Tutorial — MG5 to Contur

From Theory to Exclusion

MadGraph5
Ramon Winterhalder (UCLouvain)
Zenny Wettersten (CERN)

Rivet+Contur
Jon Butterworth (UCL)
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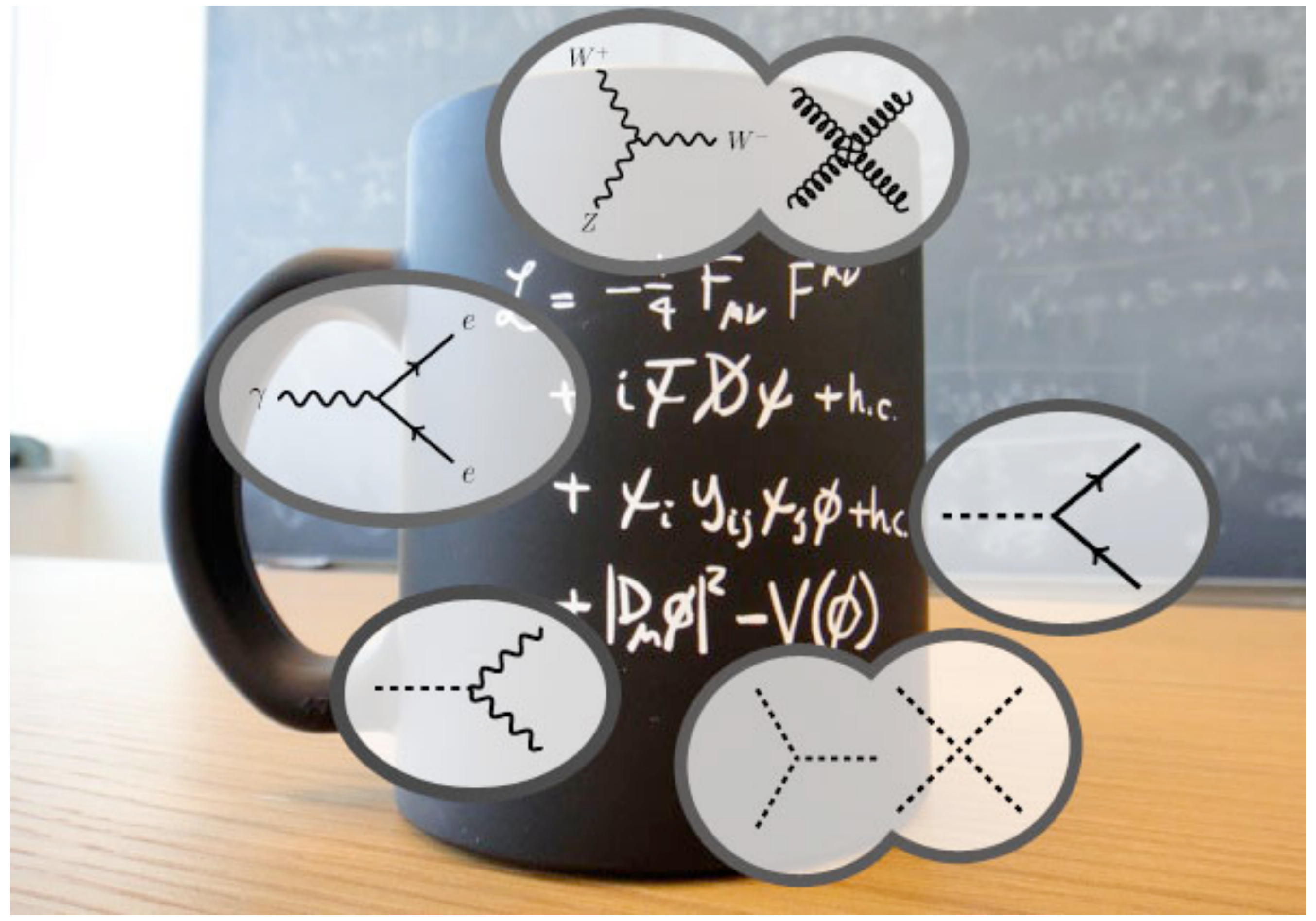
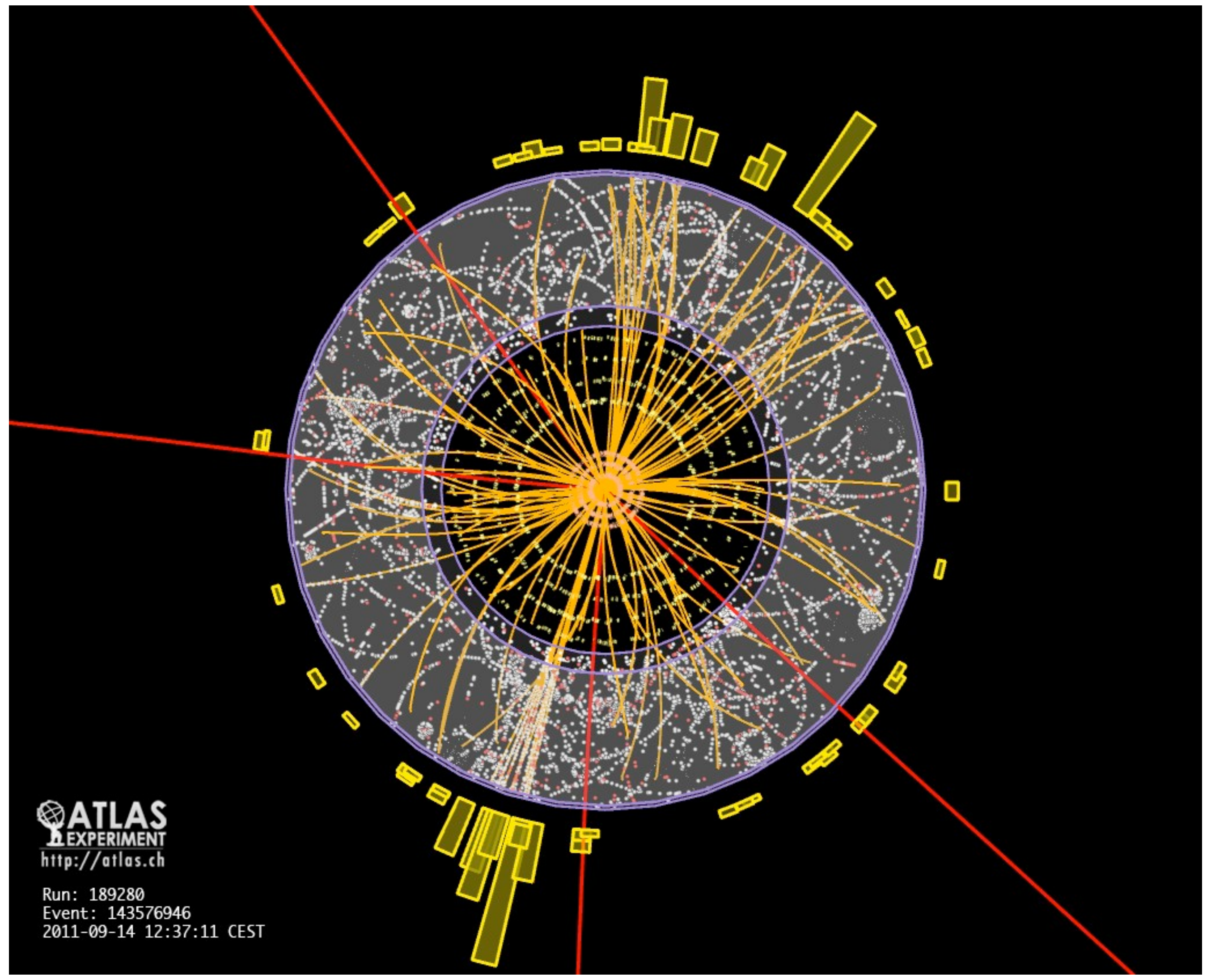
From Theory to Exclusion

Introduction

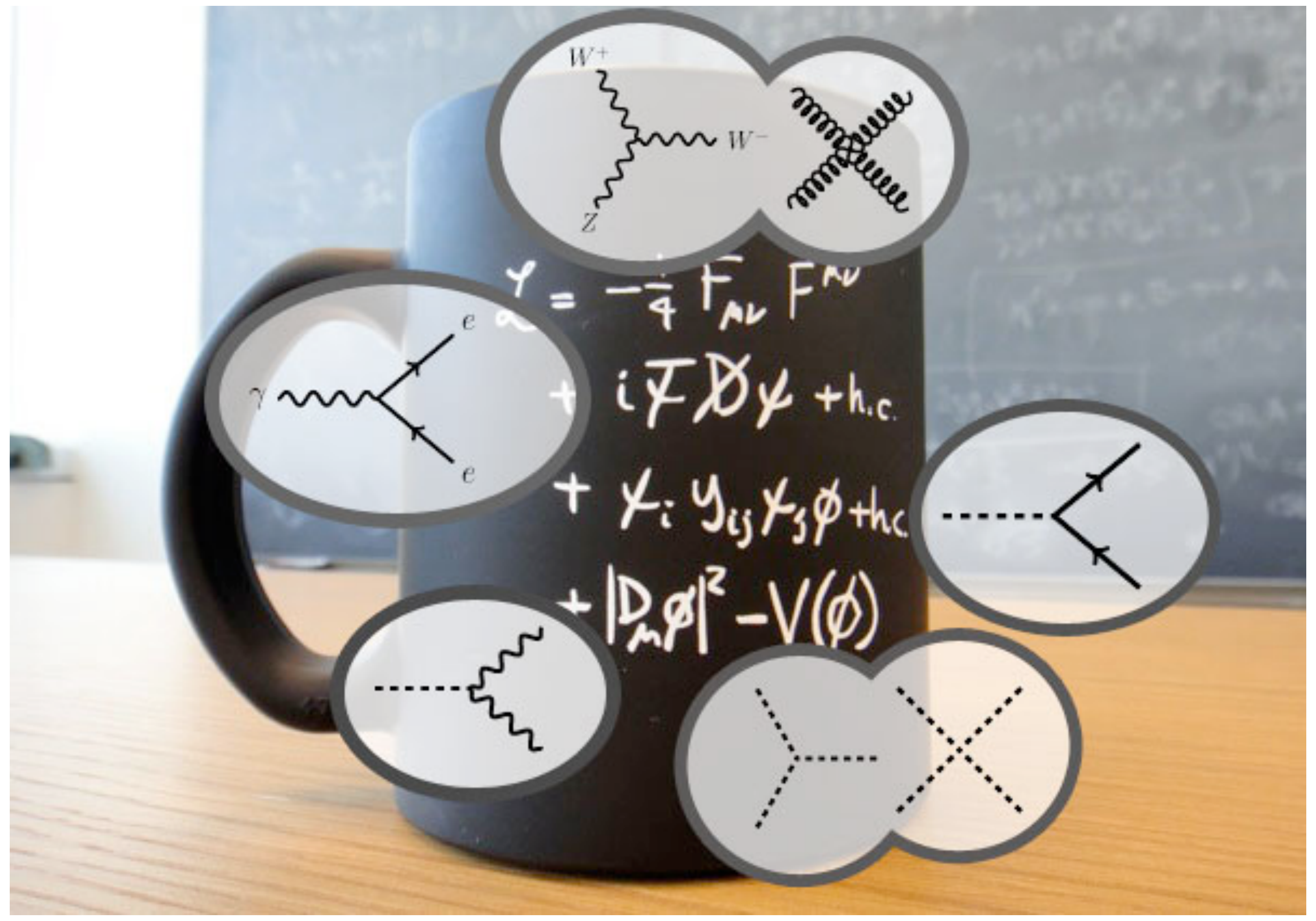
From Theory to Exclusion



Monte-Carlo Physics



From Theory to Exclusion



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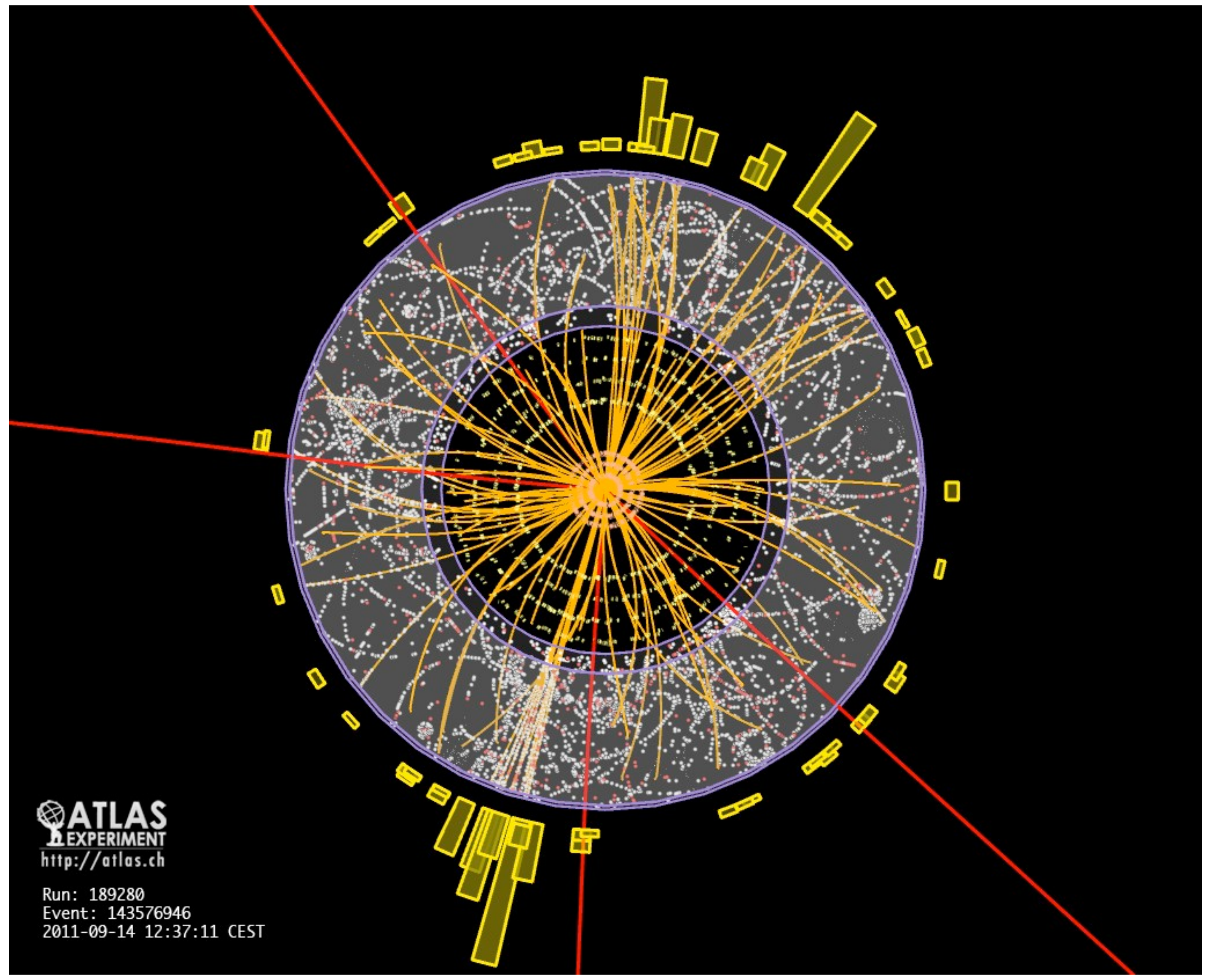


Our goal

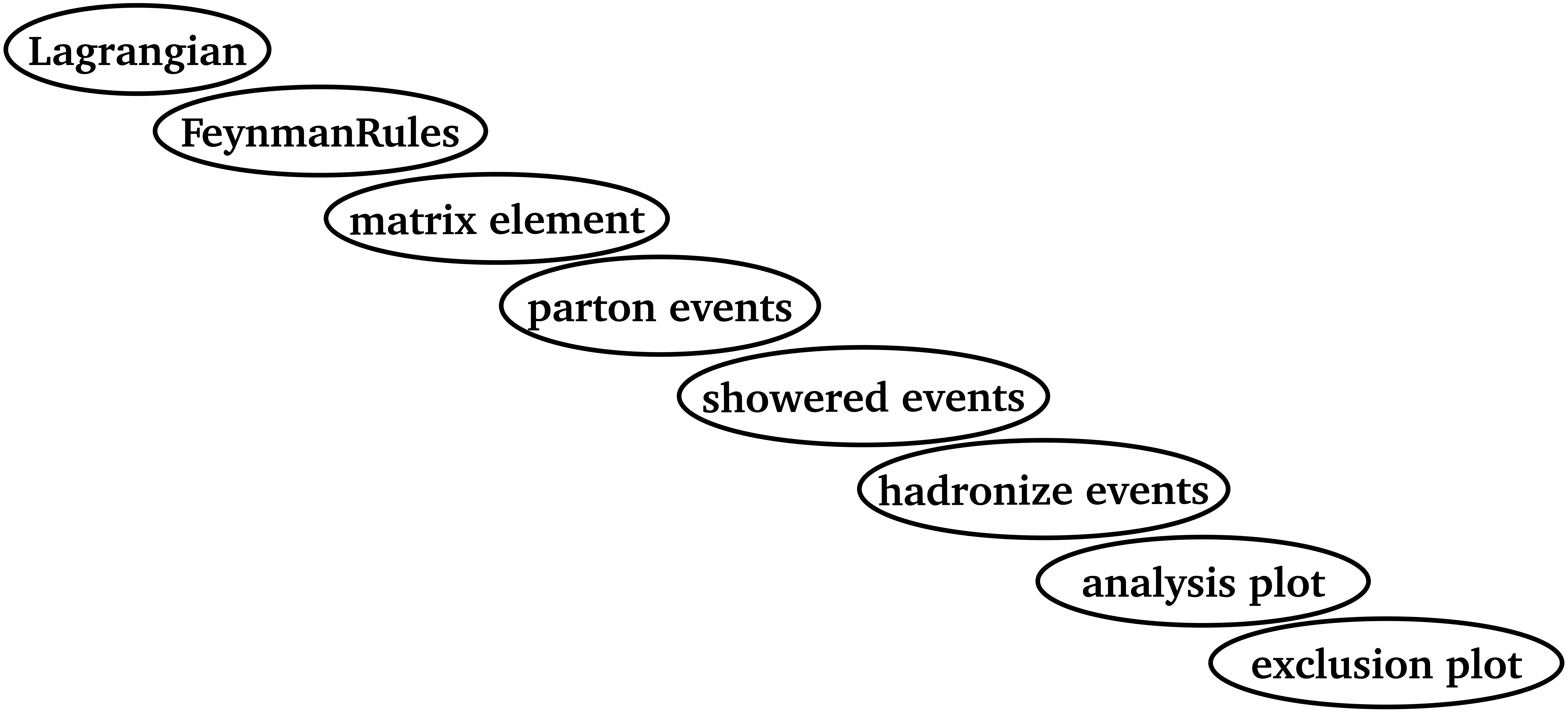
- Cross section
- Differential cross section
- Unweighted events

From Theory to Exclusion

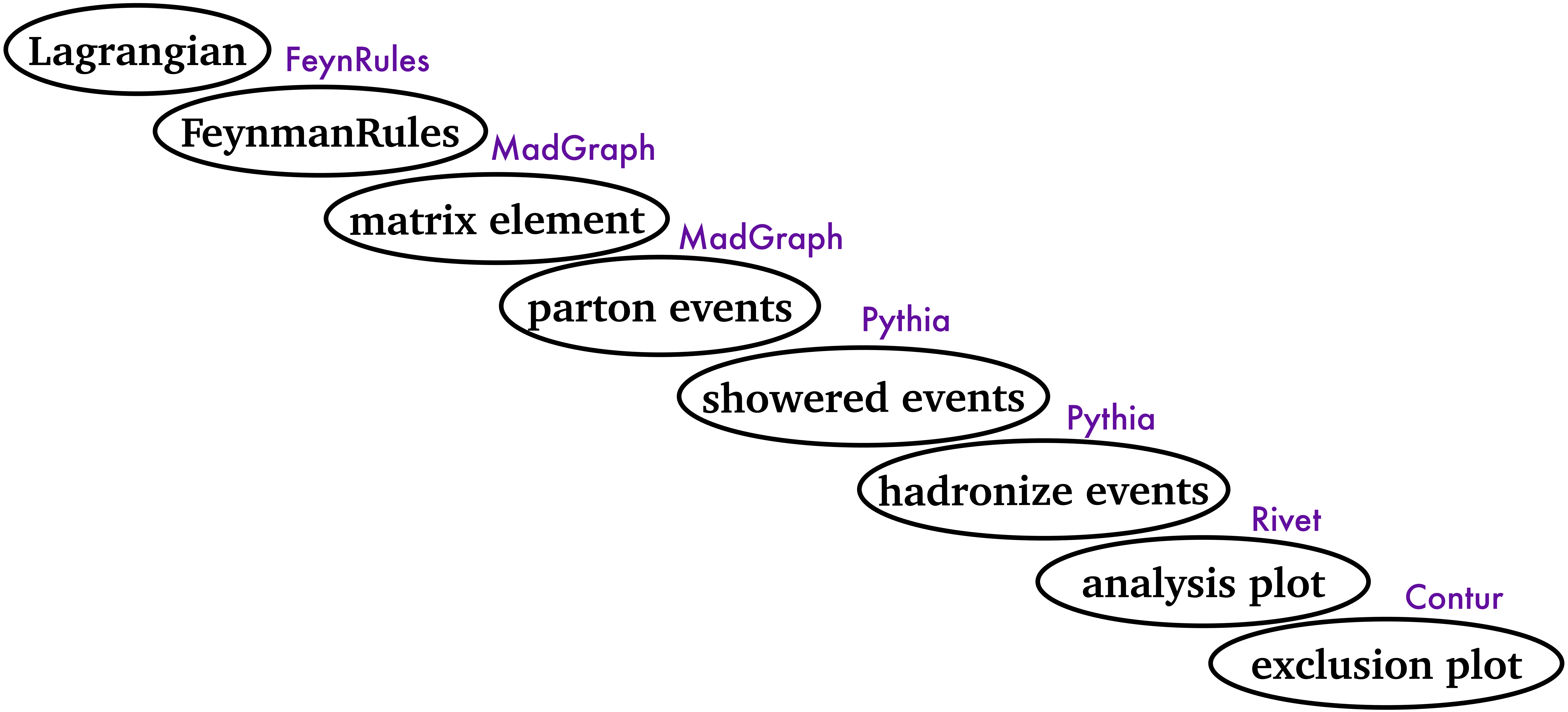
Lagrangian

exclusion plot

From Theory to Exclusion



From Theory to Exclusion



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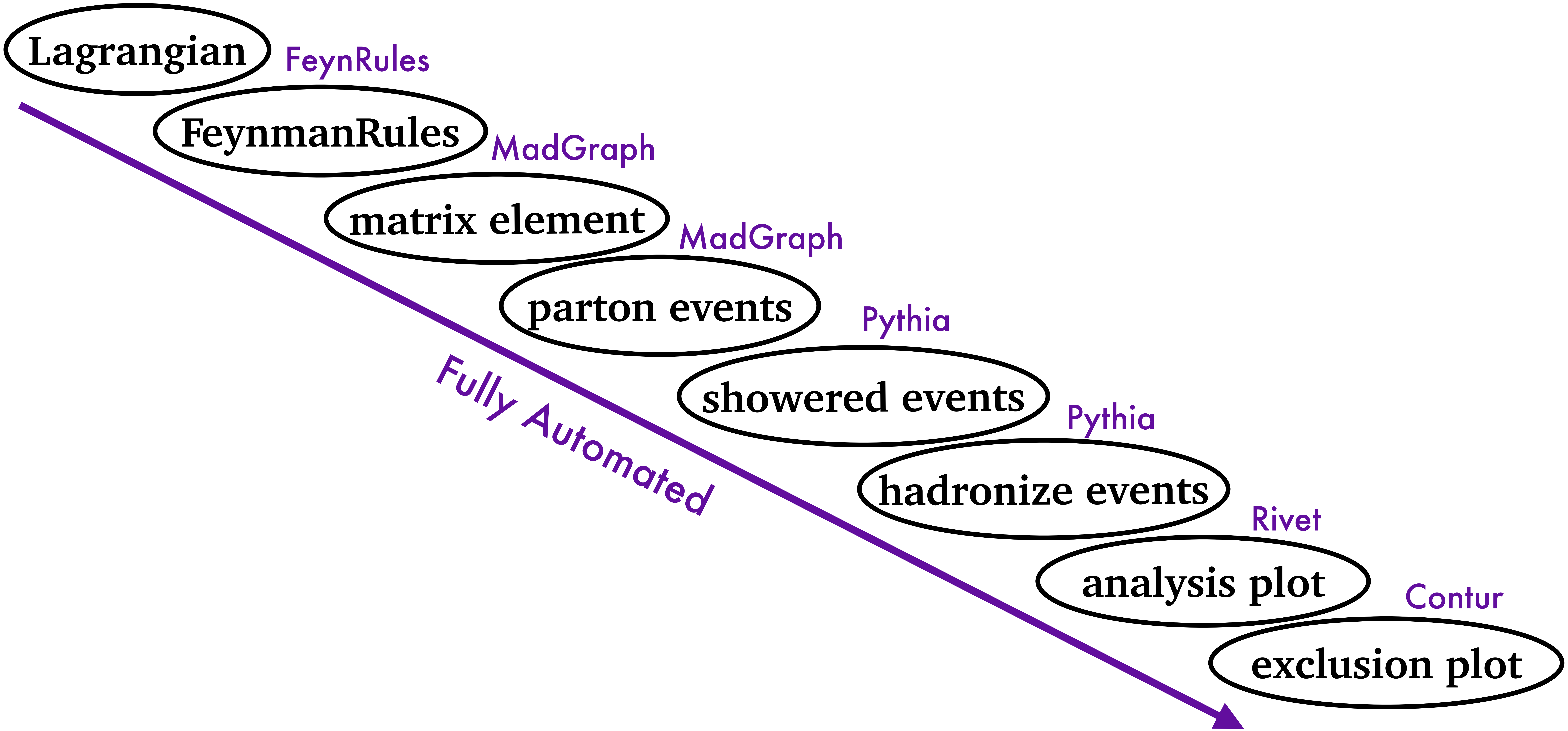

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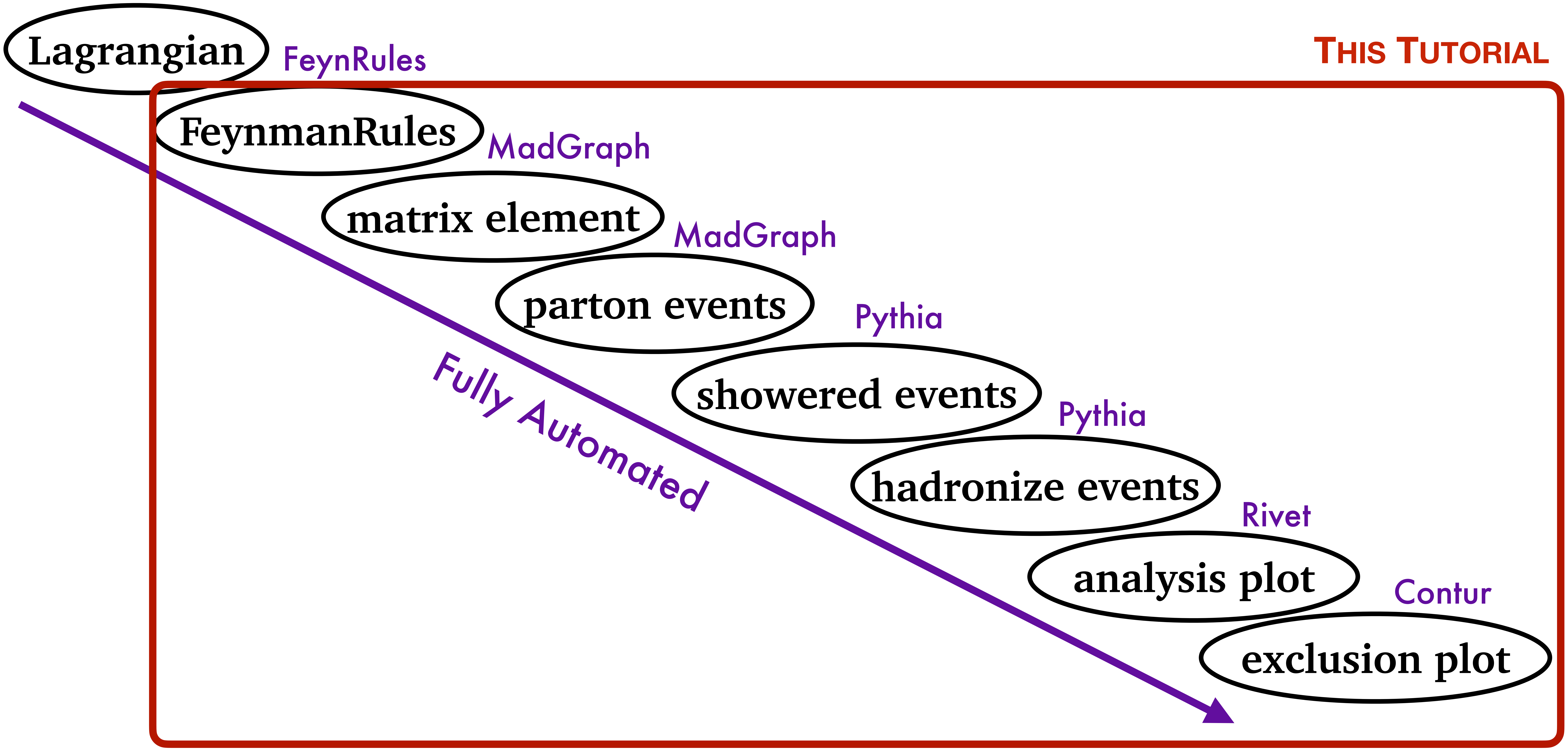

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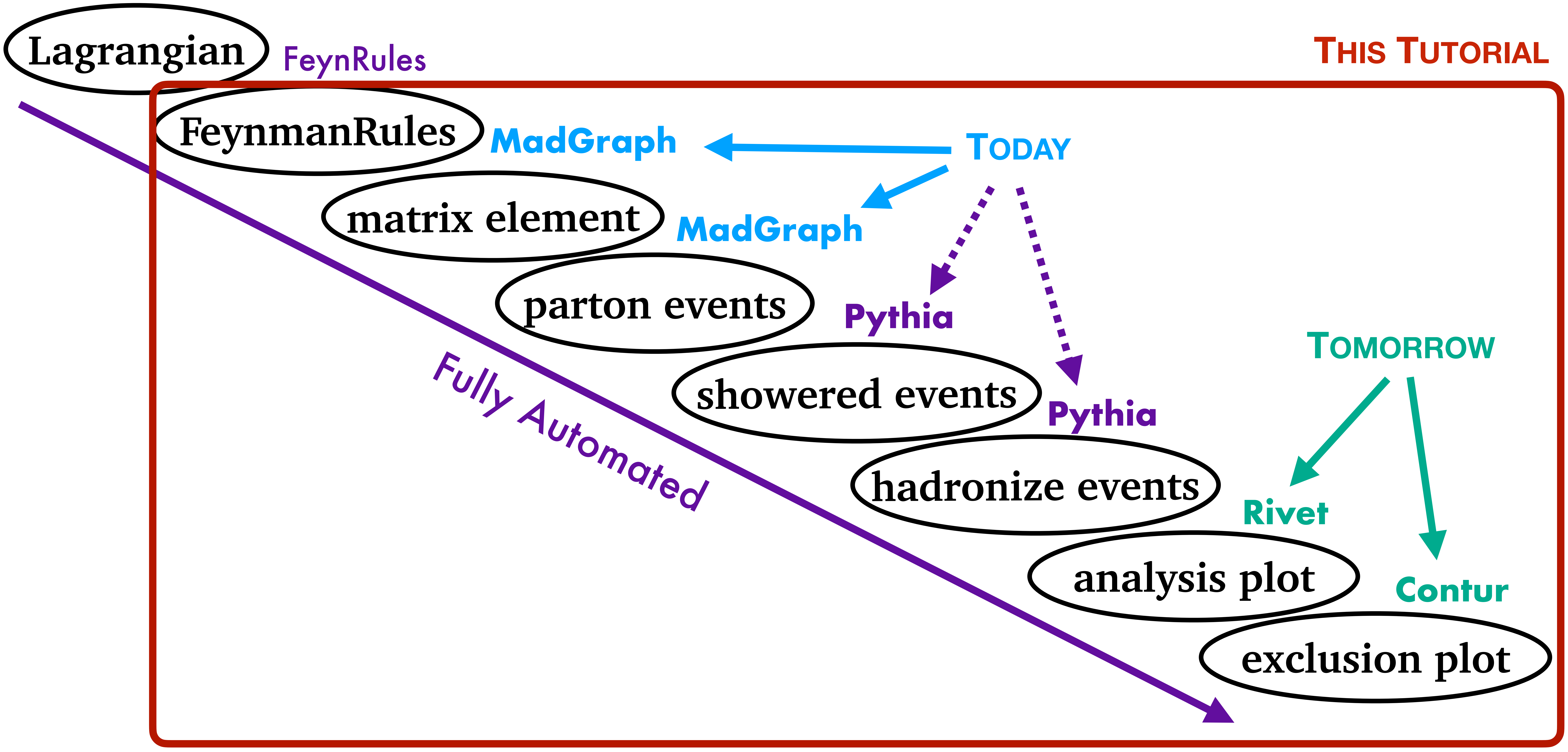

MadGraph5 Tutorial

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Setup the VM

Docker image

$ docker pull hepstore/contur-tutorial:mcnet24

$ docker run -it -v $PWD:$PWD hepstore/contur-tutorial:mcnet24 /bin/bash

$ cd /contur/

If you do $ ls, you should see the following content

```
root@9e650987cb72:/contur# ls
ChangeLog      README.md   bin                contur_user    dist     makeDoc.sh         setup.py          tests
MG5_aMC_v3_5_4 TODOmpl.md  contur             conturenv.sh   doc      requirements.in    setupContur.sh
Makefile       attic       contur-visualiser  data           docker   requirements.txt   setupPBZpWp.sh
```

Outline of the Tutorial

I. Built-in MG5 tutorial

II. Understanding the cards

III. Understanding the syntax

IV. BSM process and mass scan (bonus)

V. Generate hepMC files for the **Rivet+Contur Tutorial**

Where to find help?

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

Exercise I — Built-in Tutorial

- Launch the code

  → `$ ./bin/mg5_aMC`

- Type “tutorial”

  → Follow instructions!

Exercise II — Parameters and Cards

- Compute the LO cross-section for our BSM background (see later)
  - ➡ generate p p > mu+ mu-
- Check
  - ➡ What is the Z mass?
  - ➡ Are there any cuts? (Do we need cuts?)
  - ➡ Beam energy
- Useful cards to check are
  - ➡ **param_card:** model parameters
  - ➡ **run_card:** beam/run parameters and cuts

Exercise III — Syntax

- Generate the cross-section **and the distribution** (invariant mass) for
  - ➡ p p > mu+ mu-
  - ➡ p p > z, z > mu+ mu-
  - ➡ p p > mu+ mu- $ z (warning set sde_strategy=1 in the run_card)
  - ➡ p p > mu+ mu- / z

Hint: To plot automatically distributions

mg5> install MadAnalysis5

Exercise IV — BSM Model

Get a new model (in mg5)

```
./bin/mg5_aMC
set auto_convert_model T
import model VPrime_NLO
```

Check the model

```
./bin/mg5_aMC
import model VPrime_NLO
check p p > mu+ mu-
display particles zp
```

Exercise IV — Mass Scan

- Compute the cross-section for
  - ➡ p p > zp
    - **For zp mass 500 GeV, 1 TeV, 1.5 TeV, 2 TeV**
    - **Trick you can use:** scan:[500,1000,1500,2000]
    - Does the cross section decrease/increase (why should it)?
  - ➡ p p > zp , zp > mu+ mu-
    - **For zp mass 500 GeV, 1 TeV, 1.5 TeV, 2 TeV**
    - Does the cross-section decrease/increase (why should it be)?
    - What is the relation to the previous cross section?
    - Compute the branching ratio

Prerequisite for Contur

Generate hepMC file for process of interest

1. Launch

```
The following switches determine which programs are run:
/=================== Description ===================|============= values ==============|======== other options ========\
| 1. Choose the shower/hadronization program         |       shower = OFF                |     Pythia8                    |
| 2. Choose the detector simulation program          |     detector = Not Avail.         |     Please install module      |
| 3. Choose an analysis package (plot/convert)       |     analysis = Not Avail.         |     Please install module      |
| 4. Decay onshell particles                         |      madspin = OFF                |     ON|onshell|full            |
| 5. Add weights to events for new hypp.             |     reweight = OFF                |     ON                         |
\=============================================================================================================================/
```

2. Type 'shower=pythia8' or just '1' and press enter

```
The following switches determine which programs are run:
/=================== Description ===================|============= values ==============|======== other options ========\
| 1. Choose the shower/hadronization program         |       shower = Pythia8            |     OFF                        |
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| 4. Decay onshell particles                         |      madspin = OFF                |     ON|onshell|full            |
| 5. Add weights to events for new hypp.             |     reweight = OFF                |     ON                         |
\=============================================================================================================================/
```

3. Press enter and run. It automatically generates an hepMC file

MadGraph5 Tutorial

Solutions

Exercise II — Cards meaning

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

Param_card (Z mass, Z width, W mass)

Run_card (beam energy, pt cut on the lepton)

Exercise II — Cards meaning


```
###################################
## 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 0.000000e+00 # d : 0.0
  2 0.000000e+00 # u : 0.0
  3 0.000000e+00 # s : 0.0
  4 0.000000e+00 # c : 0.0
  11 0.000000e+00 # e- : 0.0
  12 0.000000e+00 # ve : 0.0
  13 0.000000e+00 # mu- : 0.0
  14 0.000000e+00 # vm : 0.0
  16 0.000000e+00 # vt : 0.0
  21 0.000000e+00 # g : 0.0
  22 0.000000e+00 # a : 0.0
  24 8.041900e+01 # w+ : cmath.sqrt(MZ__exp__2/2. + cmath.sqrt(MZ__exp__4/4. - (aEW*cmath.pi*MZ__exp__2)/(Gf*sqrt__2)))
```

Exercise II — Cards meaning


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```

W mass is an internal parameter!

MG5 does NOT use this value!

So you need to change MZ or Gf or alpha_EW

Exercise III — Syntax

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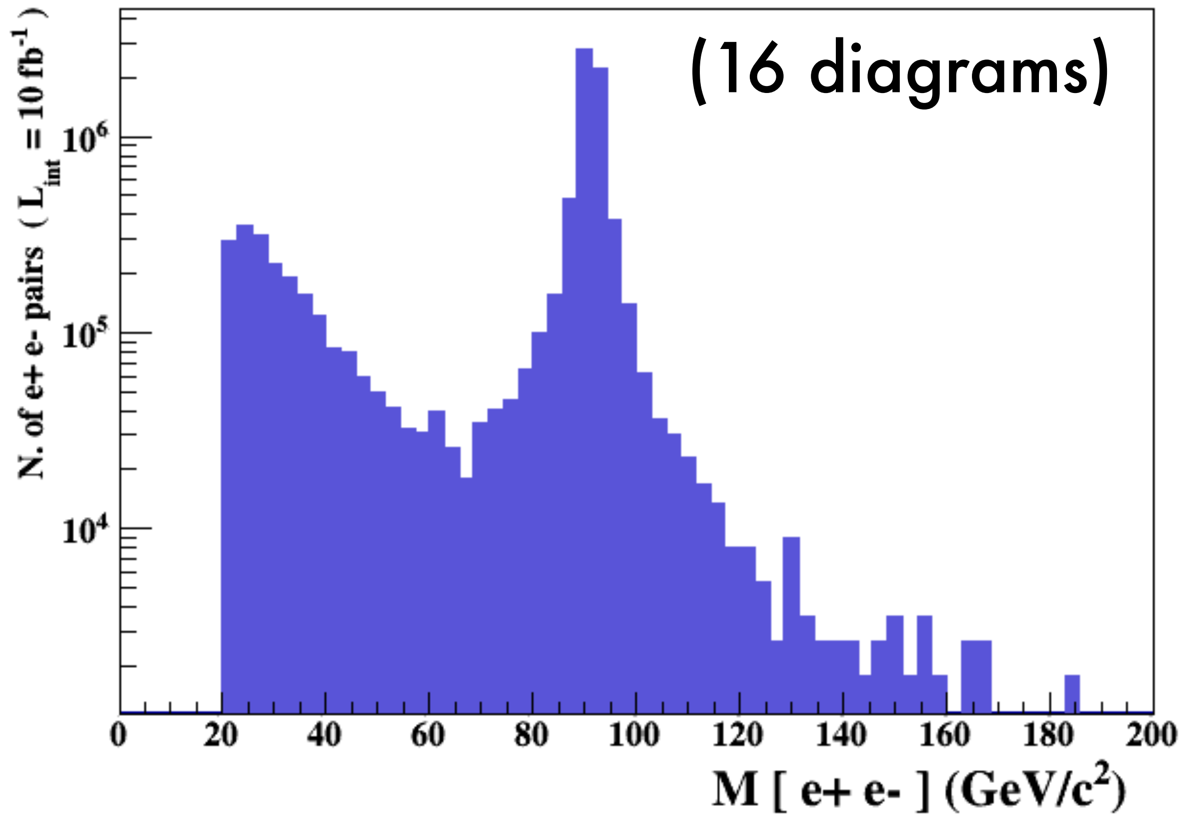
  - ➡ p p > mu+ mu-
  - ➡ p p > z, z > mu+ mu-
  - ➡ p p > mu+ mu- $ z (warning set sde_strategy=1 in the run_card)
  - ➡ p p > mu+ mu- / z

Hint: To plot automatically distributions

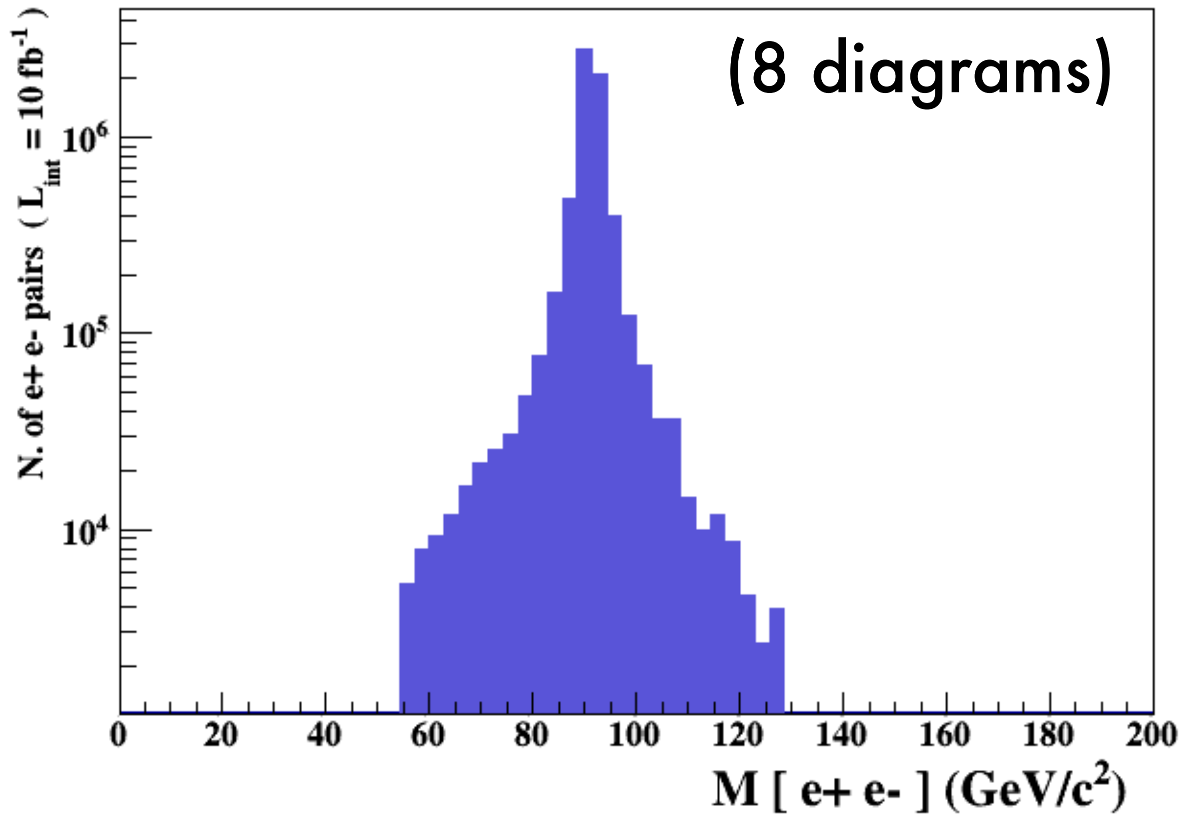
mg5> install MadAnalysis5

Understanding the Syntax

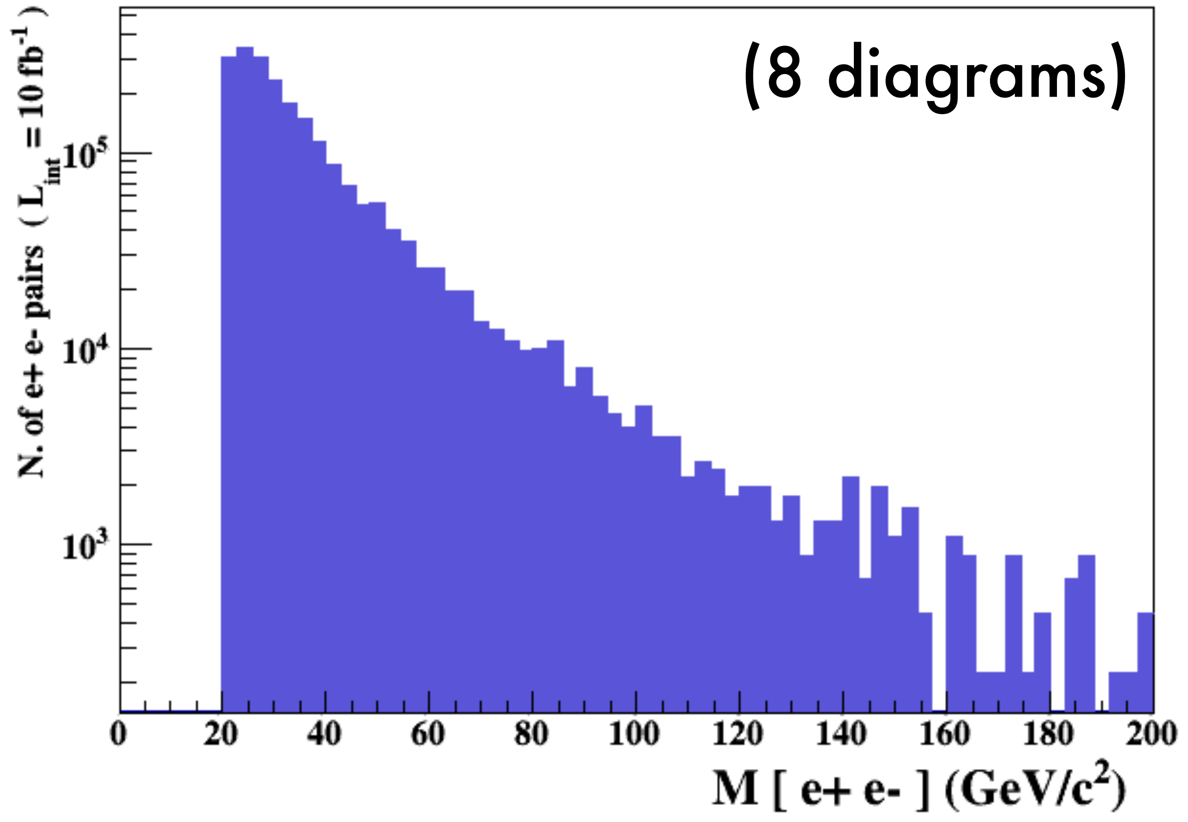
p p > mu+ mu-



p p >z , z > mu+ mu-

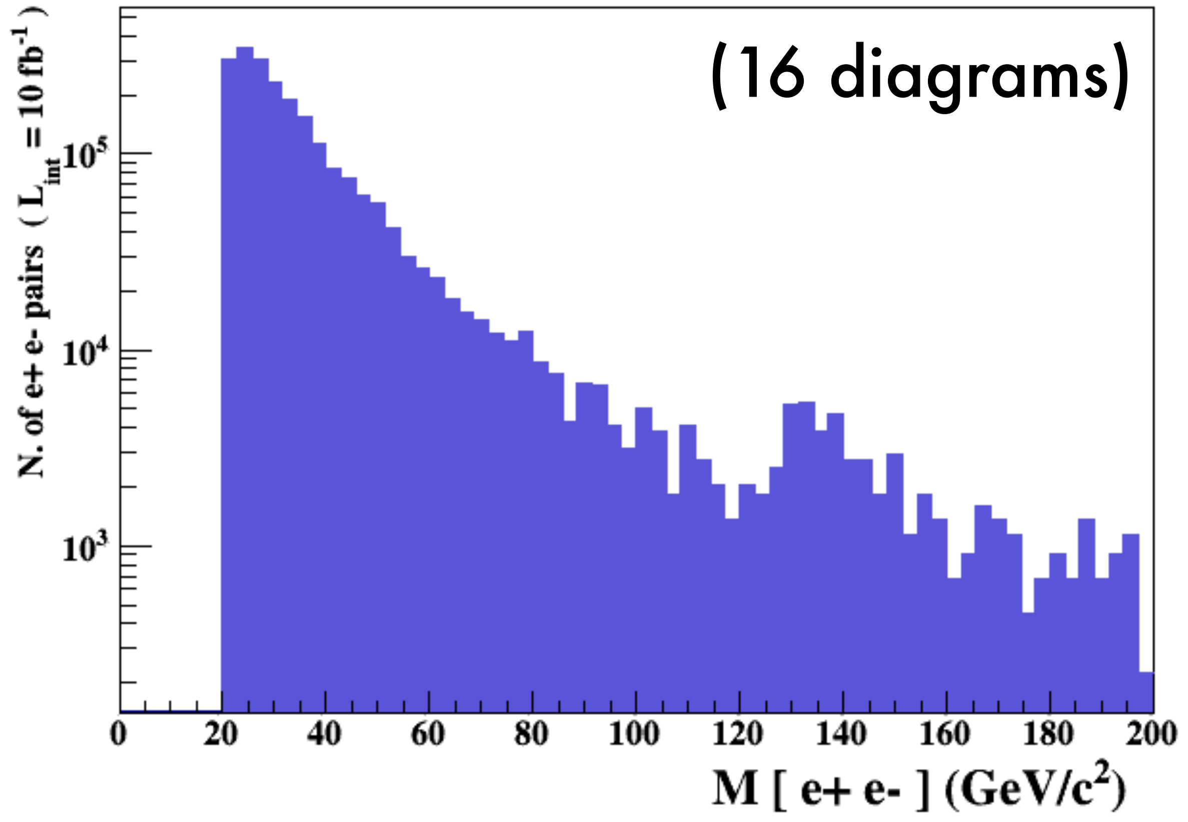


p p > mu+ mu- /z



No Z

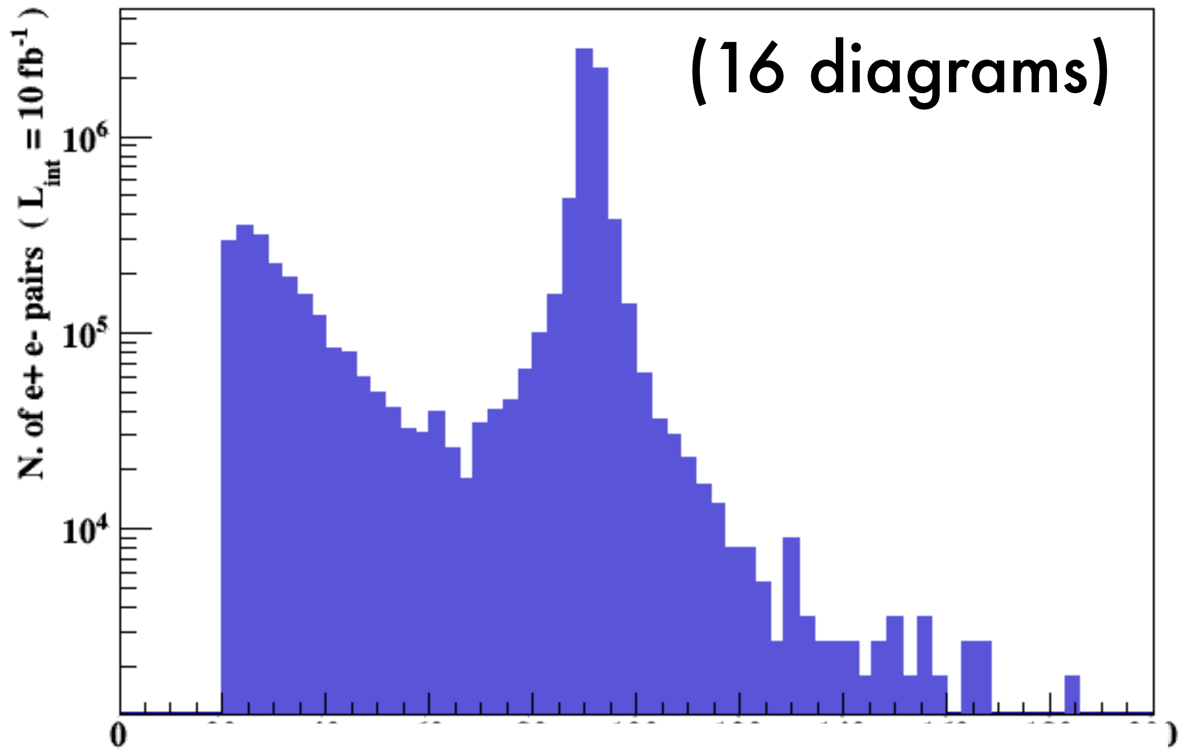
p p > mu+ mu- $ z



Z- onshell veto

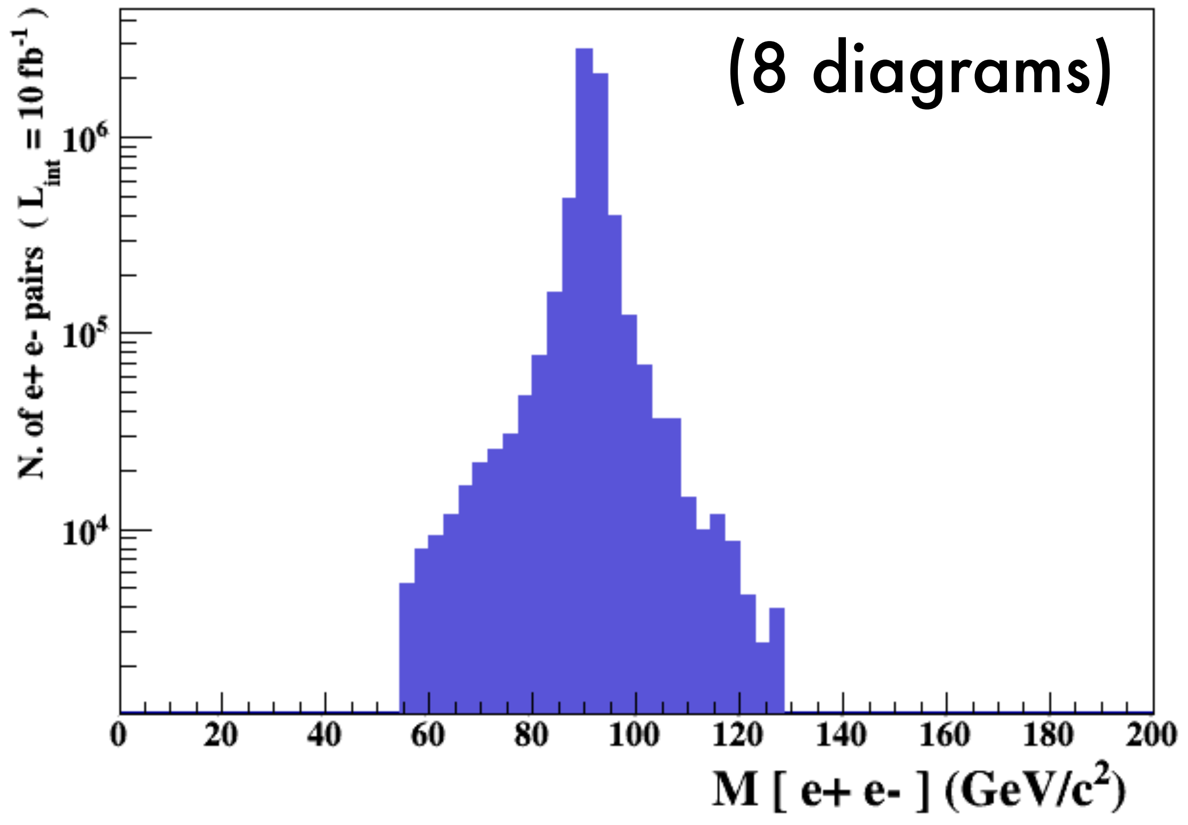
Understanding the Syntax

p p > mu+ mu-

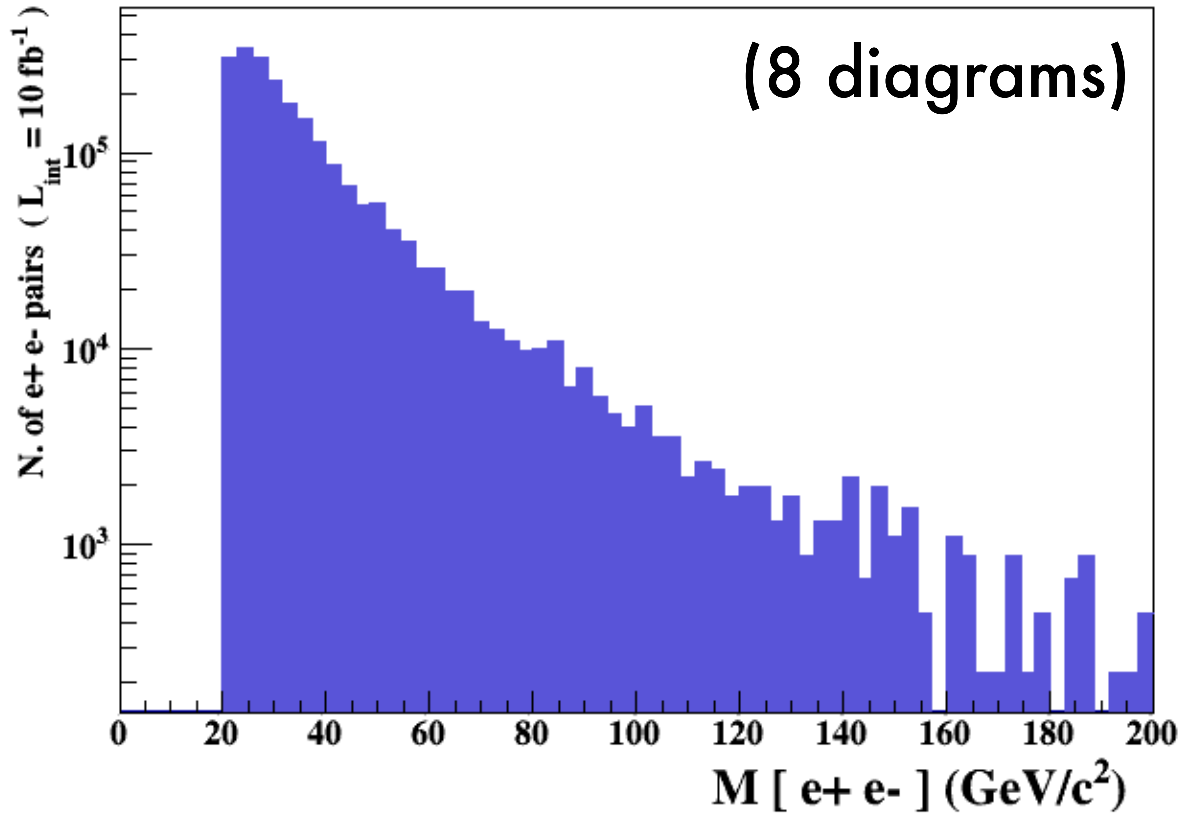


Correct Distribution

p p >z , z > mu+ mu-



p p > mu+ mu- /z



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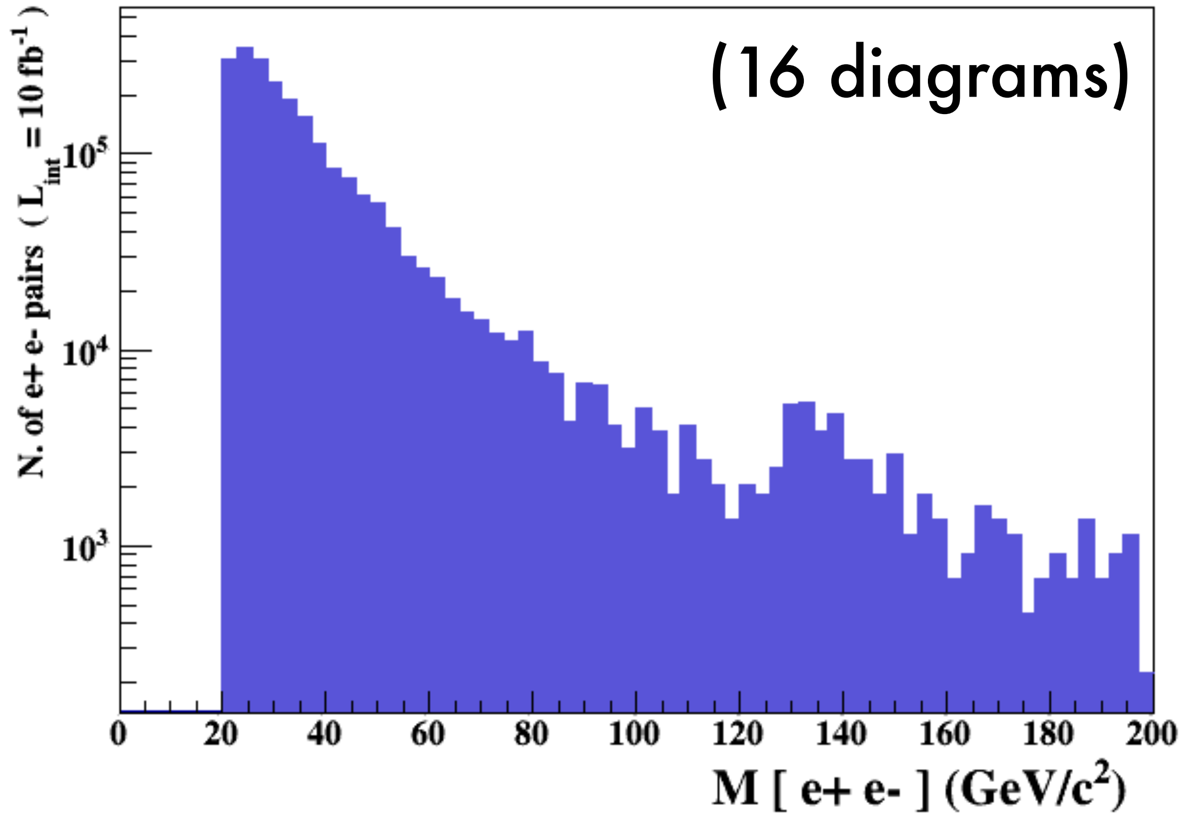

Z- onshell veto

Understanding the Syntax

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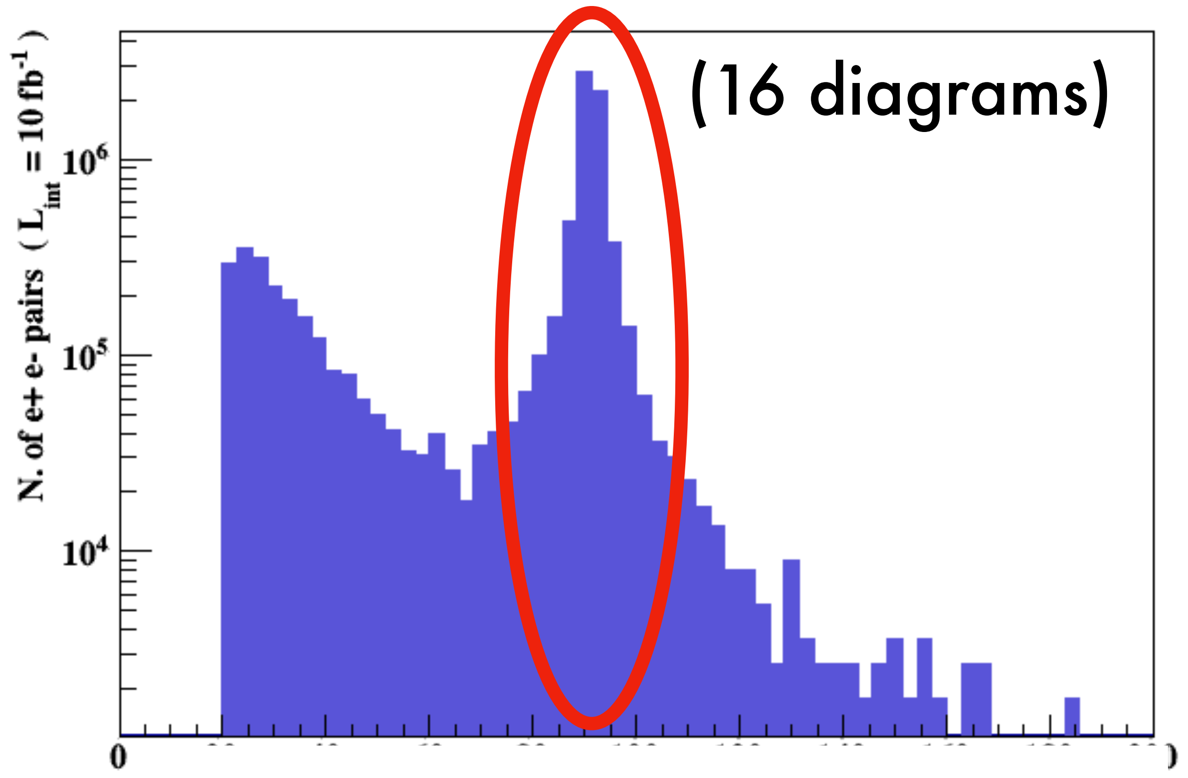

Correct Distribution

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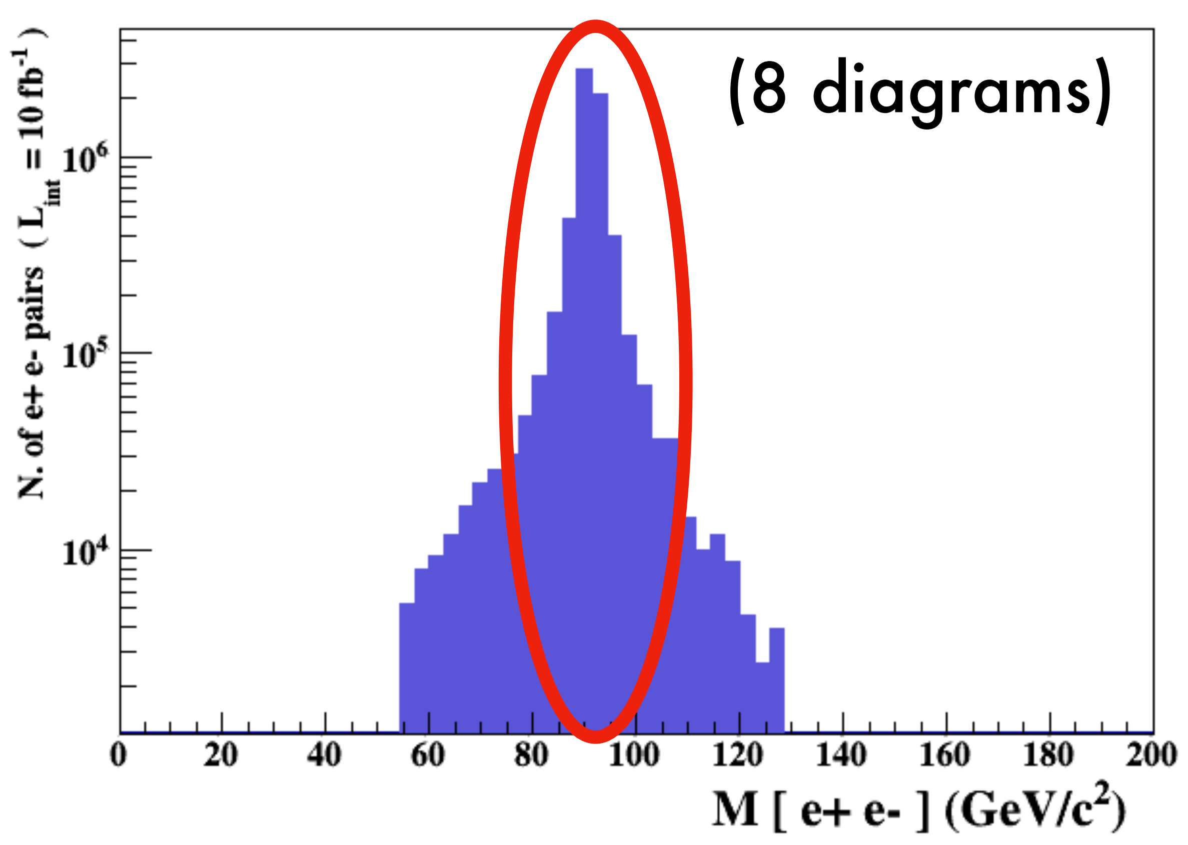
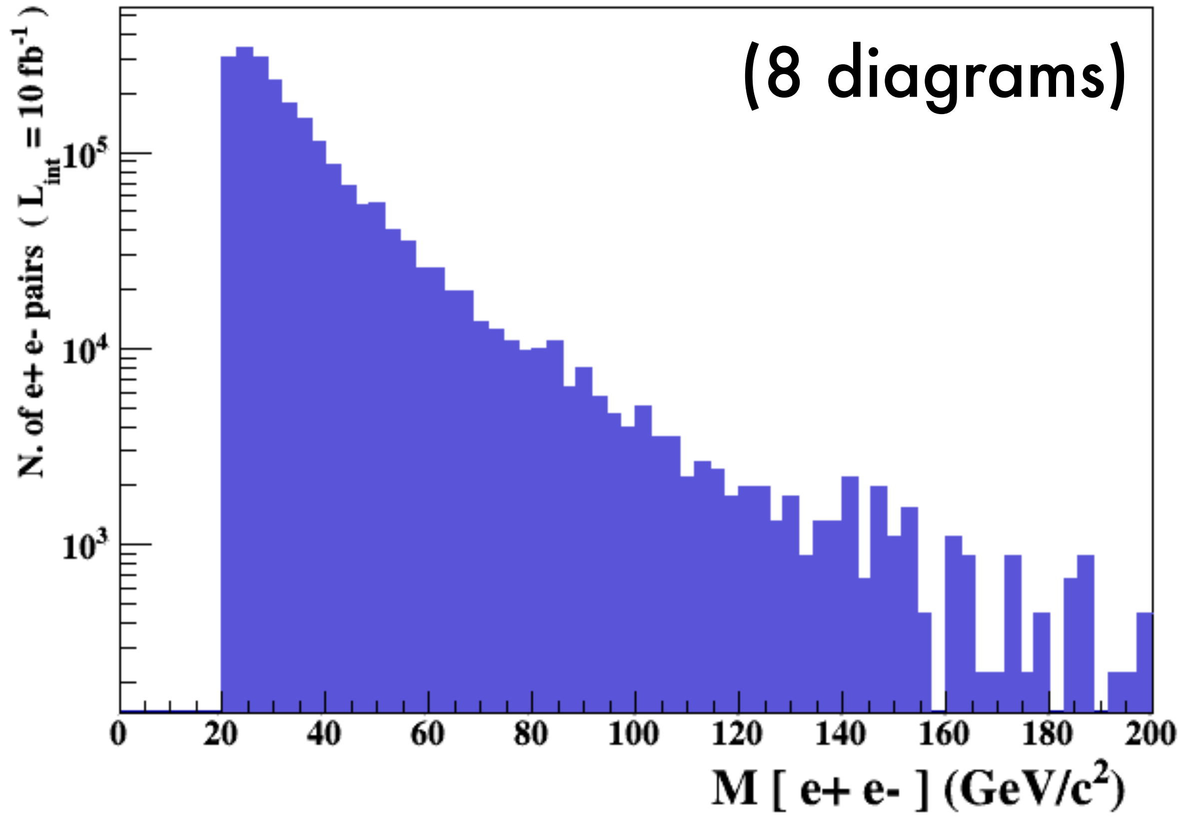


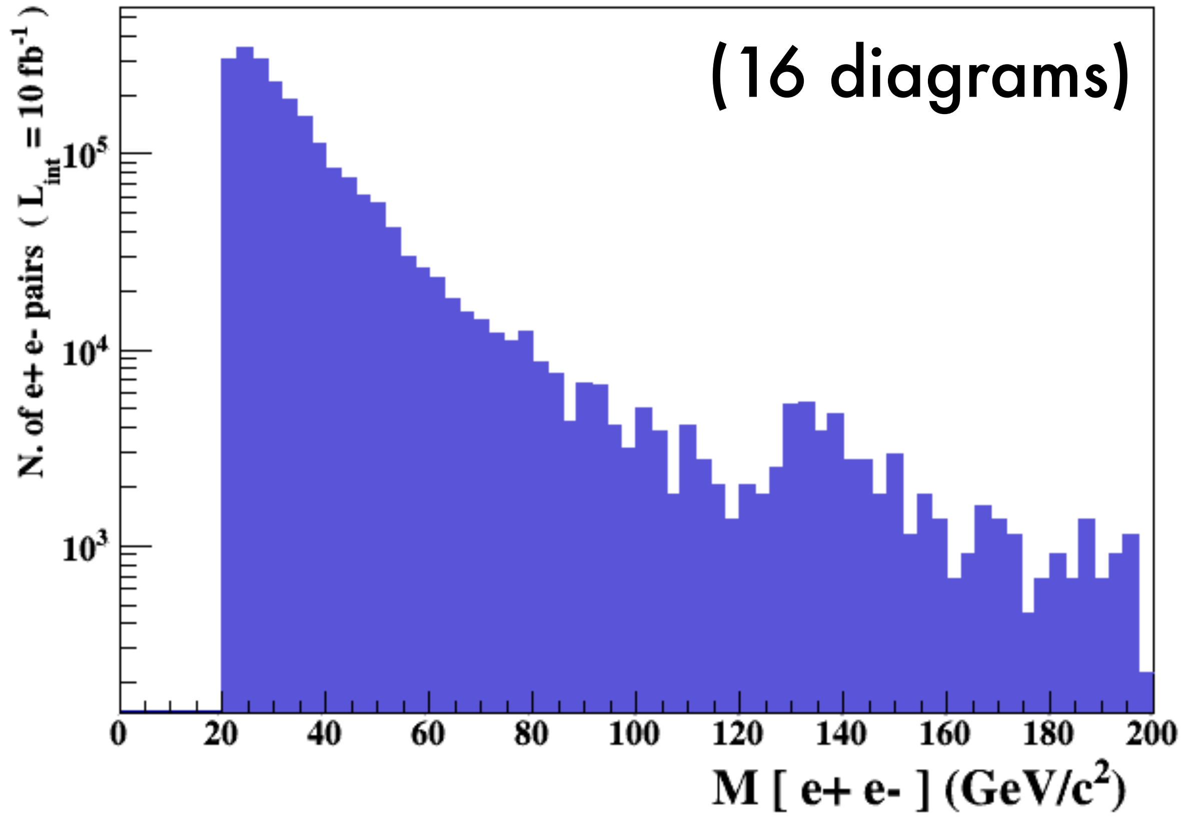
Z Peak

p p > mu+ mu- /z



No Z

p p > mu+ mu- $ z

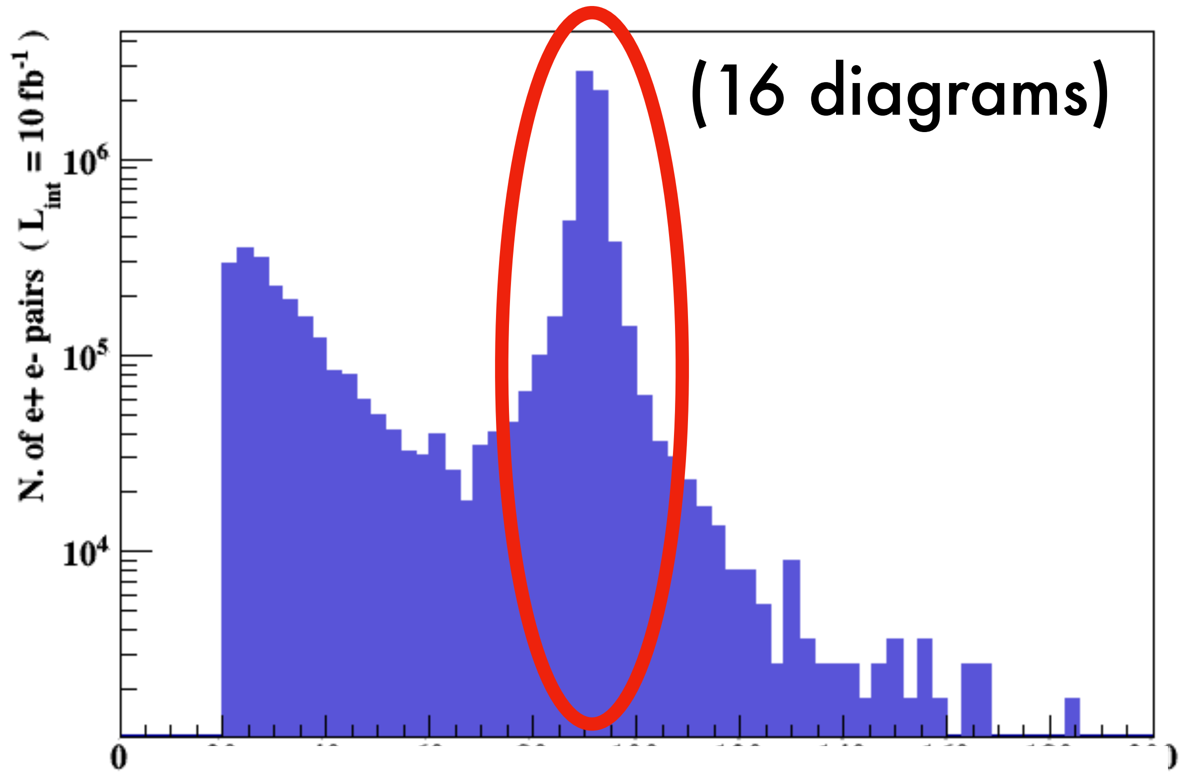


Z- onshell veto

No Z Peak

Understanding the Syntax

p p > mu+ mu-



Correct Distribution

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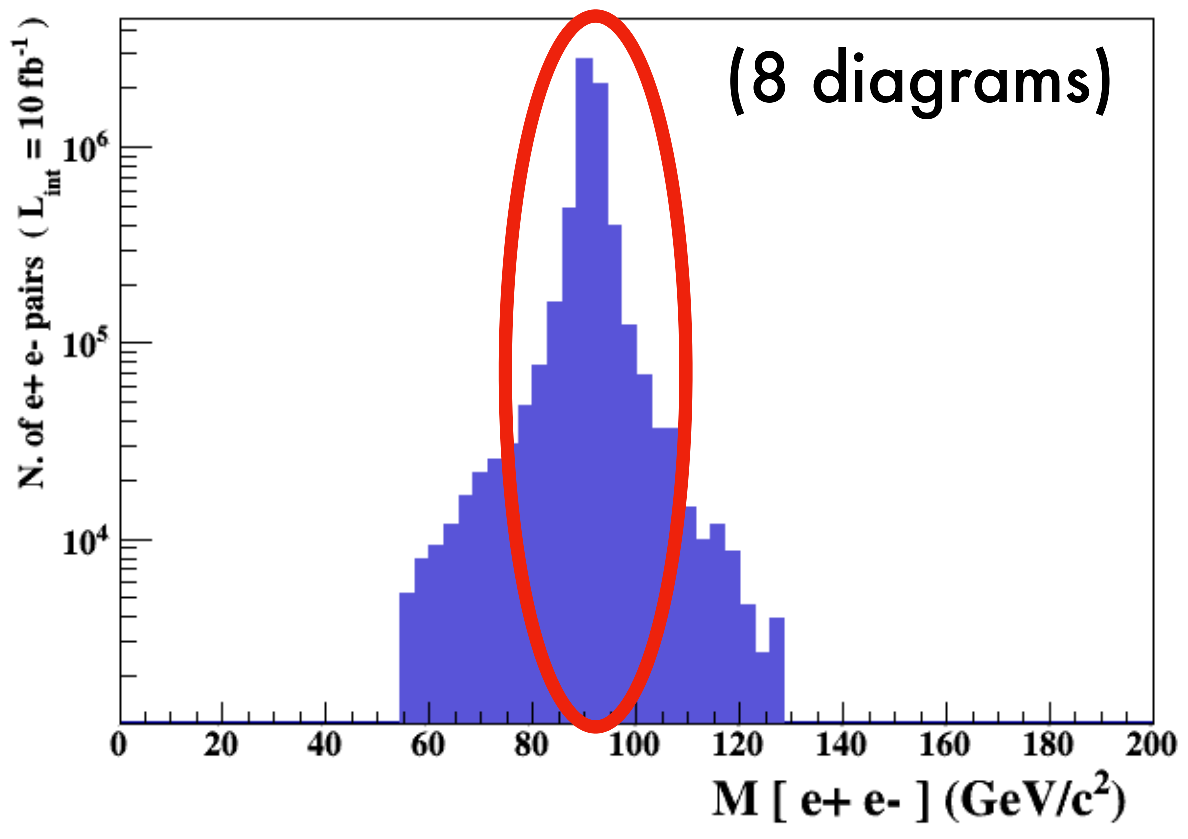

Z Peak

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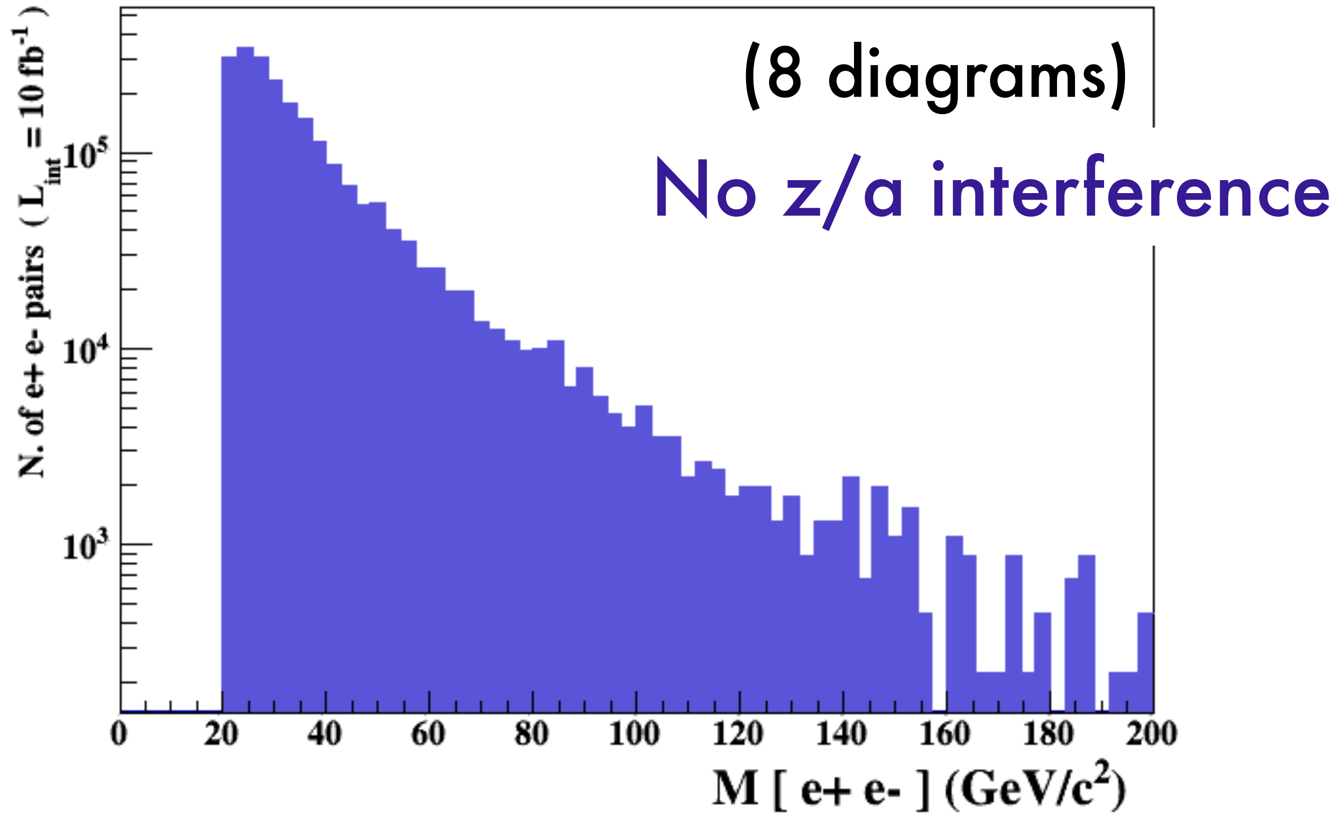
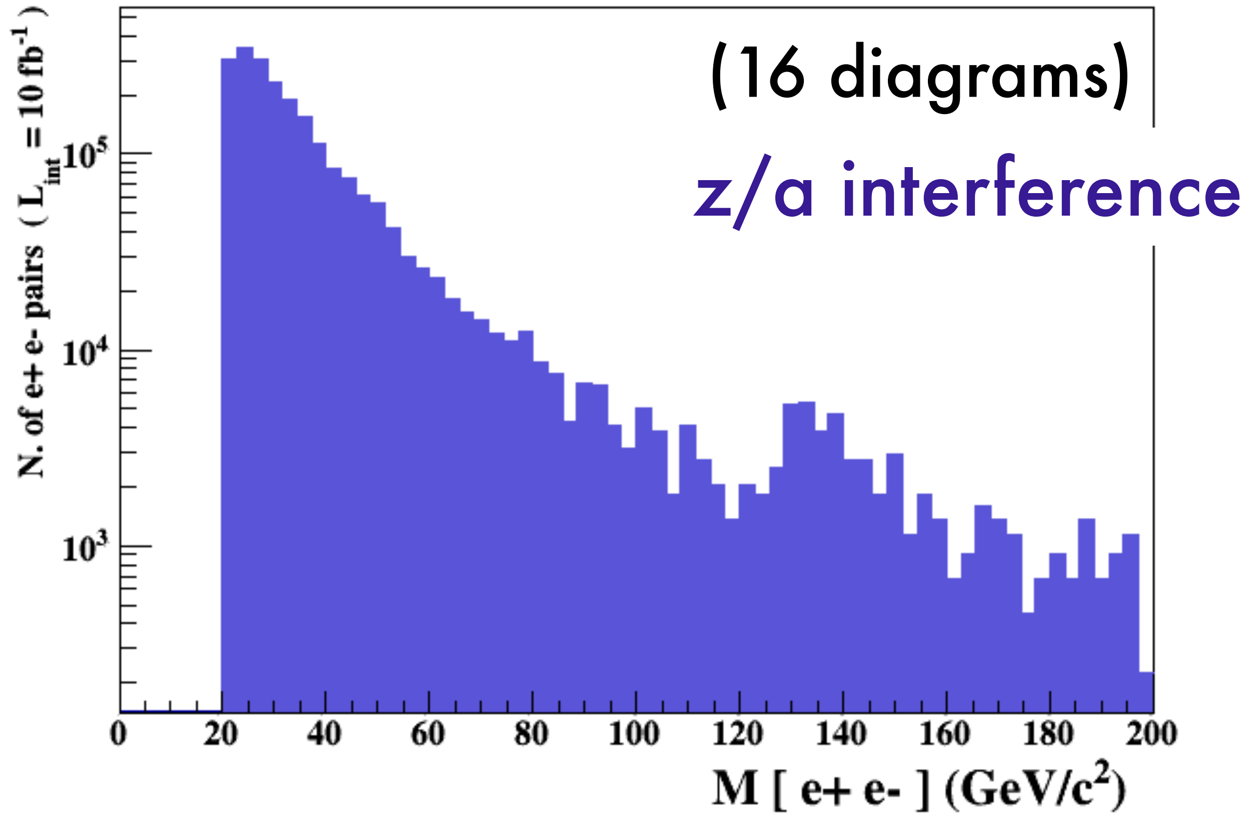


No Z

No Z Peak

p p > mu+ mu- $ z



Z- onshell veto

Understanding the Syntax

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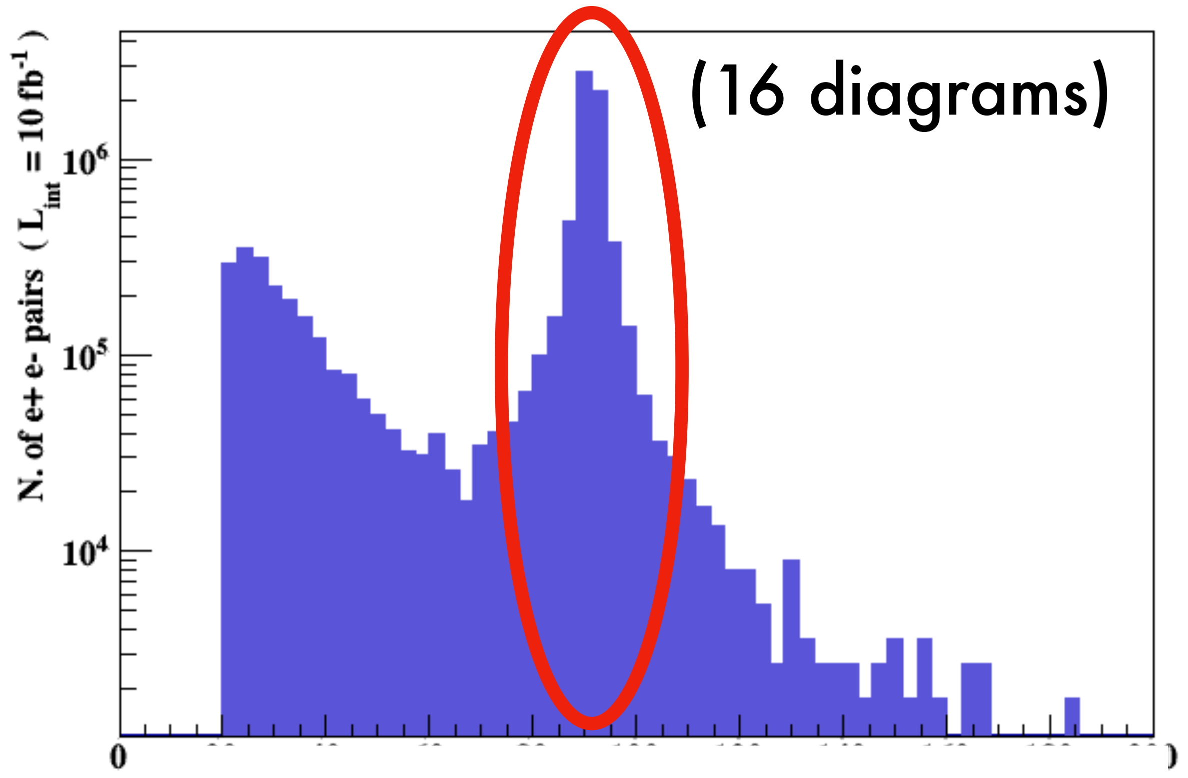

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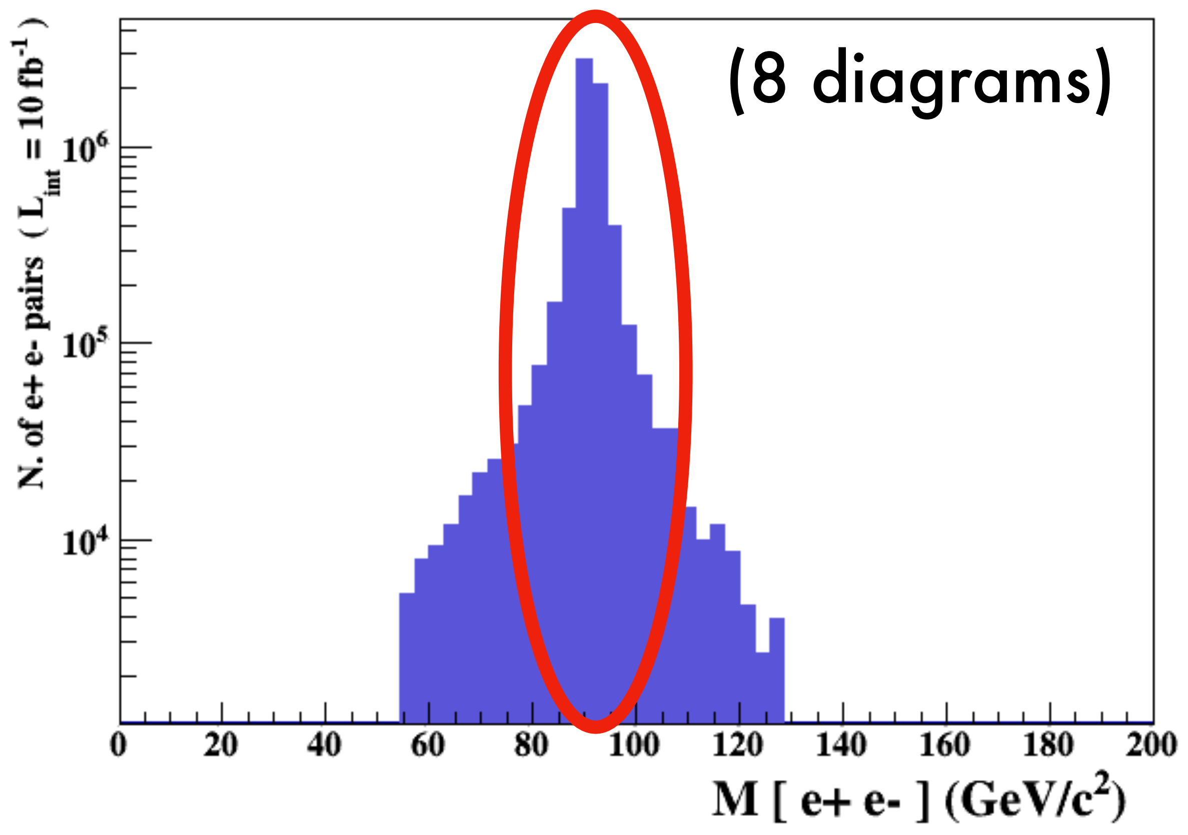

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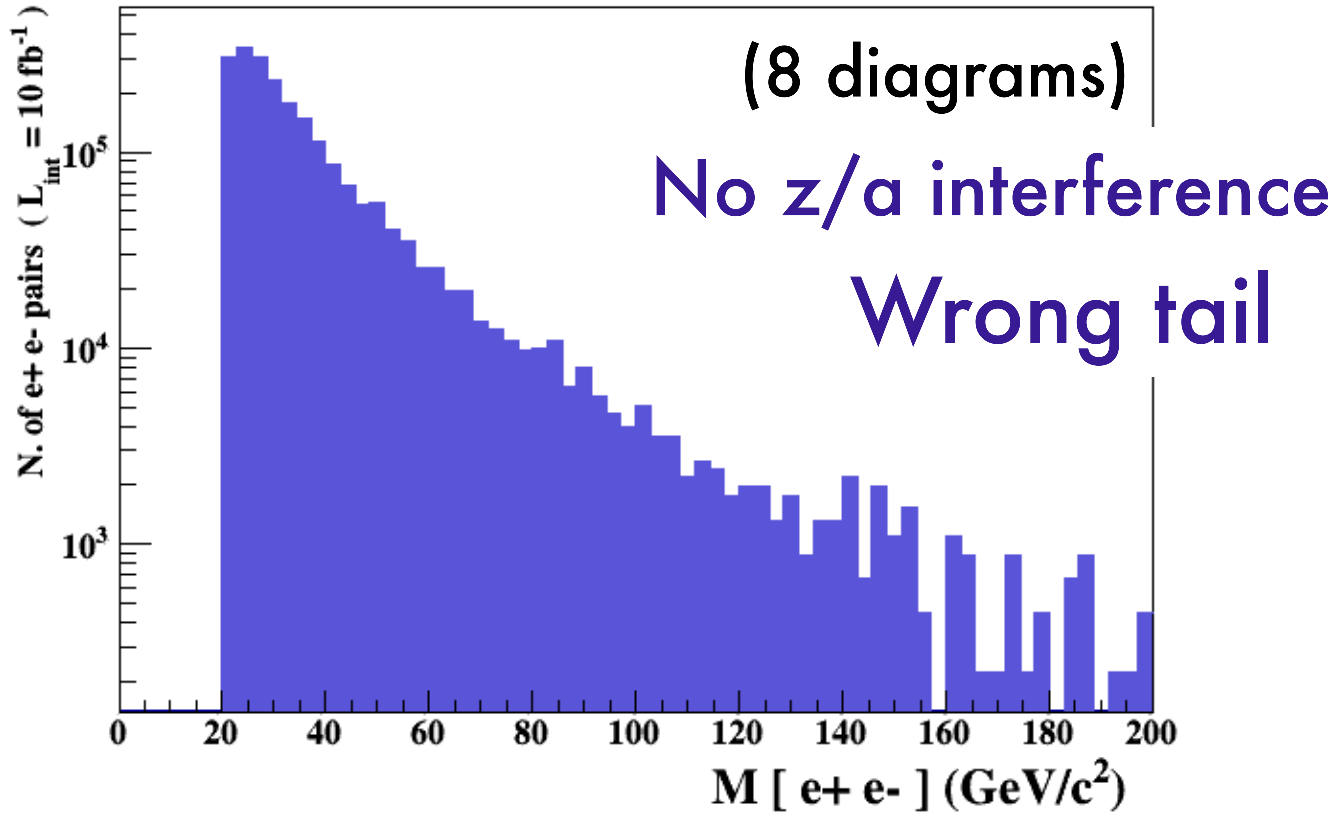

No Z Peak

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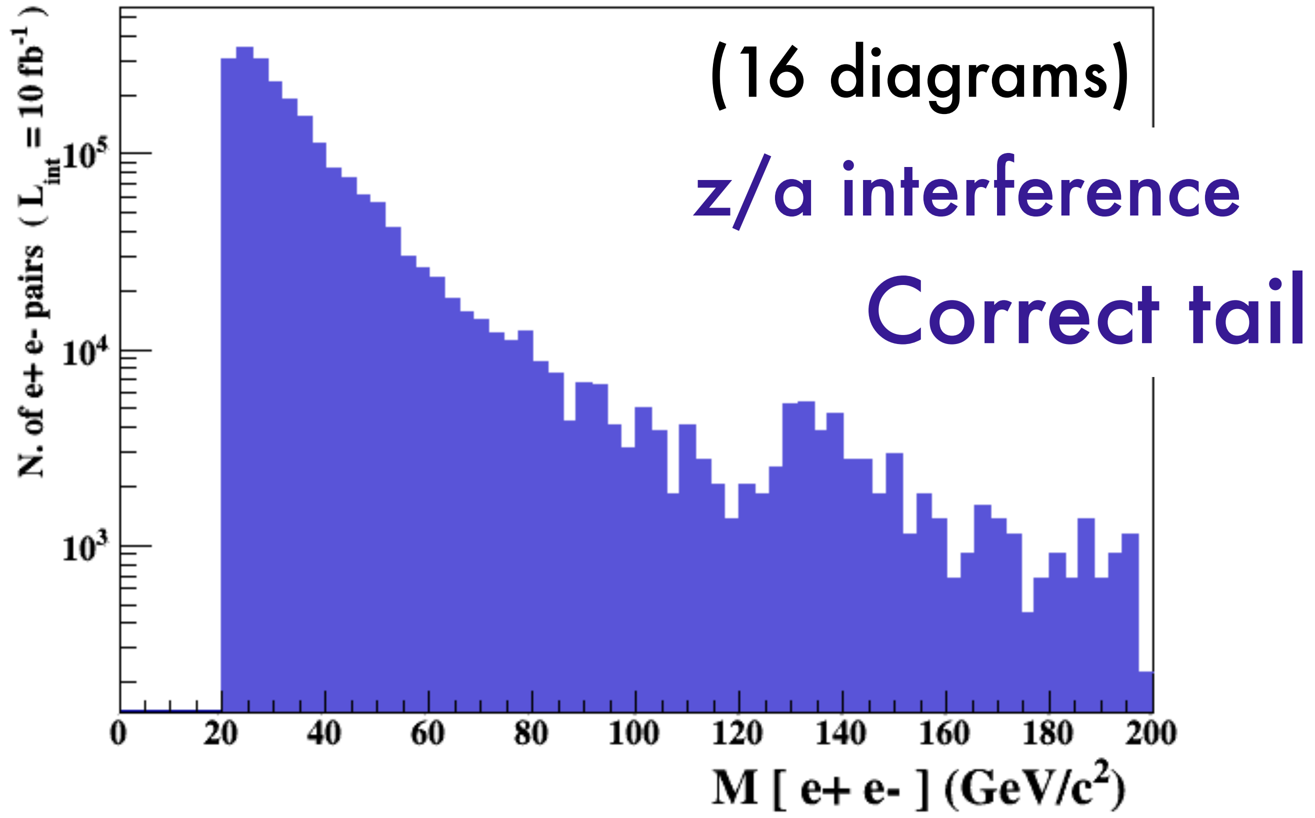
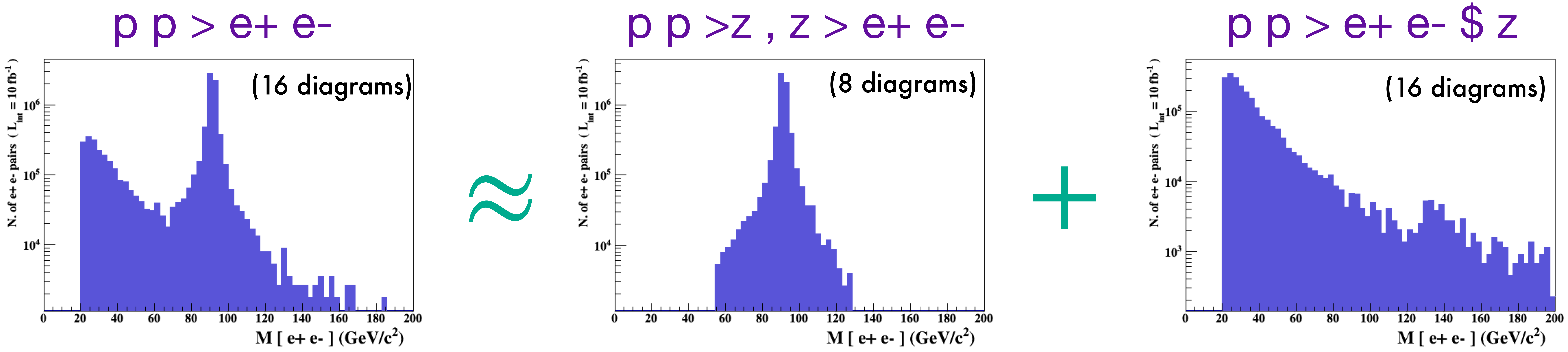


No Z

Z- onshell veto

Understanding the Syntax



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 on-shell but the photon invariant mass can be at M_Z (i.e. on-shell substraction).
- The **"/"** should be avoided → leads to **violation of gauge invariance!** ☹

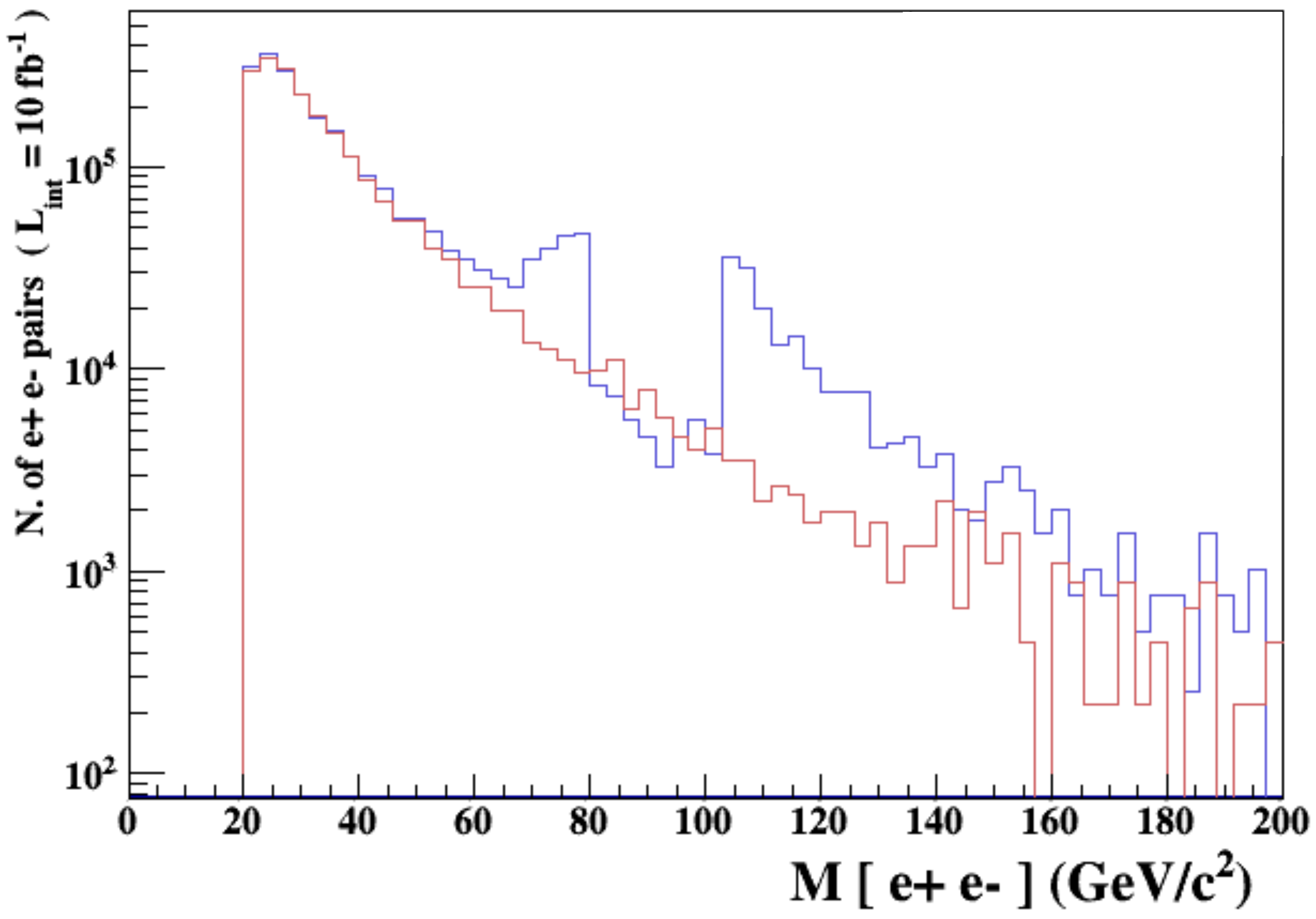
⚠️ Warning ⚠️

- 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 is done to **illustrate** how the “$” syntax works.

Understanding the $ Syntax

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

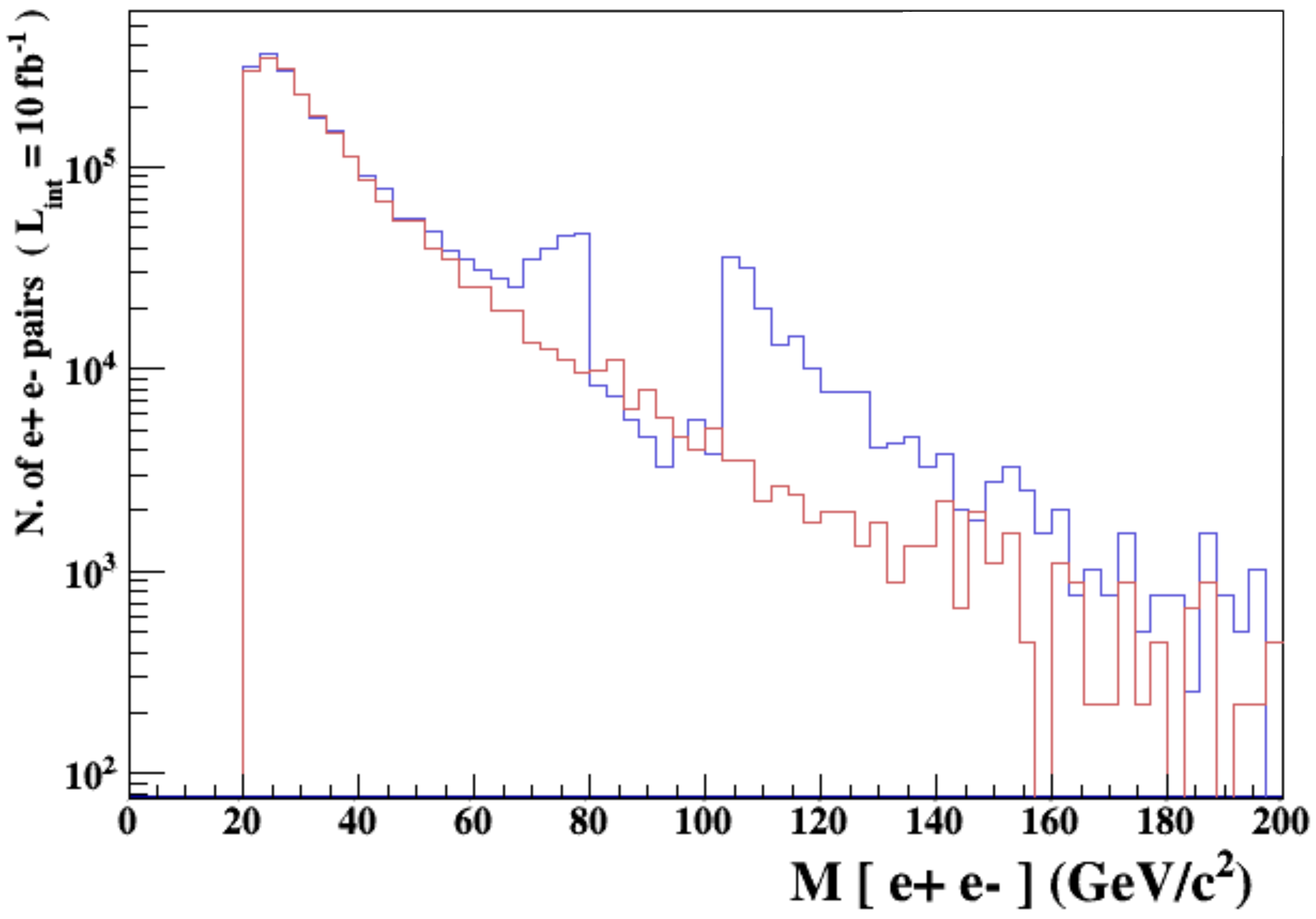
(blue curve)



Understanding the $ Syntax

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

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



Understanding the $ Syntax

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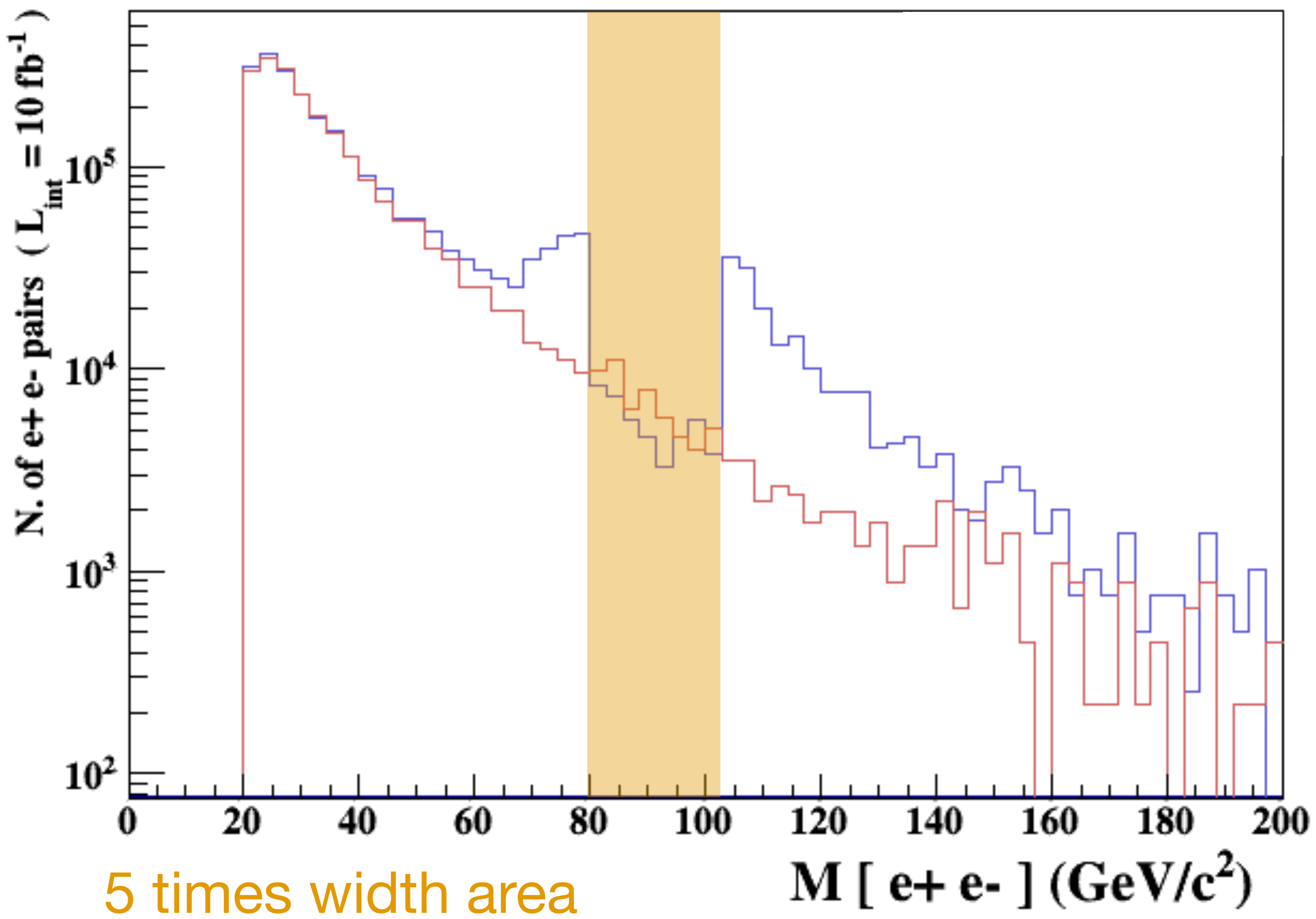

5 times width area

- Z on-shell veto

Understanding the $ Syntax

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

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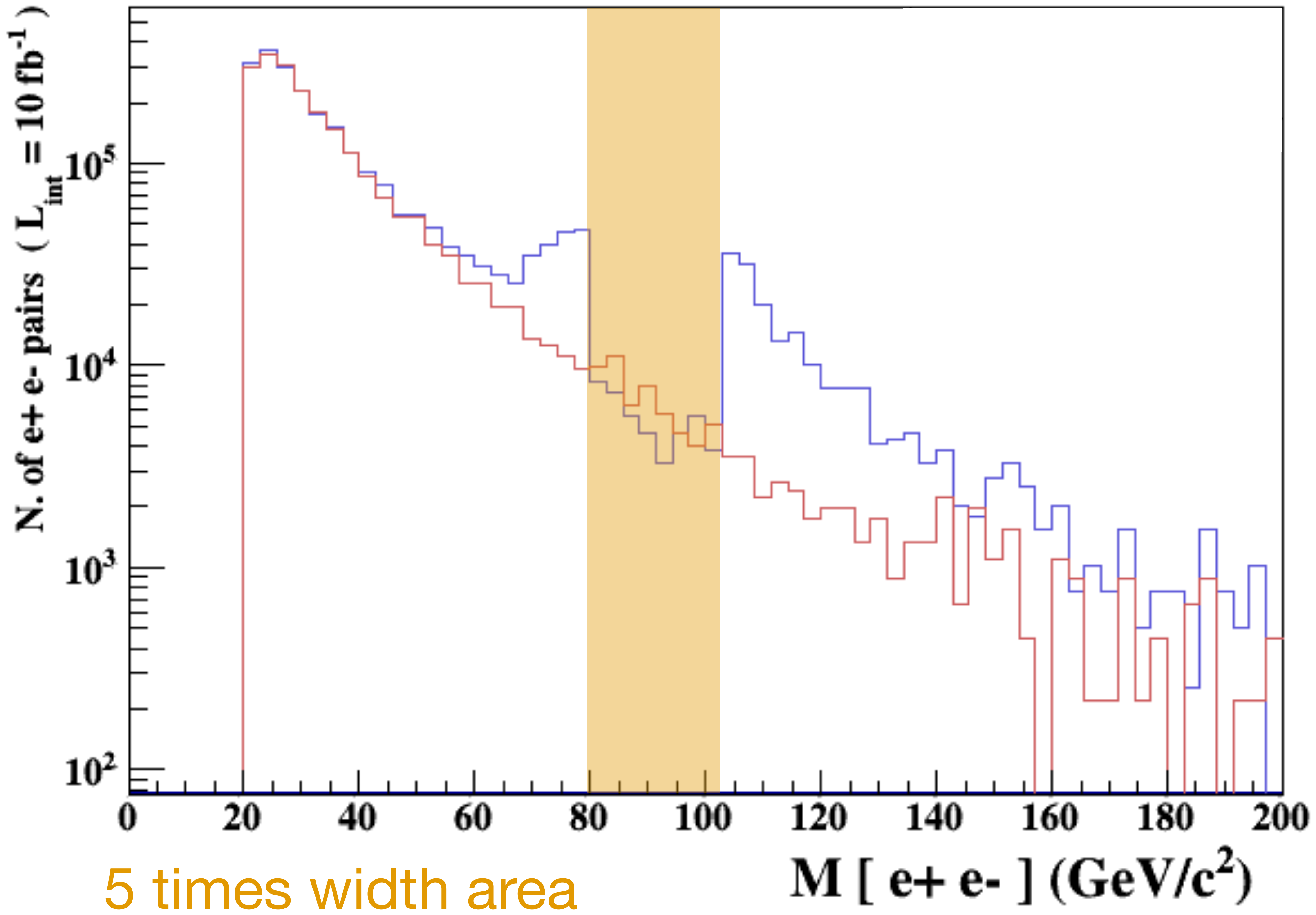
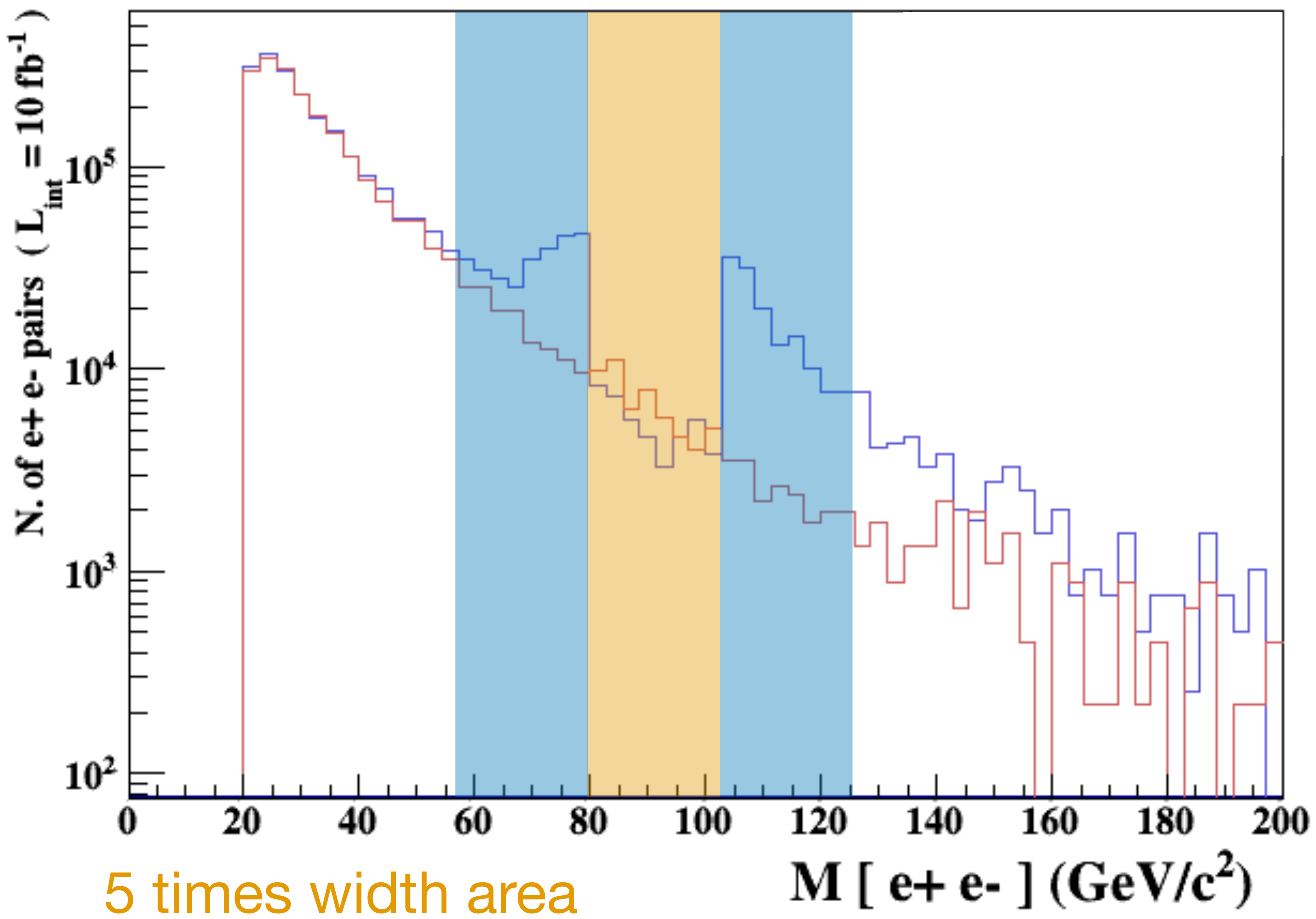


5 times width area

- Z on-shell veto
- In veto area only photon contribution

Understanding the $ Syntax

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



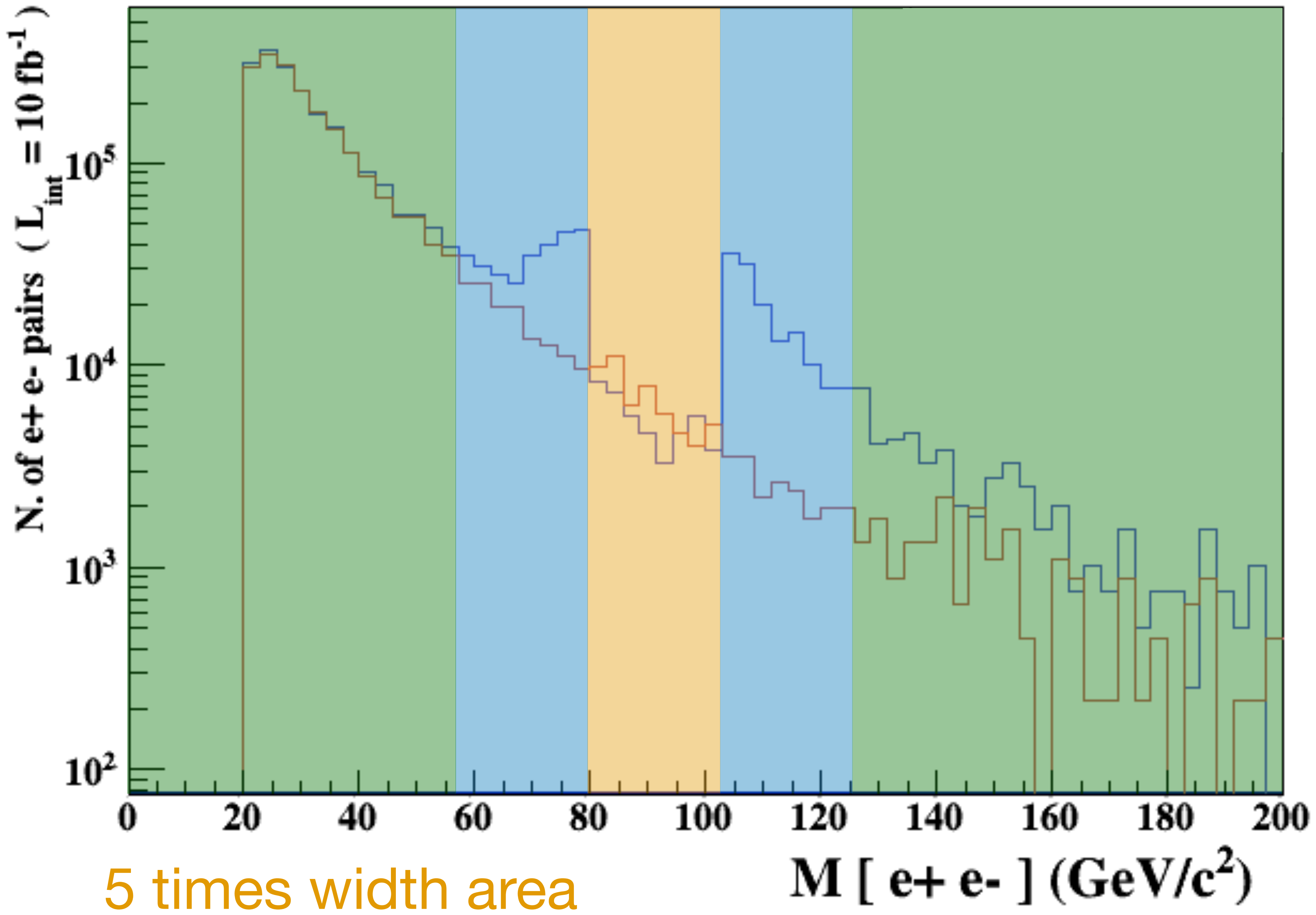
5 times width area

15 times width area

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

Understanding the $ Syntax

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



5 times width area

15 times width area

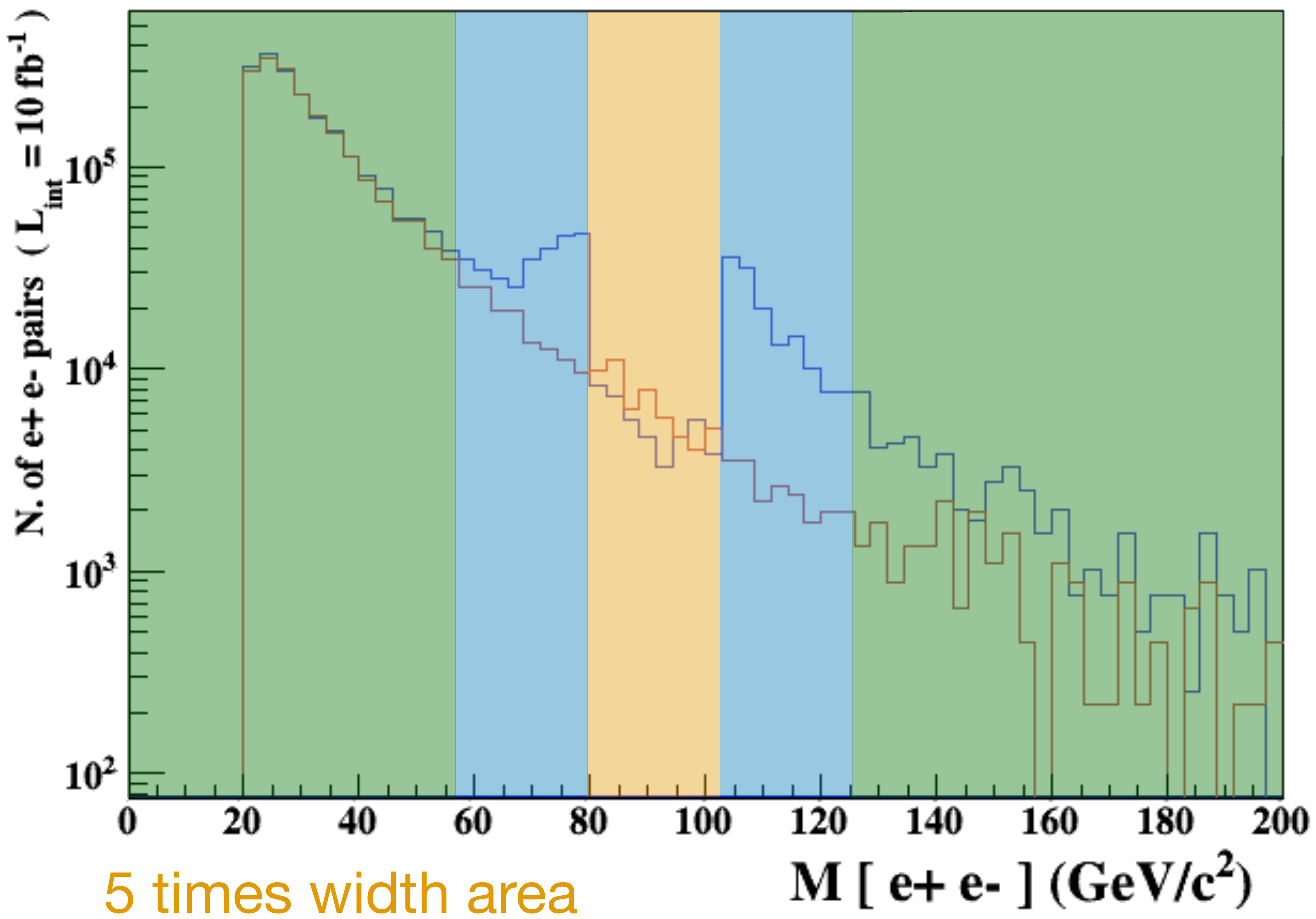
>15 times width area

- Z on-shell veto
- In veto area only photon contribution
- area sensitive to z-peak
- very off-shell Z, the difference between the curves is due to interference which **needs to be kept** in simulations.

Understanding the $ Syntax

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

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



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>15 times width area

- Z on-shell veto
- In veto area only photon contribution
- area sensitive to z-peak
- very off-shell Z, the difference between the curves is due to interference which **needs to be kept** in simulations.

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

⚠️ Be Careful ⚠️

- 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)

☹ Not gauge invariant!

☹ Ignores diagram interference!

☹ Can provide unphysical distributions.

⚠️ Be Careful ⚠️

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☹ Not gauge invariant!

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Avoid them as much as possible!

⚠️ Be Careful ⚠️

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☹ Not gauge invariant!

☹ Ignores diagram interference!

☹ Can provide unphysical distributions.

Avoid them as much as possible!

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

Preferred Syntax

- 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 cuts $|M^* - M| < BW_{cut} * \Gamma$
- Are safer to use

Preferred Syntax

- 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 cuts $|M^* - M| < BW_{cut} * \Gamma$
- Are safer to use

Prefer this syntax over previous ones!

Exercise IV — Results

p p > zp

Run	Collider	Banner	Cross section (pb)	Events	Data	Output	Action
run_01	p p 6500.0 x 6500.0 GeV	tag_1	175 ± 0.18 ± systematics	10000	parton madevent	LHE	remove run launch detector simulation
run_02	p p 6500.0 x 6500.0 GeV	tag_1	12.03 ± 0.012 ± systematics	10000	parton madevent	LHE	remove run launch detector simulation
run_03	p p 6500.0 x 6500.0 GeV	tag_1	1.981 ± 0.0017 ± systematics	10000	parton madevent	LHE	remove run launch detector simulation
run_04	p p 6500.0 x 6500.0 GeV	tag_1	0.4651 ± 0.00043 ± systematics	10000	parton madevent	LHE	remove run launch detector simulation

p p > zp , zp > mu+ mu-

Run	Collider	Banner	Cross section (pb)	Events	Data	Output	Action
run_01	p p 6500.0 x 6500.0 GeV	tag_1	0.9164 ± 0.00088 ± systematics	10000	parton madevent	LHE	remove run launch detector simulation
run_02	p p 6500.0 x 6500.0 GeV	tag_1	0.1304 ± 0.00025 ± systematics	10000	parton madevent	LHE	remove run launch detector simulation
run_03	p p 6500.0 x 6500.0 GeV	tag_1	0.03253 ± 6.5e-05 ± systematics	10000	parton madevent	LHE	remove run launch detector simulation
run_04	p p 6500.0 x 6500.0 GeV	tag_1	0.009965 ± 1.4e-05 ± systematics	10000	parton madevent	LHE	remove run launch detector simulation

Branching Ratio: **0.005 | 0.011 | 0.016 | 0.019**

→ Unstable Branching Ratio (What?)

Exercise IV — With auto width

p p > zp

Run	Collider	Banner	Cross section (pb)	Events	Data	Output	Action
run_01	p p 6500.0 x 6500.0 GeV	tag_1	175 ± 0.18 ± systematics	10000	parton madevent	LHE	remove run launch detector simulation
run_02	p p 6500.0 x 6500.0 GeV	tag_1	12.03 ± 0.012 ± systematics	10000	parton madevent	LHE	remove run launch detector simulation
run_03	p p 6500.0 x 6500.0 GeV	tag_1	1.981 ± 0.0017 ± systematics	10000	parton madevent	LHE	remove run launch detector simulation
run_04	p p 6500.0 x 6500.0 GeV	tag_1	0.4651 ± 0.00043 ± systematics	10000	parton madevent	LHE	remove run launch detector simulation

p p > zp , zp > mu+ mu-

Run	Collider	Banner	Cross section (pb)	Events	Data	Output	Action
run_05	p p 6500.0 x 6500.0 GeV	tag_1	5.647 ± 0.0055 ± systematics	10000	parton madevent	LHE	remove run launch detector simulation
run_06	p p 6500.0 x 6500.0 GeV	tag_1	0.3729 ± 0.00036 ± systematics	10000	parton madevent	LHE	remove run launch detector simulation
run_07	p p 6500.0 x 6500.0 GeV	tag_1	0.06119 ± 6.5e-05 ± systematics	10000	parton madevent	LHE	remove run launch detector simulation
run_08	p p 6500.0 x 6500.0 GeV	tag_1	0.01444 ± 1e-05 ± systematics	10000	parton madevent	LHE	remove run launch detector simulation

Branching Ratio: **0.032 | 0.031 | 0.030 | 0.03**

→ **Stable Branching Ratio (Good)**

Rivet+Contur Tutorial

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