MG5aMC tutorial

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Avoid internet !

- We are many on the room.
  - ➡ External network is bounded to be slow
- Setup Madgraph to use the local network
  - ➡ export MG5aMC_WWW="http://192.168.1.133:8000"
  - ➡ This requires version 2.6.5
- Need to download MG5aMC
  - ➡ http://192.168.1.133:8000/MG5
- For PDF:
  - ➡ http://192.168.1.133:8000/PDF

Ex. I: Install MadGraph 5!

- http://192.168.1.133:8000/MG5/
- untar it (tar -xzpvf MG5_XXX.tgz)
- launch it ($ ./bin/mg5_amc)

- learn it!
  - ➡ Type tutorial and follow instructions

- install external package
  - ➡ install pythia8
  - ➡ install MadAnalysis5
- Be sure that you have run export cmd in that shell
  - ➡ export MG5aMC_WWW="http://192.168.1.133:8000"

Where to find help (after the school)?

- Type tutorial
- 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

Ex. II : Order

Goal

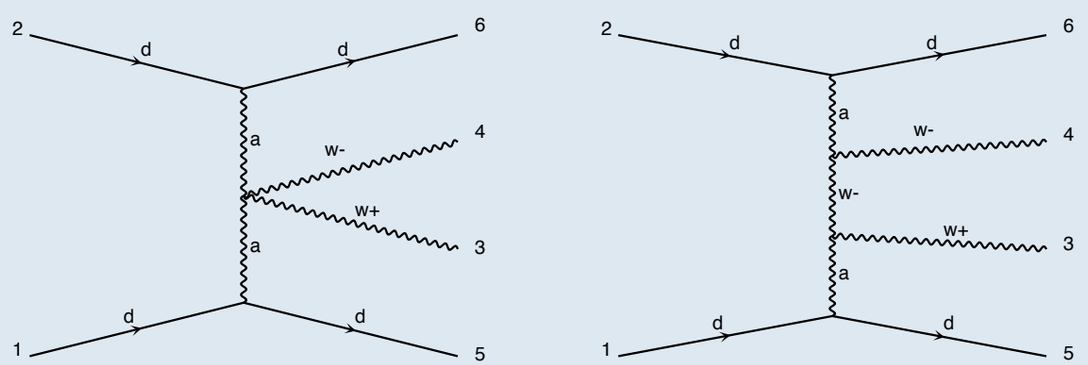
- What's the default choice for QED/QCD order

Learn

- What's the difference between
  - ➡ p p > t t~
  - ➡ p p > t t~ QED=0
  - ➡ p p > t t~ QED<=2
- Compute the cross-section for each of those and check the diagram

Check

- Generate VBF process (two jet + two W in final state) only the diagram!
- check that you have the QED diagram that you want:



Solution I : Syntax

- What's the meaning of the order QED/QCD
  - ➡ By default MG5 takes the lowest order in QED!

```
INFO: Trying coupling order WEIGHTED<=2: WEIGTHED IS 2*QED+QCD
```

  - ➡ p p > t t~ IS the same as p p > t t~ QED=0
  - ➡ p p > t t~ QED<=2 has 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

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

Ex III: What are those cards?

- Read the Cards and identify what they do
  - ➡ param_card
  - ➡ run_card:
- To see such cards run:
  - ➡ Generate p p > t t~
  - ➡ Output
  - ➡ Launch
    - ✦ Type enter to the first question
    - ✦ Now you can type 1 or 2 to see the files

Exercise III: Cards Meaning

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

Ex III: What are those cards? (Solution)

- Read the Cards and identify what they do
  - ➡ param_card: model parameters
    - ✦ Note aS is not typically not read from the param_card but from the PDF set chosen (if any)
  - ➡ run_card: beam/run parameters and cuts
    - ✦ https://answers.launchpad.net/madgraph5/+faq/2014

Exercise III: Cards Meaning (Solution)

- How do you change
  - ➡ top mass
    - ✦ Set mt 180 # or edit param_card
  - ➡ top width
    - ✦ Set wt 2.1 # or edit param_card
  - ➡ W mass
    - ✦ Set mZ 80 # or change GF/aEW !! MW is not free!
  - ➡ beam energy
    - ✦ set ebeam 7000 # or change run_card
  - ➡ pt cut on the lepton
    - ✦ set ptl 20 # or change run_card

Ex. IV: Syntax

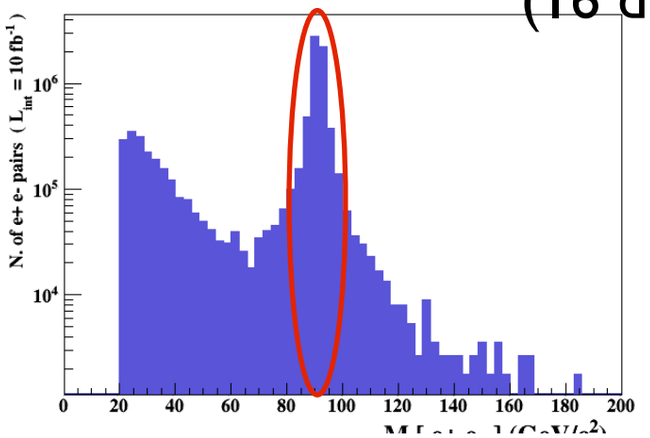
- Generate the cross-section and the distribution (invariant mass) for
  - ➡ p p > e+ e-
  - ➡ p p > z , z > e+ e-
  - ➡ p p > z > e+ e-
  - ➡ p p > e+ e- $ z
  - ➡ p p > e+ e- / z

Hint :To plot automatically distributions:
mg5> install MadAnalysis5

- Use the invariant mass distribution to determine the meaning of each syntax.

p p > e+ e-

(16 diagrams)

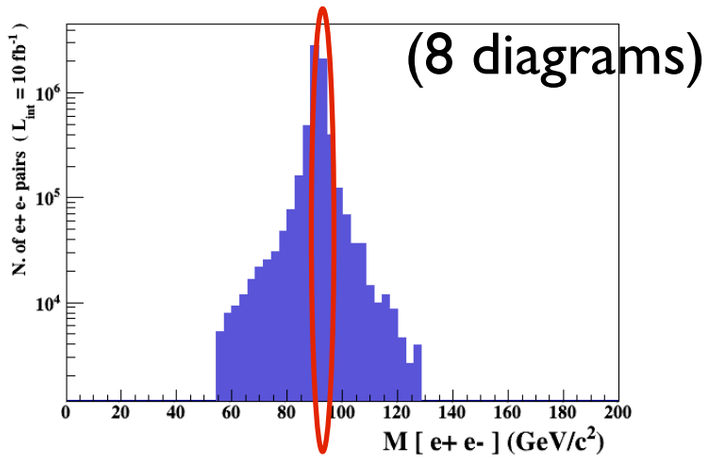


Correct Distribution

Z Peak

p p >z , z > e+ e-

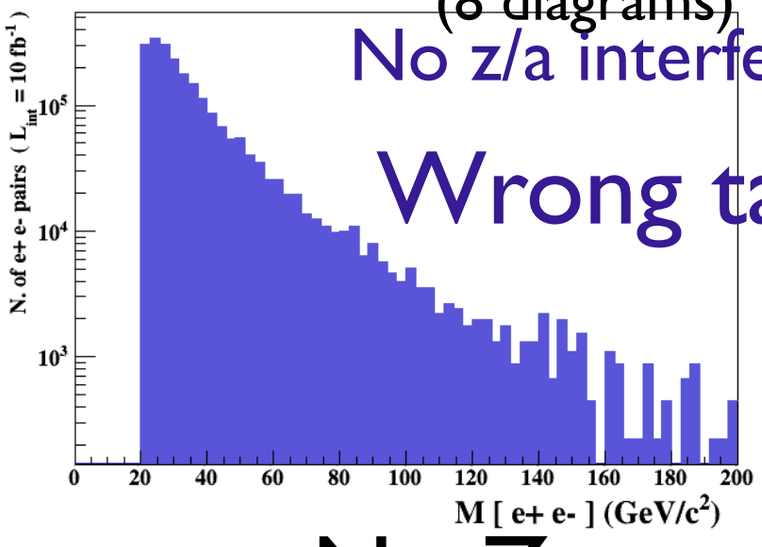
(8 diagrams)



p p > e+ e- /z

(8 diagrams)

No z/a interference



Wrong tail

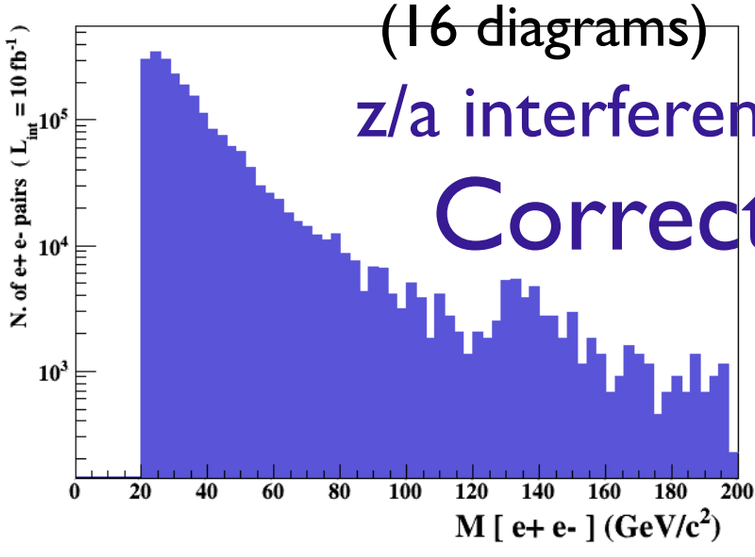
No Z

NO Z Peak

p p > e+ e- $ z

(16 diagrams)

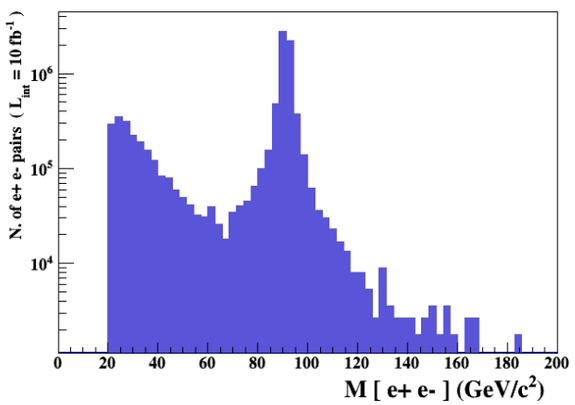
z/a interference



Correct tail

Z- onshell veto

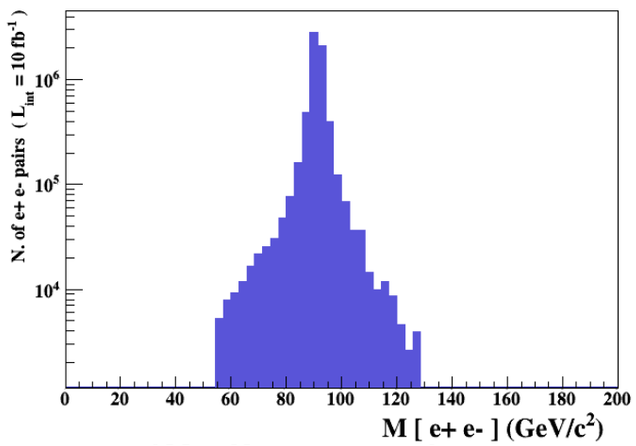
p p > e+ e-



(16 diagrams)

=

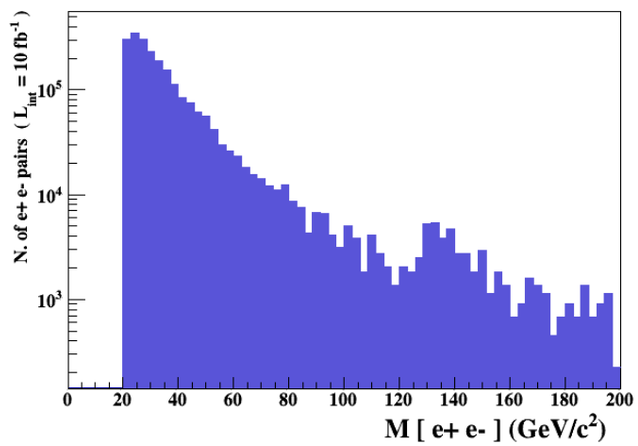
p p >z , z > e+ e-



(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.

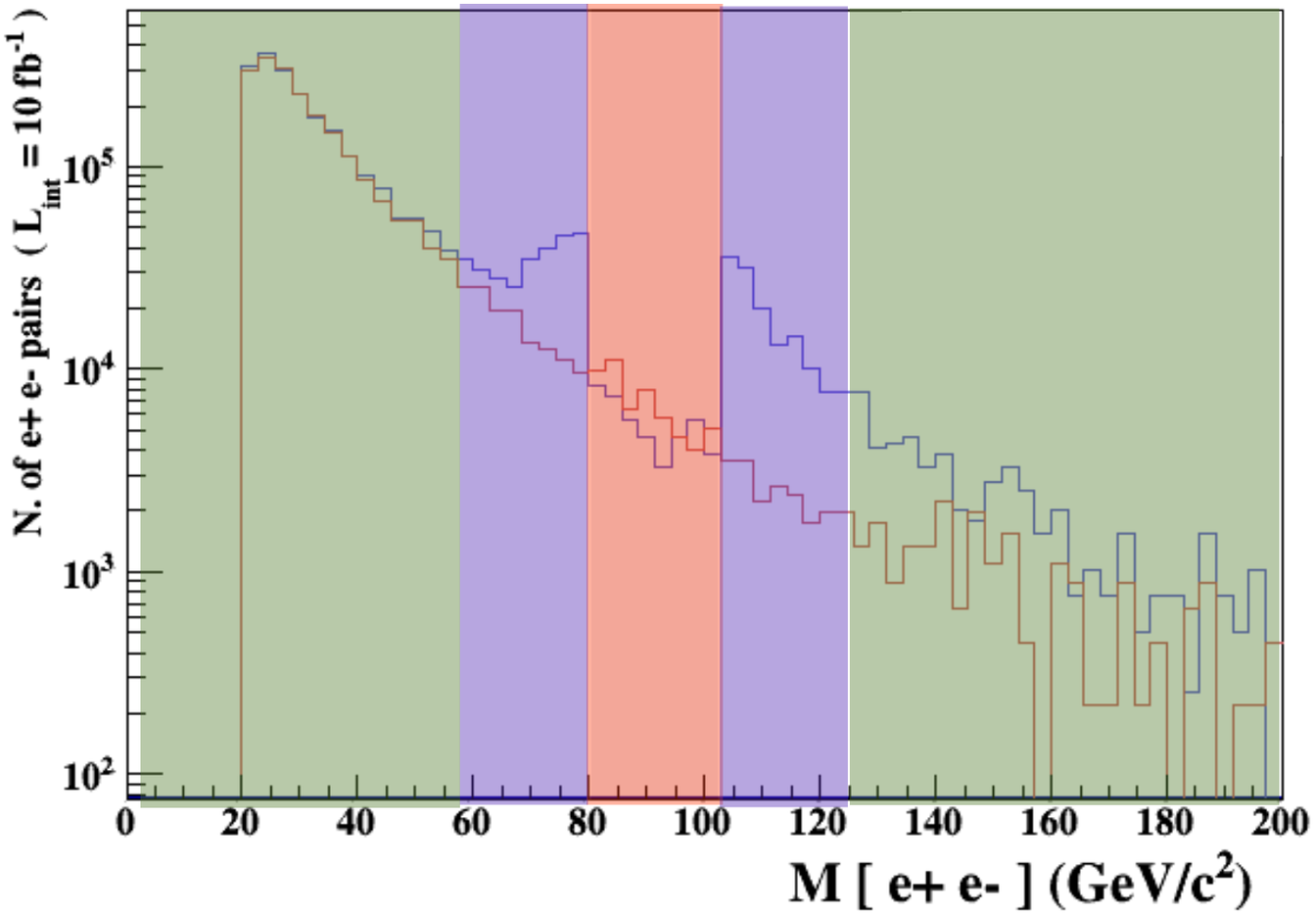
WARNING

- 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.

See previous slide warning

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

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.

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 V

- Generate top pair production at LO,
- Do the fully leptonic decay of the top pair
- Shower event with pythia8
- Plot the pt distribution of the first jet

- How to improve the simulation
  - Of the cross-section
  - Of the pt of the first/second jet
  - …

Two methods for the decay

- Generate p p > t t~, (t > w+ b, w+ > e+ ve), (t~ > w- b~, w-> e- ve~)
- output
- launch
  - ➡ Ask for Pythia8 and MA5 (rest keep on OFF)
  - ➡ set mpi OFF # This is for speed issue for the tuto

- Generate p p > t t~
- Output; Launch
  - ➡ Ask for MadSpin and Pythia8 and MA5
  - ➡ set mpi OFF # This is for speed issue for the tuto
  - ➡ decay t > w+ b, w+ > e+ ve
  - ➡ decay t~ > w- b~, w- > e- ve~

Two methods for the decay

- Generate p p > t t~, (t > w+ b, w+ > e+ ve), (t~ > w- b~, w-> e- ve~)
- Full phase-space integration
  - ➡ Does not rely on the Branching ratio
  - ➡ Rely on the full width
  - ➡ cut-off to avoid be too much off-shell

- Generate p p > t t~ + Madspin
  - ➡ Rely on the Branching ratio
  - ➡ Keep the full spin-correlation
  - ➡ Keep off-shell effects: cut-off to avoid be too much off-shell

Improve Precision

- cross-section
  - ➡ Need to go to NLO
    - ✦ No decay chain syntax (only MadSpin option)
    - ✦ generate p p > t t~ [QCD]
  - ➡ To generate events we need to know which Parton-Shower, you will use!!
    - ✦ Events generated for that specific PS
      - Using another will break NLO accuracy

➡ MadSpin decay is based on LO and NWA.

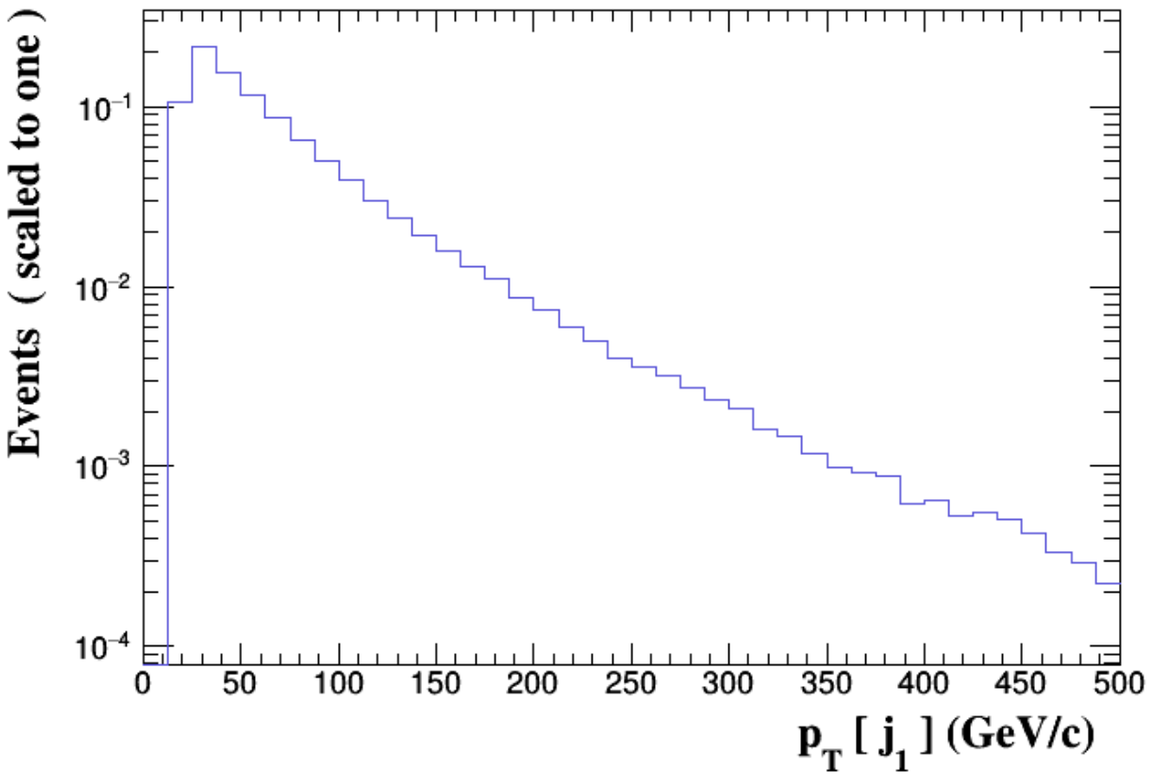
Improve Precision

- Pt of the first jet
  - ➡ Add the jet at LO:
    - ✦ generate p p > t t~ j
      - Valid for hard jet only!
  - ➡ Going to NLO: “generate p p > t t~ [QCD]”
    - ✦ As accurate at p p > t t~ j
      - But if you do “generate p p > t t~ j [QCD]”

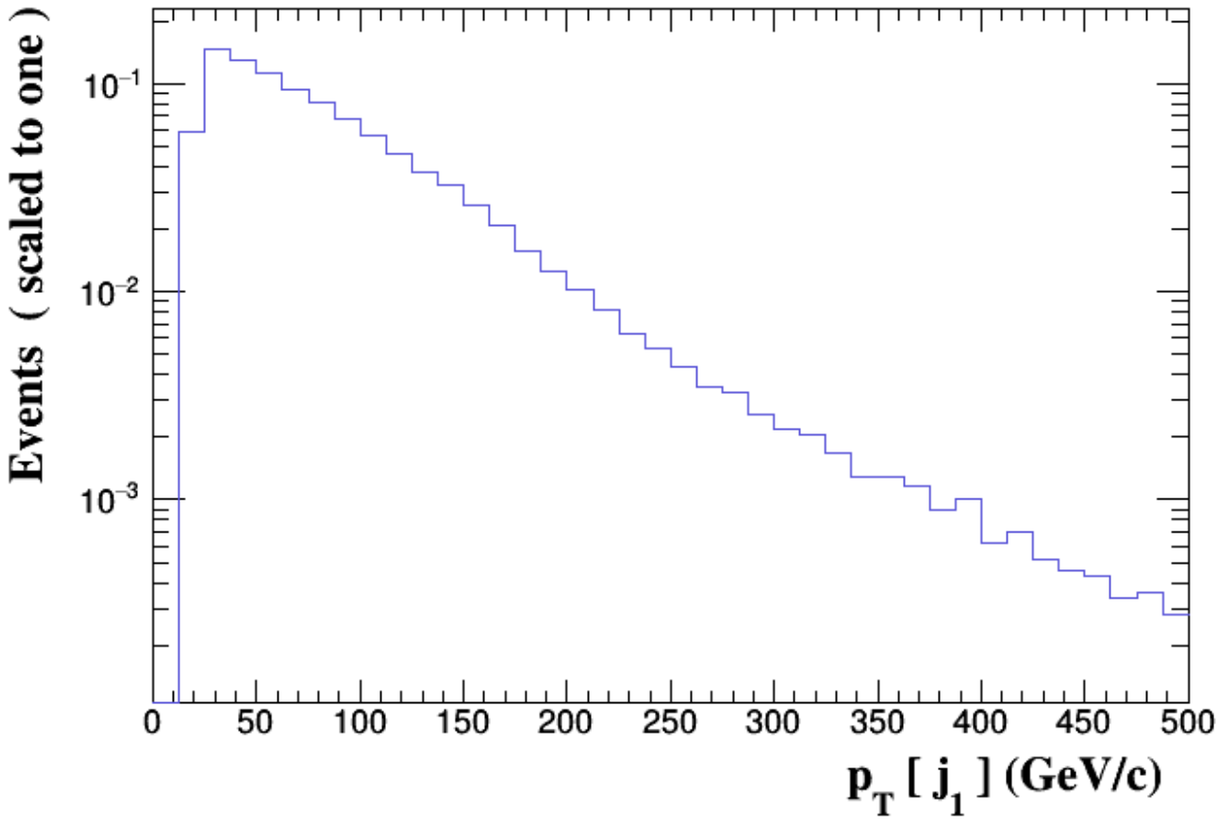
Improve Precision

- Pt of the second jet
  - ➡ Need matching/merging method
    - ✦ generate p p > t t~
    - ✦ add process p p > t t~ j
    - ✦ add process p p > t t~ j j
  - ➡ Use MLM or CKKW-L scheme (or any variation)
  - ➡ You can also use matching/merging at NLO
    - ✦ FxFx or UNLOPS
      - generate p p > t t~ [QCD]
      - add process p p > t t~ j [QCD]
      - add process p p > t t~ j j [QCD]

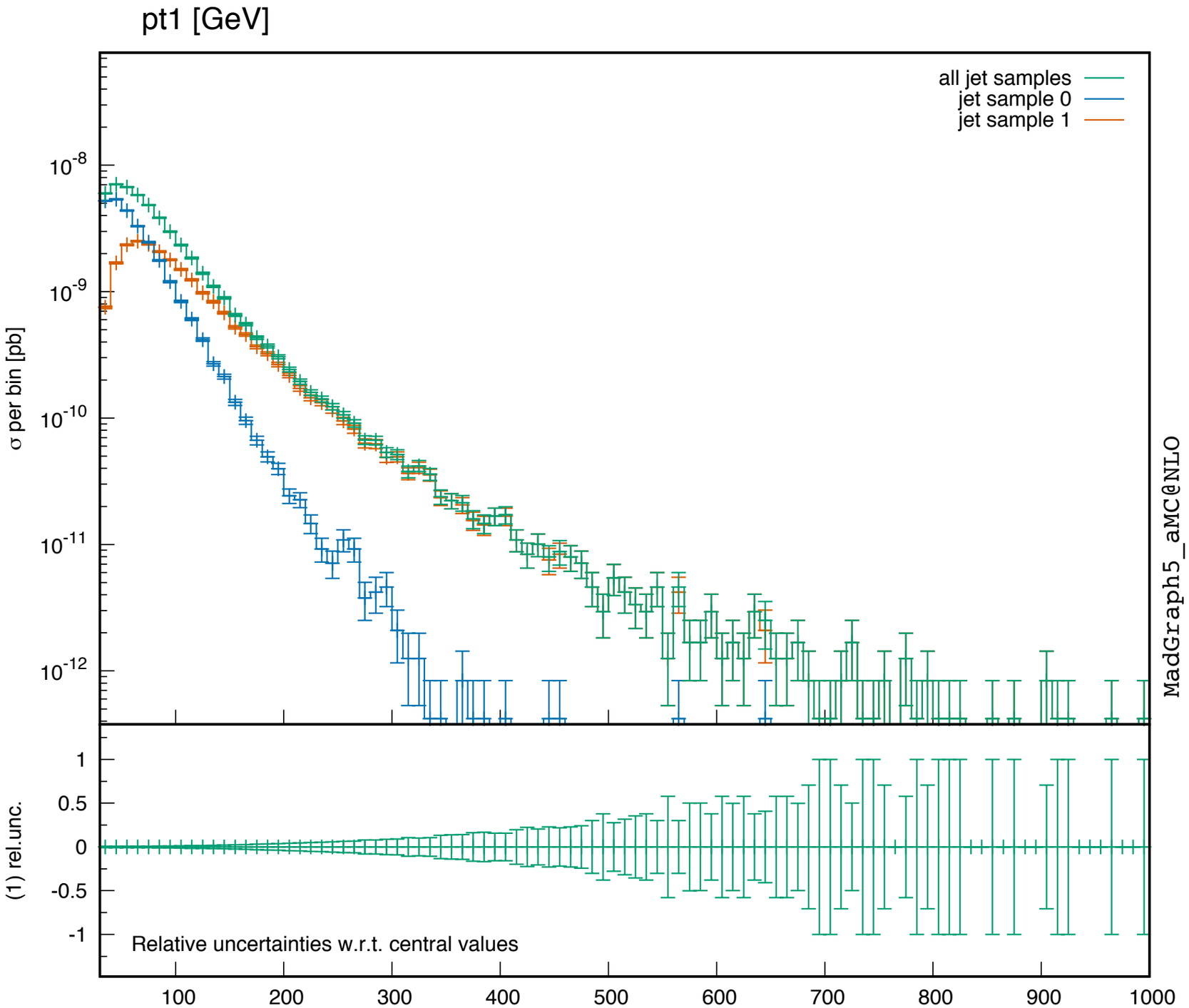
tt@LO


Events (scaled to one)
10^{-1}
10^{-2}
10^{-3}
10^{-4}
0
50
100
150
200
250
300
350
400
450
500
p_T [j_1] (GeV/c)

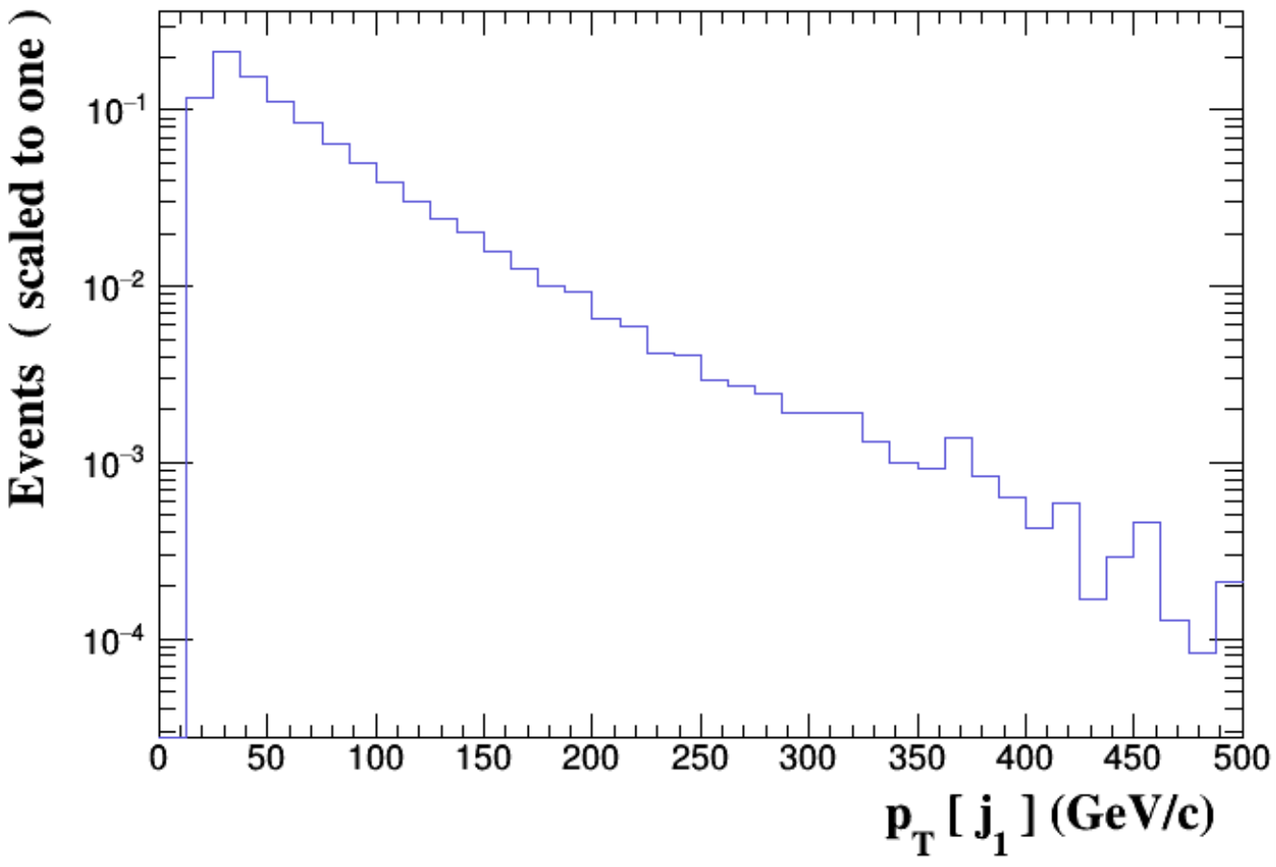
ttj@LO


Events (scaled to one)
10^{-1}
10^{-2}
10^{-3}
0
50
100
150
200
250
300
350
400
450
500
p_T [j_1] (GeV/c)

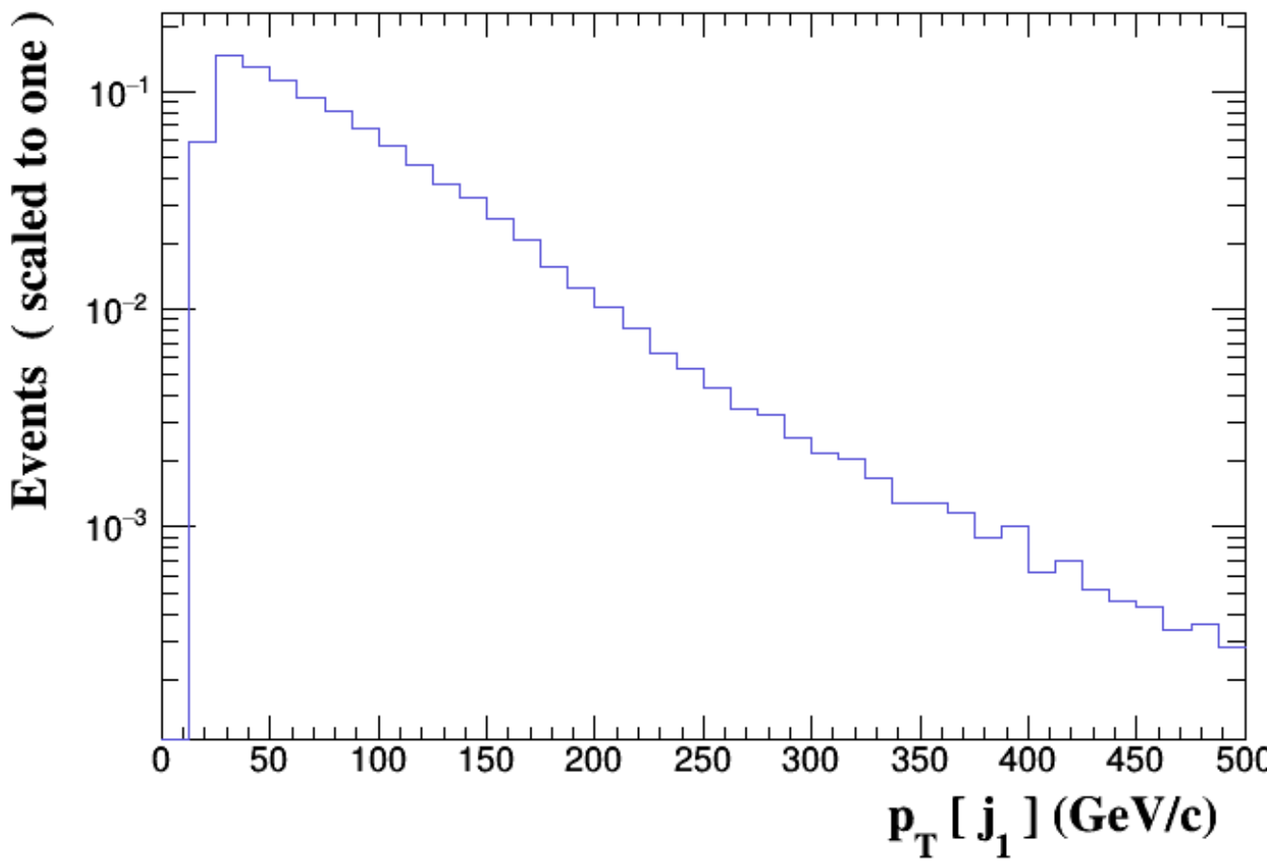
PT distribution (MLM 0+1j)



tt@NLO


Events (scaled to one)
10^{-1}
10^{-2}
10^{-3}
10^{-4}
0
50
100
150
200
250
300
350
400
450
500
p_T [j_1] (GeV/c)

ttj


Events (scaled to one)
10^{-1}
10^{-2}
10^{-3}
0
50
100
150
200
250
300
350
400
450
500
p_T [j_1] (GeV/c)

MG5aMC tutorial II

BSM

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Exercise I: Restrict Model

- Run the "export command" in your shell!
- Import model EWDim6
  - ➡ This downloads it on disk. (and change model to thato one for the diagram generation)
  - ➡ This model contains 8 dimension operator

- We want to **RESTRICT** the model to only keep one (Owww)
- Such that Feynman diagram corresponding to other operator are **NOT** generated
  - Makes more optimal code !

Exercise I: Restrict Model

- Go to models/EWdim6 directory
- Run the script
  - ➡ Python write_param_card.py
- cp param_card.dat restrict_owww.dat
  - ➡ The owww part can be changed to ANY string you want [but default and full].
- Edit that file
  - ➡ Put the c mass and b mass to zero
  - ➡ Put all the dim6 operator at 0 but CWWWL2
  - ➡ Put CWWWL2 to 9.999999e-1
- Go back to MG5_aMC
  - ➡ Import model EWdim6-owww

Restrict Model

- When importing the model with the flag

```
MG5_aMC>import model EWdim6-owww
INFO: model loaded from PYTHONPATH: /Users/omattelaer/Desktop/UFOMODEL/EWdim6
INFO: Restrict model EWdim6 with file ../../../Desktop/UFOMODEL/EWdim6/restrict_owww.dat .
INFO: Run "set stdout_level DEBUG" before import for more information.
INFO: Change particles name to pass to MG5 convention
Pass the definition of 'j' and 'p' to 5 flavour scheme.
Kept definitions of multiparticles l- / vl / l+ / vl~ unchanged
Defined multiparticle all = g u c d s b u~ c~ d~ s~ b~ a ve vm vt e- ve~ vm~ vt~ e+ t t~ z
MG5_aMC>
```

➡ MG5 mode pass to 5 flavour

➡ Less Feynman diagram generated

```
###################################
## INFORMATION FOR DIM6
###################################
Block dim6
    1 1.000000e+00 # CWWWL2

###################################
## INFORMATION FOR MASS
###################################
Block mass
    6 1.720000e+02 # MT
   13 1.056600e-01 # MM
   15 1.777000e+00 # MTA
   23 9.118760e+01 # MZ
   25 1.250000e+02 # set of param :1*MH, 1*MP
```

➡ Less parameter in the param_card

- ✦ No b/c mass option
- ✦ One Dim6 operator
- ✦ No CKM block

Restrict Model

- What's happening

1. All coupling are evaluated for that param_card
2. All vertex associated to zero coupling (exactly or very small) are **removed** from the model
3. All zero/one value of the param_card are frozen to such value (use 0.000001e-99,9.999999e-1 to avoid that)
4. If two parameters are equal (or opposite) in the same block
   - ✦ Remove one of the two parameters
   - ✦ Freeze the second one accordingly
5. If a file default_XXX.dat exists use that one as default param_card. Otherwise use the restrict_XXX.dat itself
   - ✦ can be used for benchmark
6. restrict_default.dat is automatically loaded by MG5aMC
   - ✦ Use import model EWdim6-full to bypass it

Exercise II: Validate Model

- Validate a Model/Process is always nice !!
  - ➡ You will sound like a MG5 expert
- Import model EW-dim6
- check p p > z h a

```
Lorentz invariance results:
Process          Min element       Max element       Relative diff.    Result
g g > z h a      3.0245789272e-01  3.0245789272e-01  0.0000000000e+00  Passed
u u~ > z h a     4.1915242516e-03  4.1915242516e-03  2.0693229620e-15  Passed
d d~ > z h a     1.2414404109e-03  1.2414404109e-03  2.6200262928e-15  Passed
Summary: 3/3 passed, 0/3 failed
Not checked processes: c c~ > z h a, s s~ > z h a
Gauge results:
Process          matrix            BRS               ratio             Result
g g > z h a      3.4921781373e-01  4.9684750757e-42  1.4227438809e-41  Passed
u u~ > z h a     4.9543423043e-03  8.8574527892e-34  1.7878160703e-31  Passed
d d~ > z h a     2.8216312492e-03  2.0405124807e-34  7.2316766455e-32  Passed
Summary: 3/3 passed, 0/3 failed
Process permutation results:
Process          Min element       Max element       Relative diff.    Result
g g > z h a      3.7207324869e-01  3.7207324869e-01  1.4919414773e-16  Passed
u u~ > z h a     1.2564293427e-02  1.2564293427e-02  2.7613546055e-16  Passed
d d~ > z h a     1.3180098875e-02  1.3180098875e-02  1.3161687879e-16  Passed
Summary: 3/3 passed, 0/3 failed
```

- Lorentz
  - ➡ Very sensitive to gauge
- Gauge
  - Epsilon replaced
- MG5 consistency
  - Change num method

Exercise III: Width

- Compute p p > w+ w- b b~
  - ➡ Change the top quark width
  - ➡ How the cross-section changes (and why)
- compute p p > t t~, t > w+ b, t~ > w- b~
  - ➡ Change the top quark width
  - ➡ How the cross-section changes (and why)
- compute p p > t t~ + Madspin decay
  - ➡ Change the top quark width (but keep BR to 1)
  - ➡ How the cross-section changes (and why)

Exercise III: Width

- Compute p p > w+ w- b b~
  - ➡ Cross-section as 1/ Gamma
- compute p p > t t~, t > w+ b, t~ > w- b~
  - ➡ Cross-section as 1/Gamma
- compute p p > t t~ + Madspin decay
  - ➡ Constant (use the Branching ratio information)
    - ✦ If MadSpin does not re-compute the width
- The width is consider as a free parameter in the computation.
  - ➡ Need to be provided correctly for the cross-section/ shape

Exercise III: Width - Part II

- Compare
  - ➡ generate p p > w+ j
  - ➡ generate p p > w+ j, w+ > e+ ve
- Compare
  - ➡ generate p p > e+ ve j
  - ➡ generate p p > w+ j, w+ > e+ ve
- Redo the comparison when modifying the run_card parameter “cut_decays”

Width Solution

Goal • understanding decay-chain handling

generate p p > w+ j
output; launch

generate p p > w+ j, w+ > e+ ve
output; launch

generate p p > e+ ve j
output; launch

Wrong width	Correct width	+cut_decays=T
21437 pb * BR 2304 pb	21437 pb * BR 2304 pb	21437 pb * BR 2304 pb
32514 pb	2329 pb	1588 pb
33095 pb	1606 pb	1606 pb

Remember

- We do not use the BR information. The cross-section depends of the total width
- particle from on shell decay do not have cut by default

Exercise III: Width - Part II

- Compare
  - ➡ generate p p > w+ j
  - ➡ generate p p > w+ j, w+ > e+ ve
- Compare
  - ➡ generate p p > e+ ve j
  - ➡ generate p p > w+ j, w+ > e+ ve

- The community fight on the default of that parameter! Some believe that the first comparison should be the one working and some the second

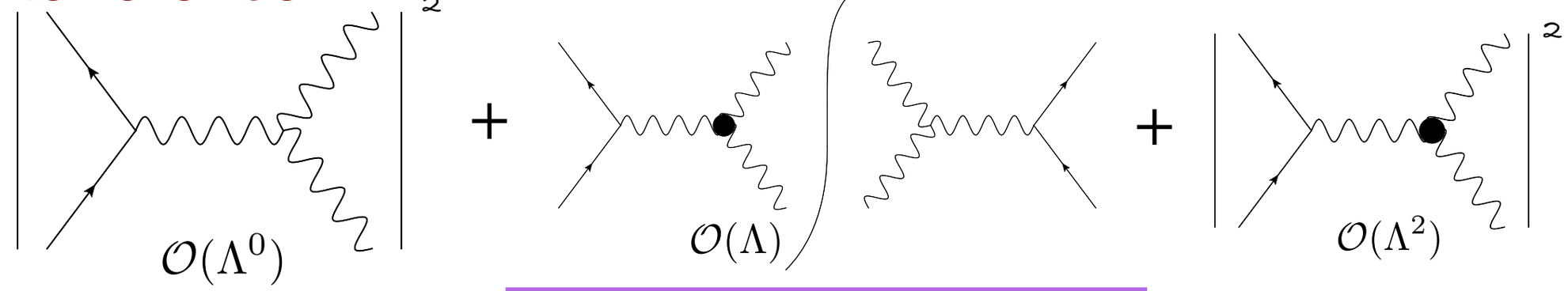
Width: Trick

- Width are consider as free parameter
  - ➡ Not really True
- We can compute them automatically !!
  - ➡ “set wt Auto” # or inside the param_card
  - ➡ Tree-Level computation
    - ✦ Not valid for the Higgs (but for heft model)
  - ➡ Include 3 body decay (bypass them if not relevant)
- **Check it for the top/W/Z**

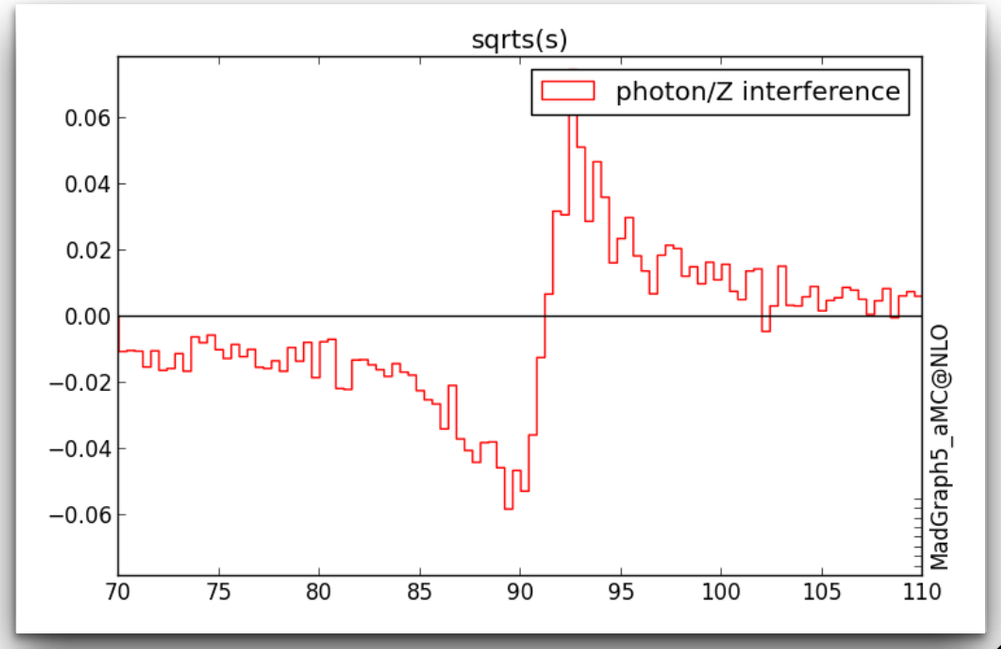
- 2 body computation can be done analytically
  - Fasten the computation (need recent UFO model)

Exercise IV: Interference

Interference



Example



Exercise

- Use your EWDIM6 model
- Compute cross-section without the square part

Exercise V: Automation

- 2 Goals:
  - ➡ How to do a parameter scan
  - ➡ How to avoid the cli (command line interface)

Parameter scan

Parameter scan:

- compute the cross-section for a couple of mass

```
generate p p > go go
```

- for that you can enter for the go mass:

```
set mgo scan:[100,200, 300]
```

```
set mgo scan:[100*i for i in range(1,4)]
```

Any python syntax is valid!!

Width -> no problem

```
set mgo scan:[100,200, 300]
```

```
set wgo Auto
```

Recomputed for each benchmark

Output

- One additional output file scan_XX.dat

```
#run_name              mass#1000021          cross
run_01                 5.000000e+01          1.004913e+06
run_02                 1.000000e+02          5.471439e+04
run_03                 1.500000e+02          8.679740e+03
```

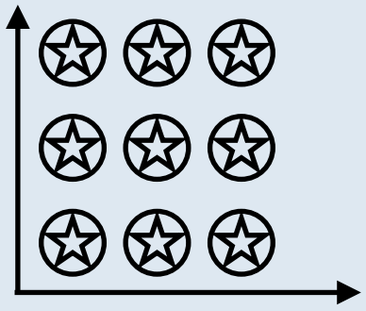
More than one parameter

2D scan

- No correlation

```
set mgo scan:[100,200, 300]
```

```
set mneu1 scan:[100*i for i in range(1,4)]
```

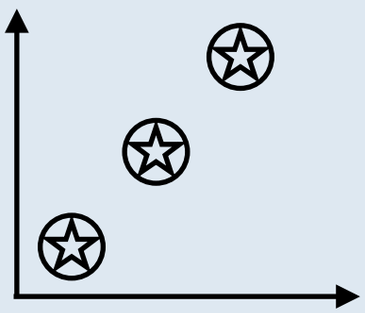


1D scan

- No correlation

```
set mgo scan1:[100,200, 300]
```

```
set mneu1 scan1:[100*i for i in range(1,4)]
```



EFT operator scan

```
set dim6 1 scan1:[1 if i==0 else 0 for i in range(3)]
```

```
set dim6 2 scan1:[1 if i==1 else 0 for i in range(3)]
```

```
set dim6 3 scan1:[1 if i==2 else 0 for i in range(3)]
```

Automation

scripting

- write in a file (./MYFILE)
- run it as ./bin/mg5_aMC ./MYFILE

```
import model EWdim6
generate p p > z h
ouput TUTO
launch
  set nevents 5000
  set LHC 13
launch
  set LHC 14
```

Comment on scripting

- Do not use ./bin/mg5_aMC < ./MYFILE
- If an answer to a question is not present: Default is taken automatically
- EVERYTHING that you type can be put in the entry file

EFT related trick!

- If you specify one coupling order
  - ➡ Generate p p > t t~ QED<=2
  - ➡ All other coupling will be assume to be infinite
    - ✦ Some model restrict EFT operator to one
    - ✦ So their maximum will be one
- This can be changed with
  - ➡ set default_unset_couplings 0
    - ✦ (before the generate command)
- Useful for EFT model when they have plenty of coupling order