set width 9000008 Auto
launch
set Muv 500
set width 9000008 Auto
█
```

- Run it by:

- `./bin/mg5 PATH`

- (smarter than `./bin/mg5 < PATH`)

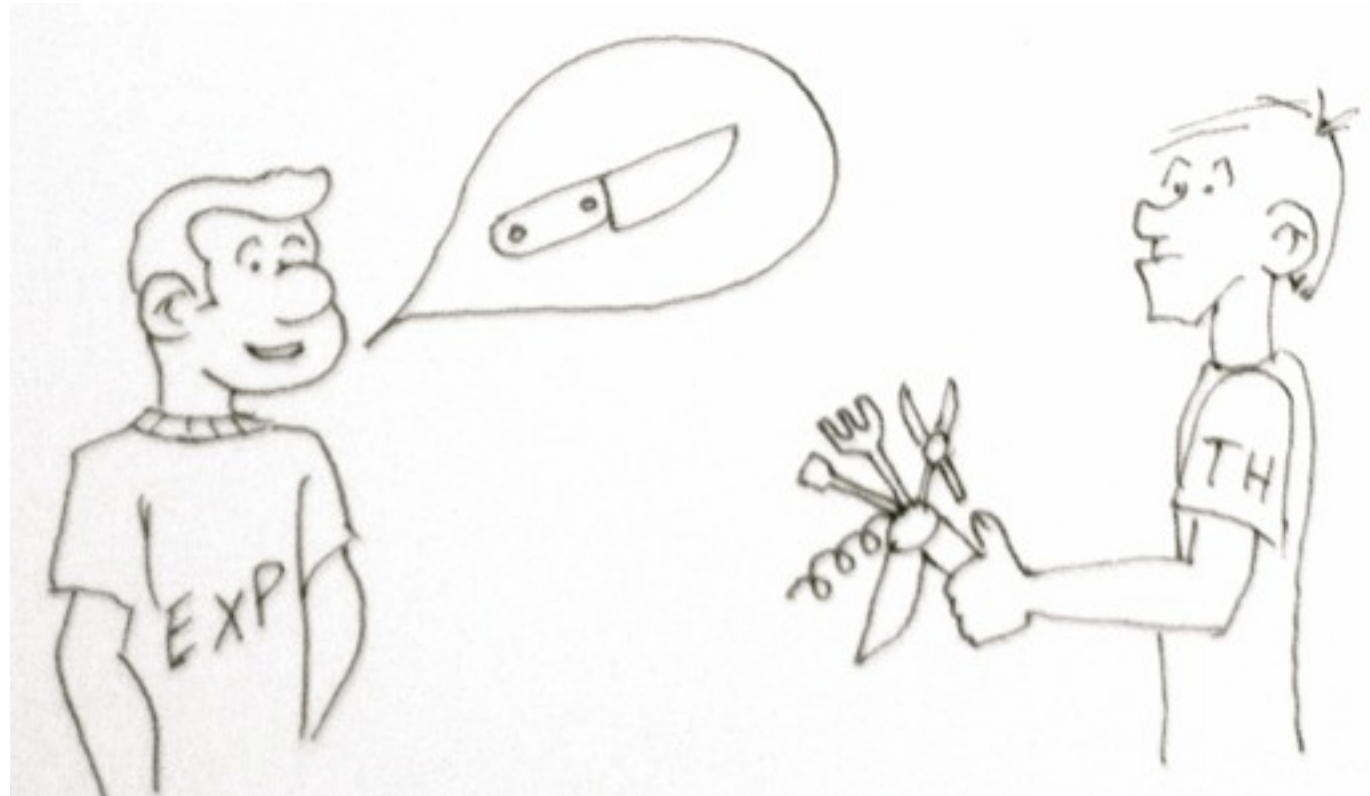
Exercise V: Optimize

- generate $p \rightarrow w^+ w^-$
- Force light quark to be massless
- With **ONLY**

$$\mathcal{O}_{WWW} = \text{Tr}[W_{\mu\nu} W^{\nu\rho} W_{\rho}^{\mu}]$$

Model **EWDIM6** has this operator implemented. **But** some other operators as well.

Exercise 4: Make an efficient generation



- When studying Operators, we want to study those one (or two) at the time.
- Theoretician wants to provide a single model

➔ How to have an efficient generation?

Model too generic

Solution I:

- Restrict the model to what you need!

Model too generic

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- Restrict the model to what you need!
 - Put your param_card in the model directory with name “restrict_NAME”
 - import your model as “MODEL-NAME”

Model too generic

Solution I:

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What is this doing ?

- **Remove** all interaction with zero coupling
- **Optimize** Model
- **Simplify** Param_card

Model too generic

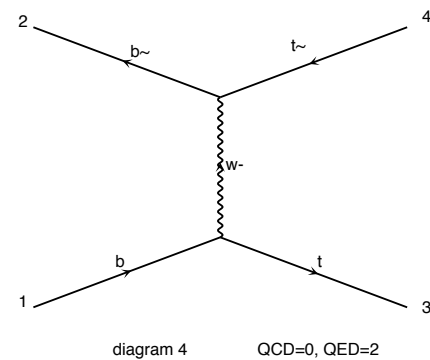
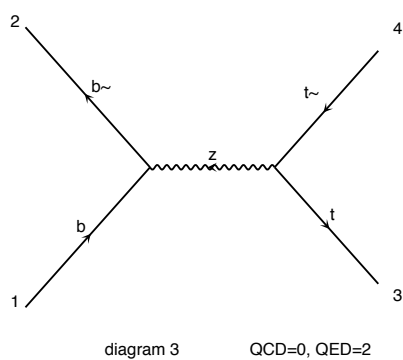
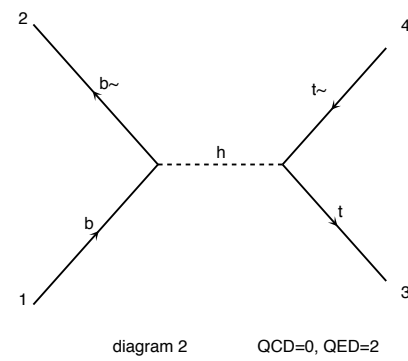
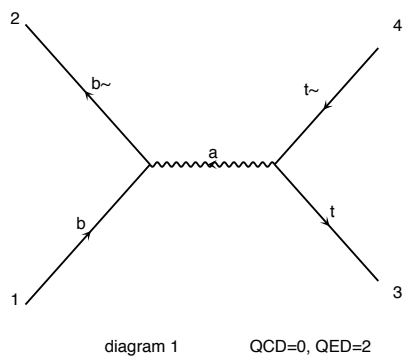
Solution I:

Examples: sm-ckm sm-lepton_masses sm-no_b_mass
sm-no_masses sm-no_tau_mass
sm-zeromass_ckm

Example

$$b \bar{b} \rightarrow t \bar{t} \quad \text{QCD}=0$$

SM



Example

$$b \bar{b} \rightarrow t \bar{t} \quad \text{QCD}=0$$

SM

SM-no_b_mass

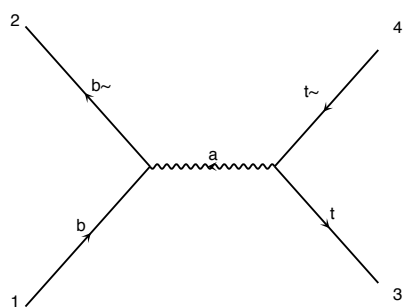


diagram 1 QCD=0, QED=2

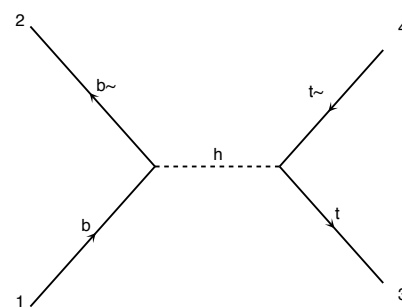


diagram 2 QCD=0, QED=2

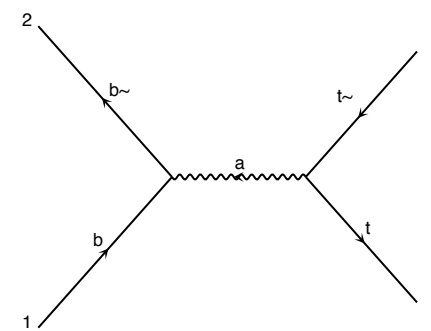


diagram 1 QCD=0, QED=2

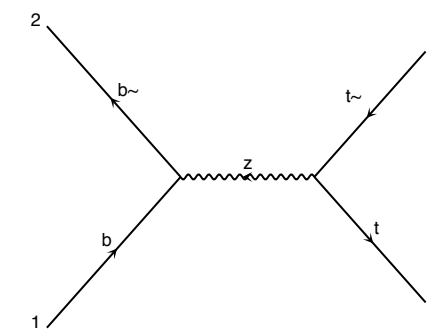


diagram 2 QCD=0, QED=2

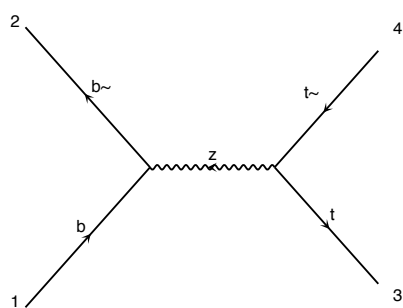


diagram 3 QCD=0, QED=2

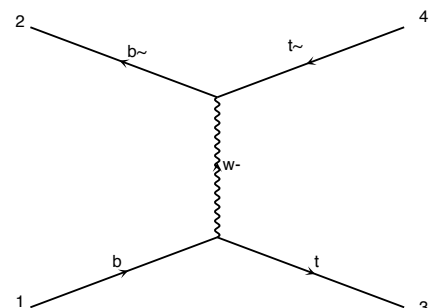


diagram 4 QCD=0, QED=2

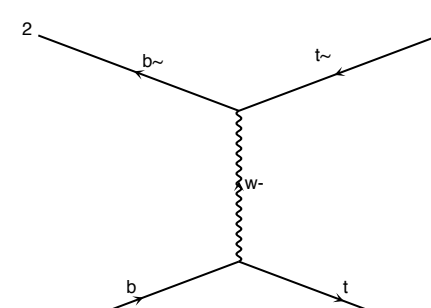


diagram 3 QCD=0, QED=2

Example

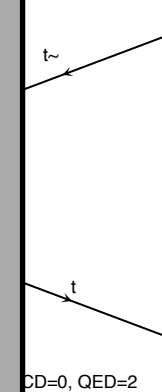
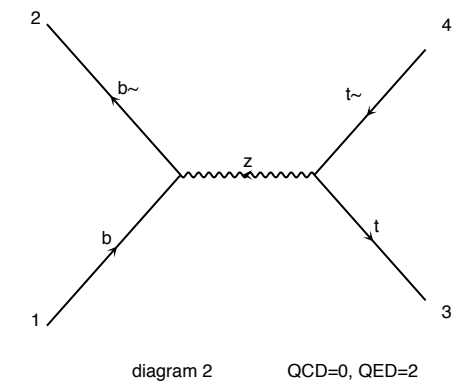
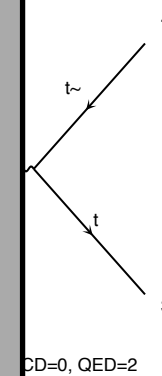
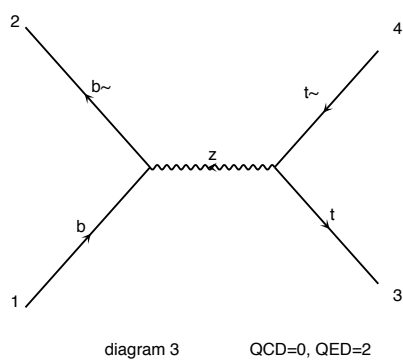
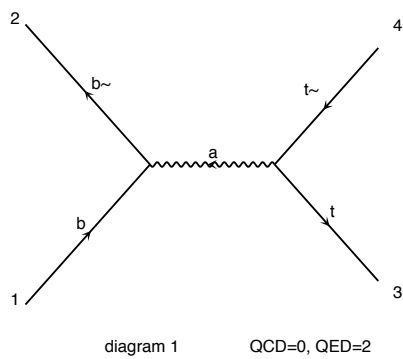
$$b \bar{b} \rightarrow t \bar{t} \quad \text{QCD}=0$$

SM

SM-no_b_mass

restriction card:

```
#####
## INFORMATION FOR MASS
#####
Block MASS
  4 0.000000e+00 # MC
  5 0.000000e+00 # MB
  6 1.730000e+02 # MT
 11 0.000000e+00 # Me
 13 0.000000e+00 # MM
 15 1.777000e+00 # MTA
 23 9.118800e+01 # MZ
 25 1.200000e+02 # MH
```



Example

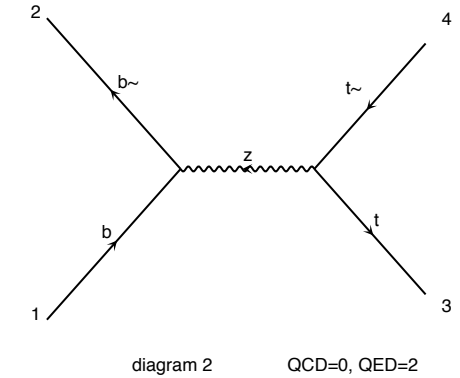
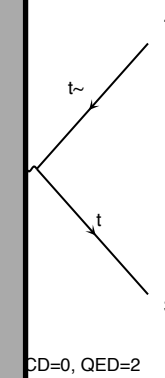
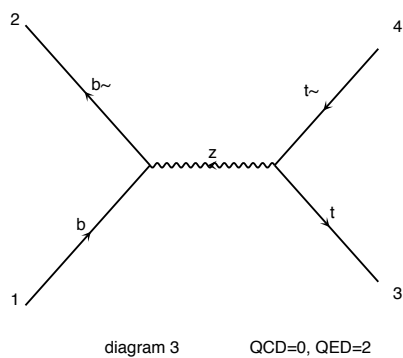
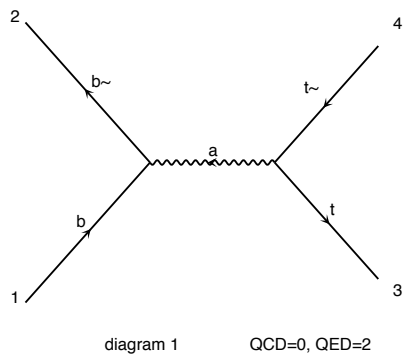
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13 0.000000e+00 # MM
15 1.777000e+00 # MTA
23 9.118800e+01 # MZ
25 1.200000e+02 # MH
```



Example

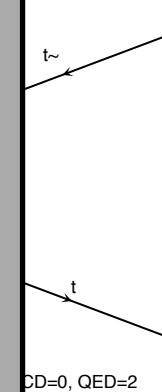
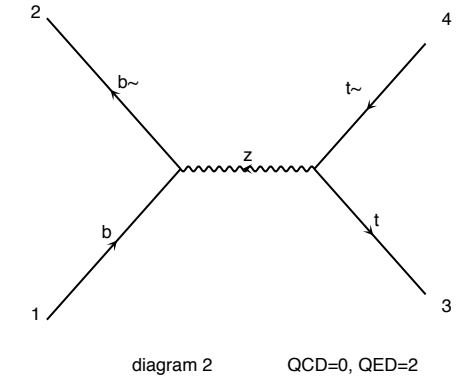
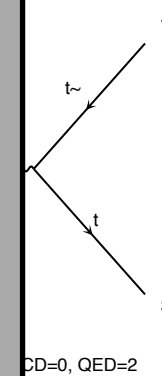
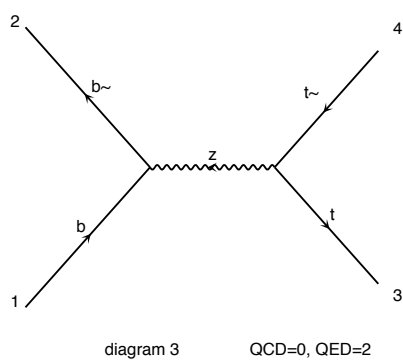
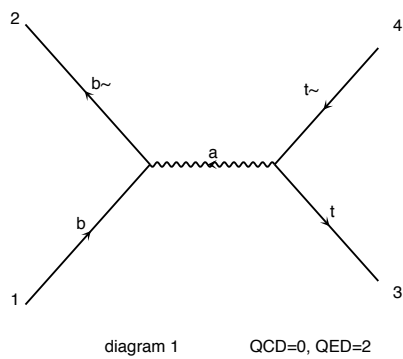
$$b \bar{b} \rightarrow t \bar{t} \text{ QCD}=0$$

SM

SM-no_b_mass

restriction card:

```
#####
## INFORMATION FOR MASS
#####
Block MASS
4 #####
5 ## INFORMATION FOR YUKAWA
6 #####
7 Block YUKAWA
8
9 4 0.000000e+00 # ymc
10 5 0.000000e+00 # ymb
11 6 1.645000e+02 # ymt
12 11 0.000000e+00 # yme
13 13 0.000000e+00 # ymm
14 15 1.777000e+00 # ymtau
15
```

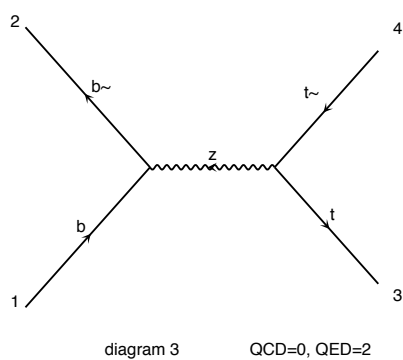
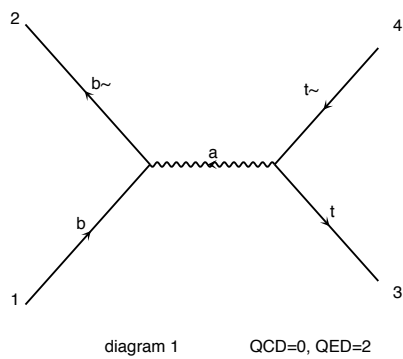


Example

$$b \bar{b} \rightarrow t \bar{t} \text{ QCD}=0$$

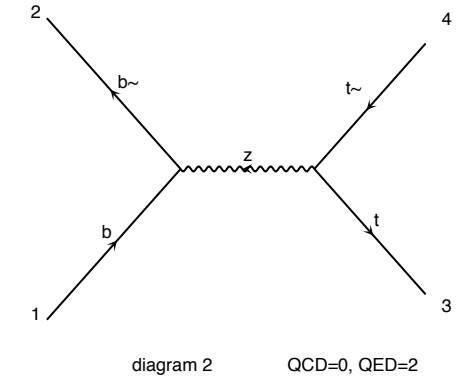
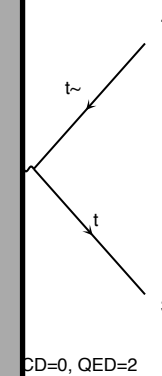
SM

SM-no_b_mass



restriction card:

```
#####
## INFORMATION FOR MASS
#####
Block MASS
4
5
6
11
13
15
#####
## INFORMATION FOR YUKAWA
#####
Block YUKAWA
4 0.000000e+00 # ymc
5 0.000000e+00 # ymb
6 1.645000e+02 # ymt
11 0.000000e+00 # yme
13 0.000000e+00 # ymm
15 1.777000e+00 # ymtau
```



Example

$b \bar{b} \rightarrow t \bar{t}$ QCD=0

SM

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 1.200000e+02 # MH
## Not dependent parameter.
## Those values should be edited for
## analytical expression. MG5 ignore
## but they are important for interf
## to external program such as Pyth
 12 0.000000 # ve : 0.0
 14 0.000000 # vm : 0.0
 16 0.000000 # vt : 0.0
  2 0.000000 # u : 0.0
  4 0.000000 # c : 0.0
  1 0.000000 # d : 0.0
  3 0.000000 # s : 0.0
```

SM-no_b_mass

Param_card:

```
#####
## INFORMATION FOR MASS
#####
Block mass
  6 1.730000e+02 # MT
 15 1.777000e+00 # MTA
 23 9.118800e+01 # MZ
 25 1.200000e+02 # MH
## Not dependent parameter.
## Those values should be edited for
## analytical expression. MG5 ignore
## but they are important for interf
## to external program such as Pyth
 12 0.000000 # ve : 0.0
 14 0.000000 # vm : 0.0
 16 0.000000 # vt : 0.0
  2 0.000000 # u : 0.0
  4 0.000000 # c : 0.0
  1 0.000000 # d : 0.0
  3 0.000000 # s : 0.0
  5 0.000000 # b : 0.0
```


Example

$b b^{\sim} > t t^{\sim}$ QCD=0

SM

SM-no_b_mass

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 1.200000e+02 # MH
## Not dependent parameter.
## Those values should be edited for
## analytical expression. MG5 ignore
## but they are important for interf
## to external program such as Pyth
12 0.000000 # ve : 0.0
14 0.000000 # vm : 0.0
16 0.000000 # vt : 0.0
 2 0.000000 # u : 0.0
 4 0.000000 # c : 0.0
 1 0.000000 # d : 0.0
 3 0.000000 # s : 0.0
```

Param_card:

```
#####
## INFORMATION FOR MASS
#####
Block mass
 6 1.730000e+02 # MT
15 1.777000e+00 # MTA
23 9.118800e+01 # MZ
25 1.200000e+02 # MH
## Not dependent parameter.
## Those values should be edited for
## analytical expression. MG5 ignore
## but they are important for interf
## to external program such as Pyth
12 0.000000 # ve : 0.0
14 0.000000 # vm : 0.0
16 0.000000 # vt : 0.0
 2 0.000000 # u : 0.0
 4 0.000000 # c : 0.0
 1 0.000000 # d : 0.0
 3 0.000000 # s : 0.0
 5 0.000000 # b : 0.0
```

Model too generic

Solution I:

Examples: sm-ckm sm-lepton_masses sm-no_b_mass
sm-no_masses sm-no_tau_mass
sm-zeromass_ckm

- **Advantages**

- ☞ Easy to implement for the final user
- ☞ Quite optimal

What you need to do !

Model too generic

Solution I:

Examples: sm-ckm sm-lepton_masses sm-no_b_mass
sm-no_masses sm-no_tau_mass
sm-zeromass_ckm

- **Advantages**

- ☞ Easy to implement for the final user
- ☞ Quite optimal

- **Drawbacks**

- ☞ Potential accidental removal
 - ☞ The number of restriction card to cover all cases
- What you need to do !**

Model Too Generic

Solution II:

- Create your restriction card on the flight:

I. Filling in the form:

Model: EWdim6

Options:

sm customization

diagonal ckm

c mass = 0

b mass = 0

tau mass = 0

muon mass = 0

electron mass = 0

Adding Dim6 Operator

CWWW

CW

CB

CWWW CP violating

CW CP violating

Input Processes:

First process

Process: Order Automatic Add Decay

p and j definitions:

Sum over leptons:

Add process Submit

Web Page In Development

Model Too Generic

Solution II:

- Create your restriction card on the flight:

```
m_5>customize_model
INFO: load particles
INFO: load vertices
sm customization:
  1: diagonal ckm [True]
  2: c mass = 0 [True]
  3: b mass = 0 [False]
  4: tau mass = 0 [False]
  5: muon mass = 0 [True]
  6: electron mass = 0 [True]
Adding Dim6 Operator:
  7: CWW [True]
  8: CW [True]
  9: CB [True]
 10: CWW CP violating [False]
 11: CW CP violating [False]
Enter a number to change it's status or press enter to validate [0, 1, 2, 3, 4, 5, 6, 7, 8, ... ][60s to answer]
```

Available Now!

This require some work of the model builder

=> Not available for all model

Exercise VI: Matching + Merging

Merging ME with PS

[Mangano]
[Catani, Krauss, Kuhn, Webber]

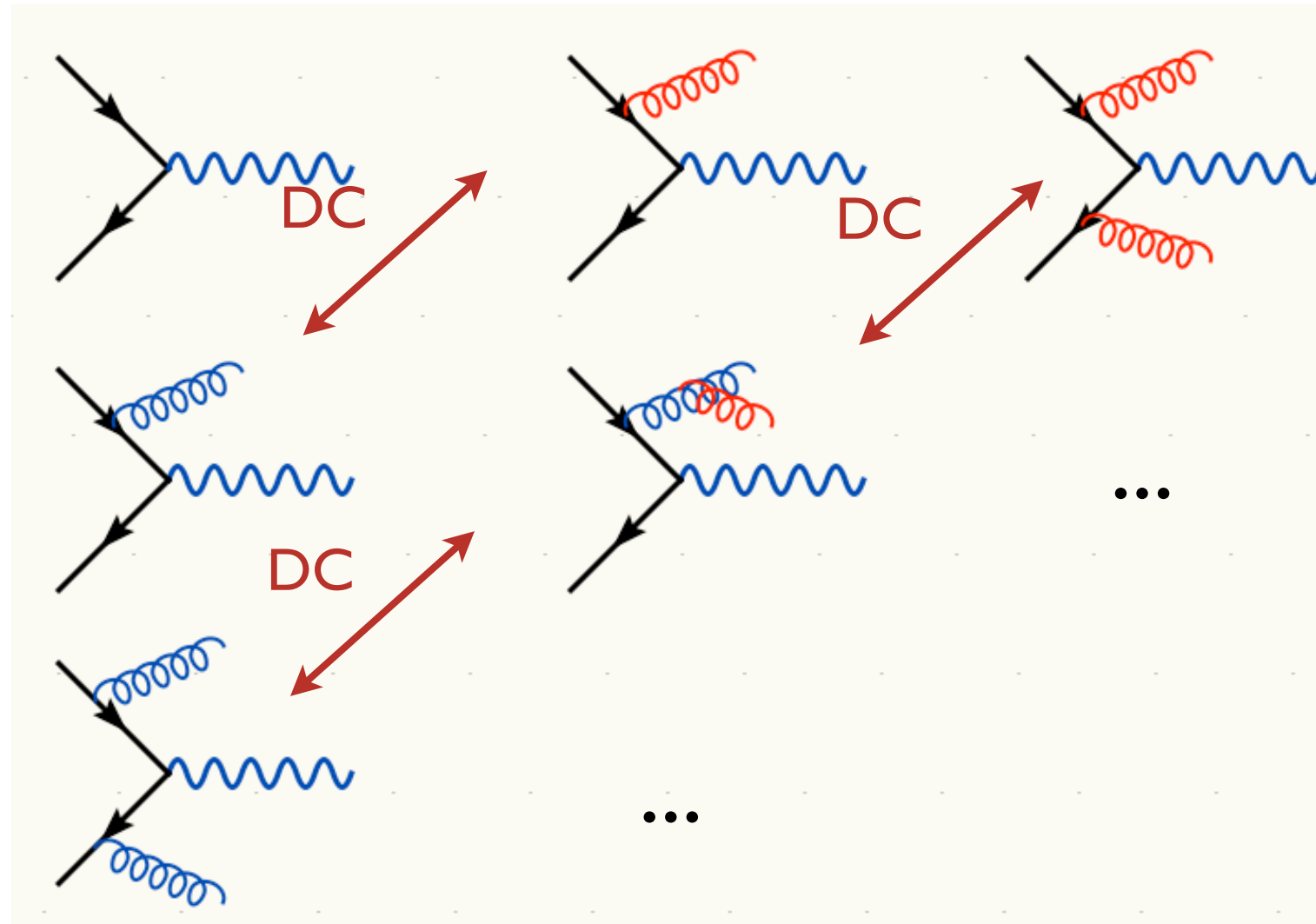
PS →

$$pp \rightarrow W^+$$

$$pp \rightarrow W^+ j \text{ ME}$$



$$pp \rightarrow W^+ jj$$

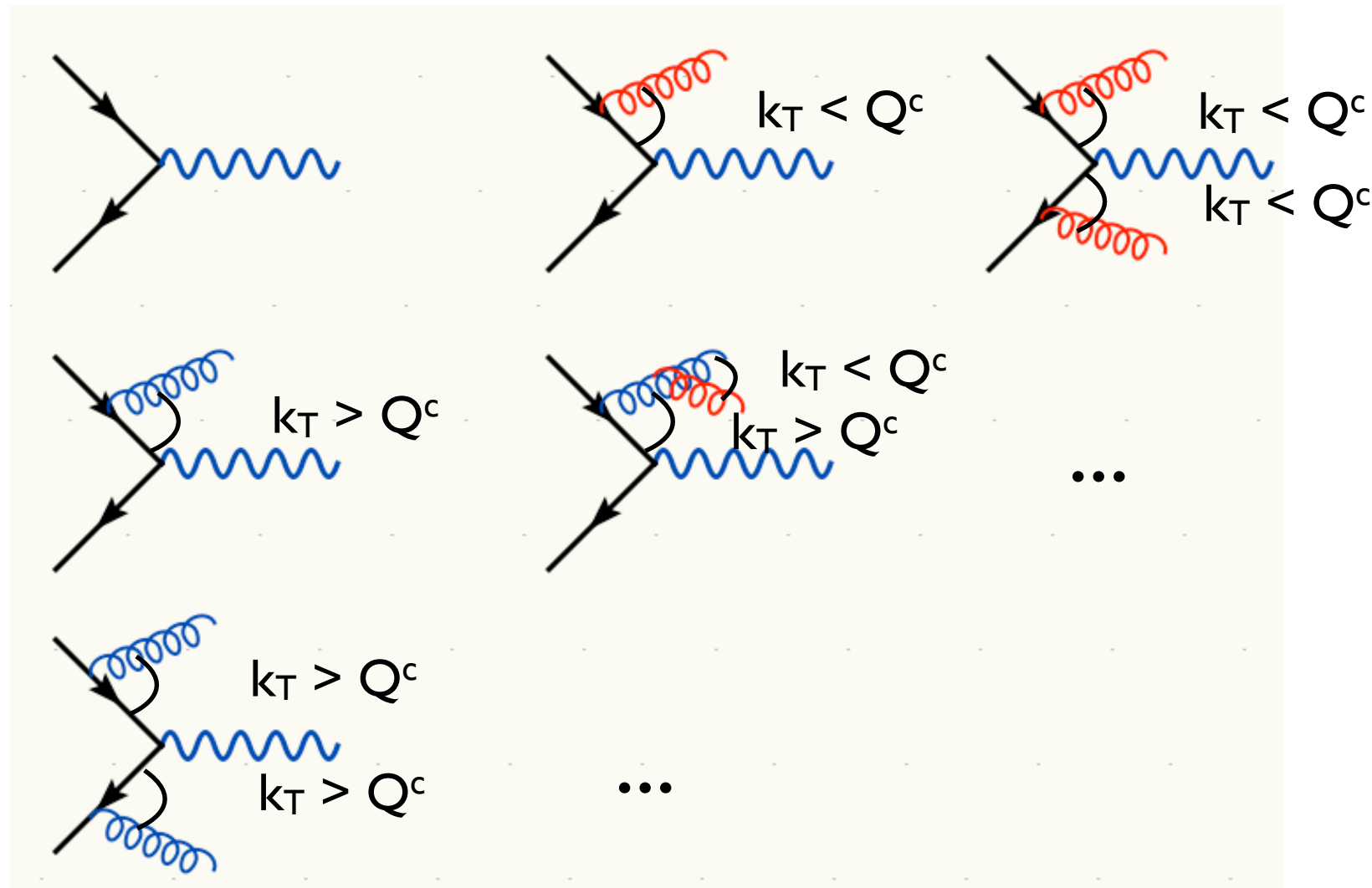


Merging ME with PS

[Mangano]
[Catani, Krauss, Kuhn, Webber]

PS →

ME



Double counting between ME and PS easily avoided using phase space cut between the two: PS below cutoff, ME above cutoff.

MLM algorithm in a nutshell

1. Generate ME events (with different parton multiplicities) using parton-level cuts ($p_T^{\text{ME}}/\Delta R$ or k_T^{ME})
2. Cluster each event and reweight α_s and PDFs based on the scales in the corresponding clustering vertices
3. Run the parton shower with starting scale $t_0 = m_T$.
4. Check that the number of jets after parton shower is the same as ME partons, and that all jets after parton shower are matched to the ME partons at a scale Q^{match} .
If yes, keep the event. If no, reject the event. Q^{match} is called the *matching scale*.
5. For highest multiplicity, allow radiation $<$ lowest ME scale

Excercise 5: Matching + Merging

- In `run_card`: put `icckw=1`
 - set the value for `xqcut`
- In `pythia_card` set a value for `qcut`

Exercises

Time to play around yourselves! Some suggestions:

1. Generate $p p \rightarrow w^+ w^-$ with 0 jets, 0,1 jets and 0,1,2 jets
(Each on different computers - use the most powerful computer for 0,1,2 jets)
 - a. Generate 20,000 events for a couple of different x_{qcut} values.
 - b. Compare the distributions (before and after Pythia) and cross sections (before and after Pythia) between the different processes, and between the different x_{qcut} values.
 - c. Summarize: How many jets do we need to simulate? What is a good x_{qcut} value? How are the distributions affected?
2. Do the same exercise for matched squark production
($p p \rightarrow u \bar{u} + 0,1$ jets)
 - a. Run with and without “\$ go” - how does the result change?
 - b. With “\$ go”, do the exercises a.-c. under 1. What is a good choice for matching scale?

Exercise VII: aMC@NLO

- Download the 2.0.0.beta2 version
- gcc 4.6 (or more recent)
- fastjet
 - enter the path in `./input/mg5_configuration`
- for the shower, you need to install extra package
 - install MCatNLO-utilities

aMC@NLO

- Follow the tutorial [[tutorial aMC@NLO](#)]
- Generate top-quark pair production with full spin correlation decay.
- **hint:** top decay can't be done @NLO, use Madspin for the decay
 - MadSpin is automatically installed.
 - is proposed to you when you do **launch**

Congratulations!