Overview of MadGraph5_aMC@NLO

Olivier Mattelaer
UCLouvain
CP3/CISM

Plan

- Details of the computation
  - Evaluation of matrix-element
  - Phase-Space integration
- What is MG5_aMC

What are my goals

Title

- Justify why **analytic** computation are **SLOWER** than **numerical** computation
- Justify why **adding cuts** to the code are **POSSIBLE** but can lead to **PROBLEM**
- Overview of MG5_aMC
  - ➡ What does each package
- Details on small width handling

Matrix-Element

Calculate a given process (e.g. gluino pair)

- Determine the production mechanism

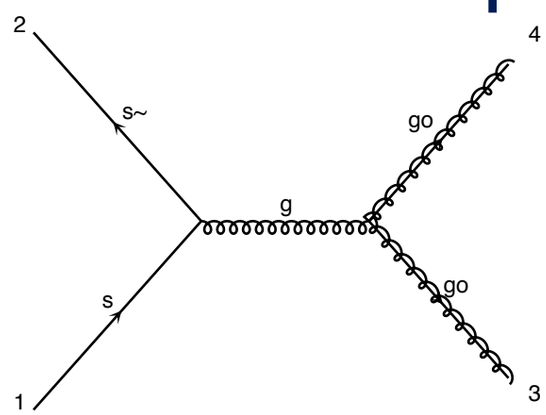


diagram 1 QCD=2, QED=0

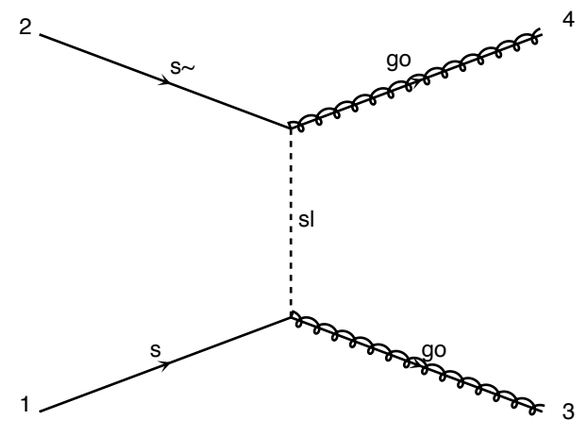


diagram 2 QCD=2, QED=0

- Evaluate the matrix-element

$$|\mathcal{M}|^2$$

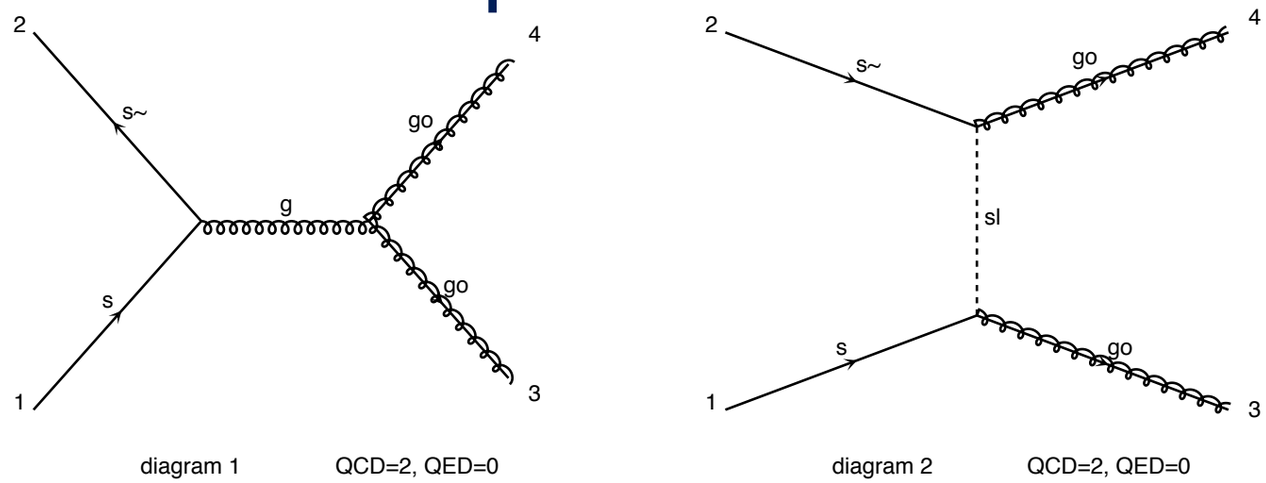
- Phase-Space Integration

$$\sigma = \frac{1}{2s} \int |\mathcal{M}|^2 d\Phi(n)$$

Matrix-Element

Calculate a given process (e.g. gluino pair)

- Determine the production mechanism



Easy

- Evaluate the matrix-element

$$|\mathcal{M}|^2$$

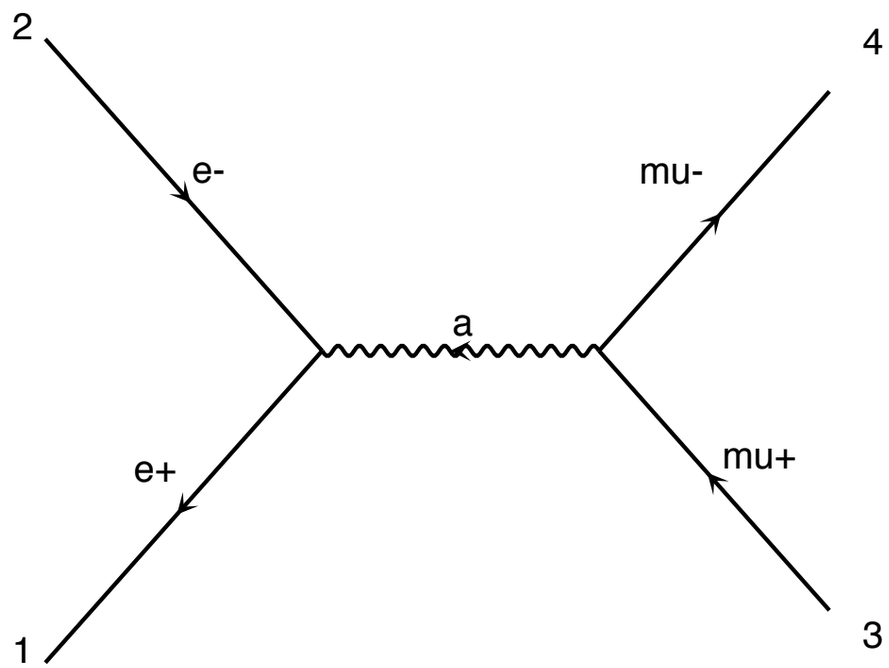
Hard

- Phase-Space Integration

$$\sigma = \frac{1}{2s} \int |\mathcal{M}|^2 d\Phi(n)$$

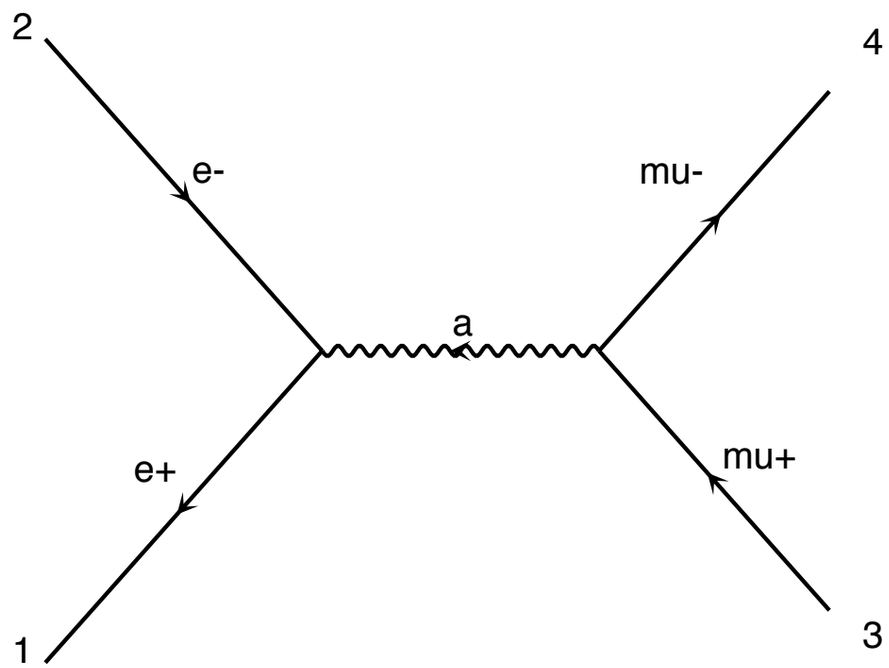
Very Hard
(in general)

Matrix Element



$$\mathcal{M} = e^2 (\bar{u}\gamma^\mu v) \frac{g_{\mu\nu}}{q^2} (\bar{v}\gamma^\nu u)$$

Matrix Element



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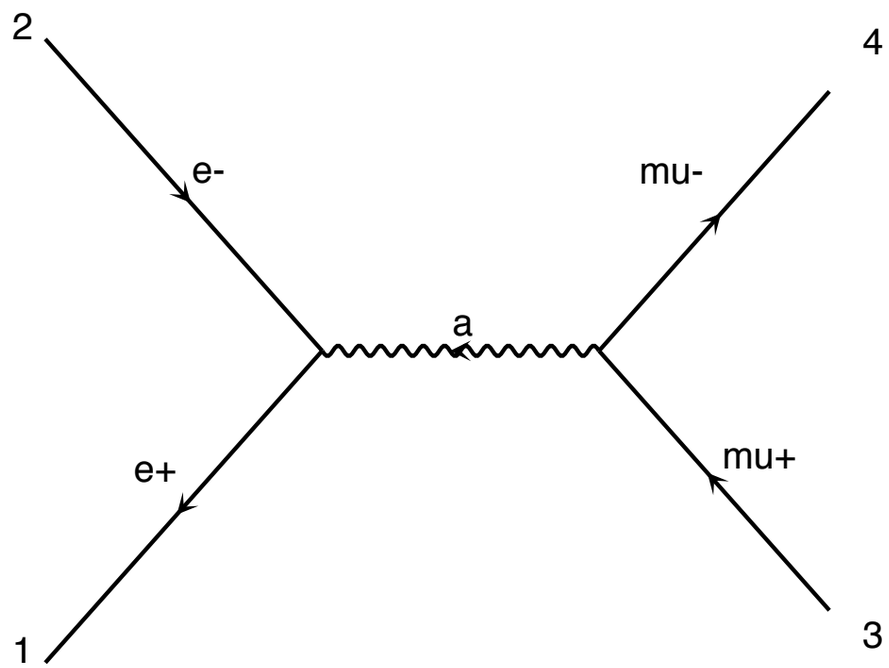
$$\frac{1}{4}\sum_{pol} |\mathcal{M}|^2 = \frac{1}{4}\sum_{pol} \mathcal{M}^* \mathcal{M}$$

Matrix Element



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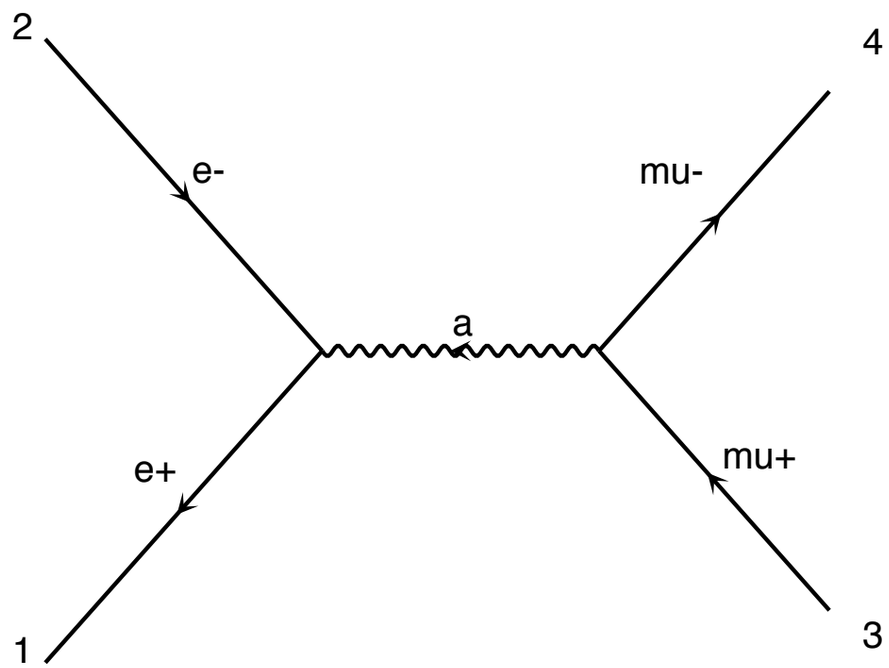
Matrix Element



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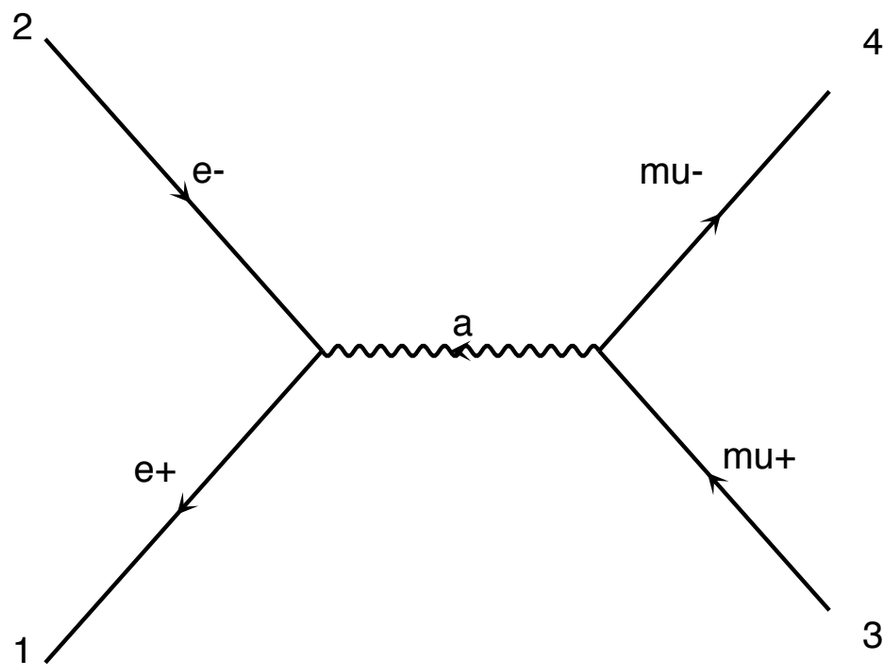
$$\rightarrow \quad \frac{e^4}{4q^4} Tr[\not{p}_1 \gamma^\mu \not{p}_2 \gamma^\nu] Tr[\not{p}_3 \gamma_\mu \not{p}_4 \gamma_\nu]$$

Matrix Element



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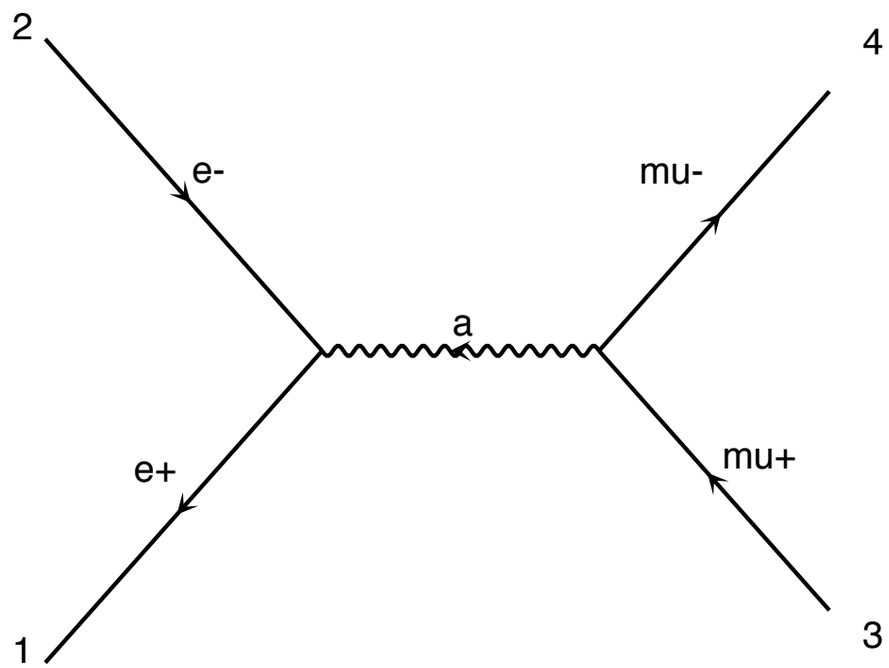
$$\rightarrow \quad \frac{8e^4}{q^4}\left[(p_1.p_3)(p_2.p_4) + (p_1.p_4)(p_2.p_3)\right]$$

Matrix Element



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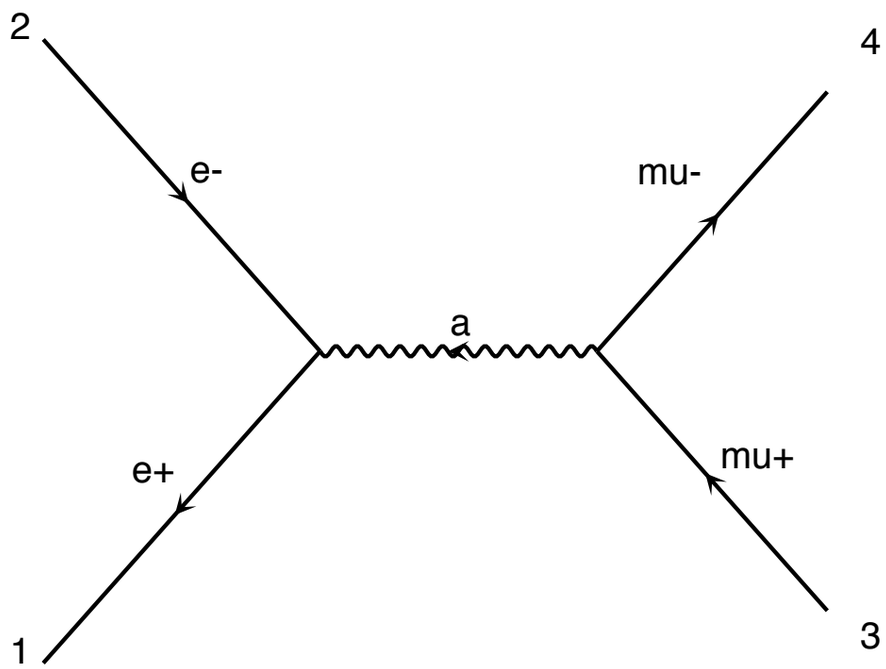
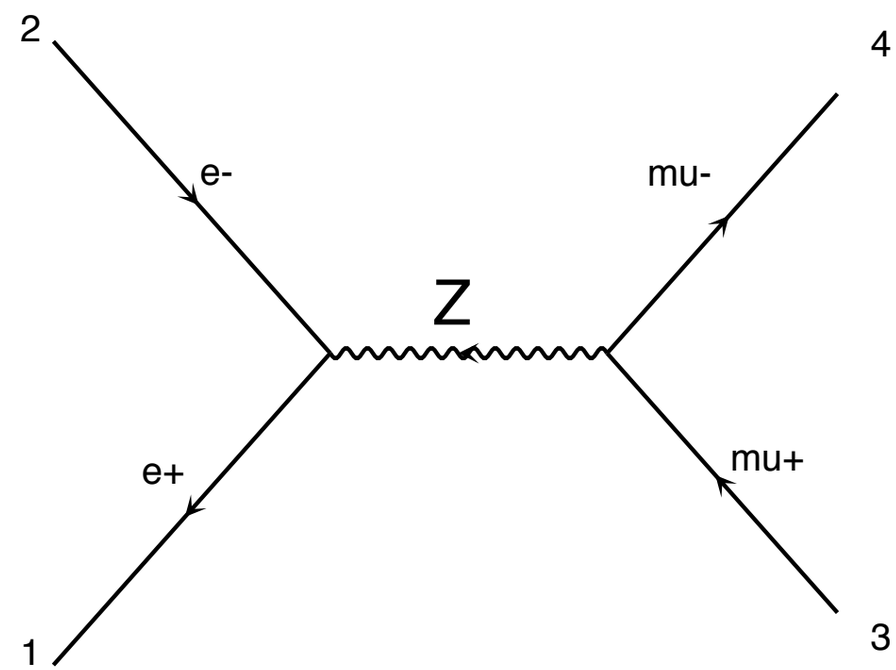
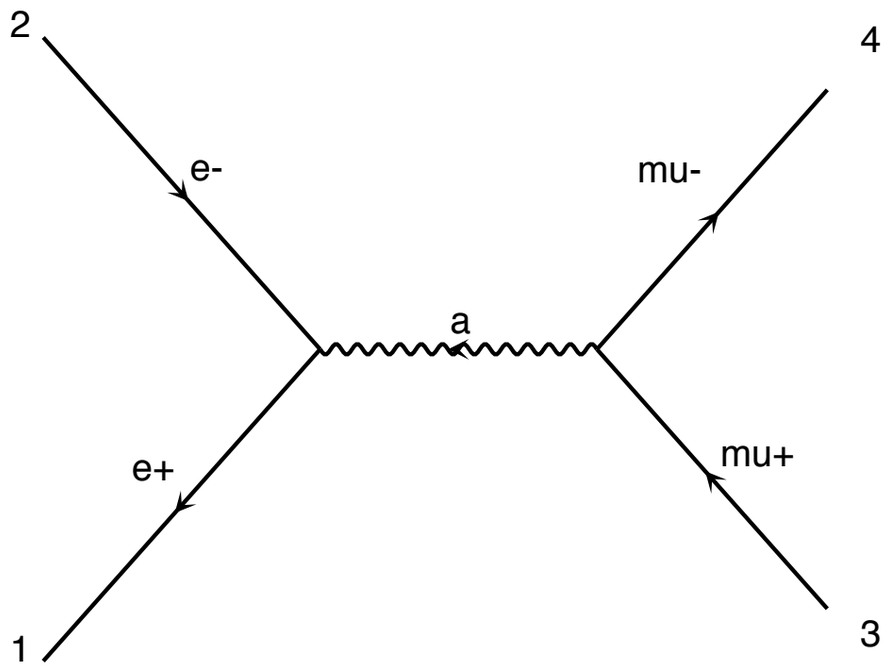
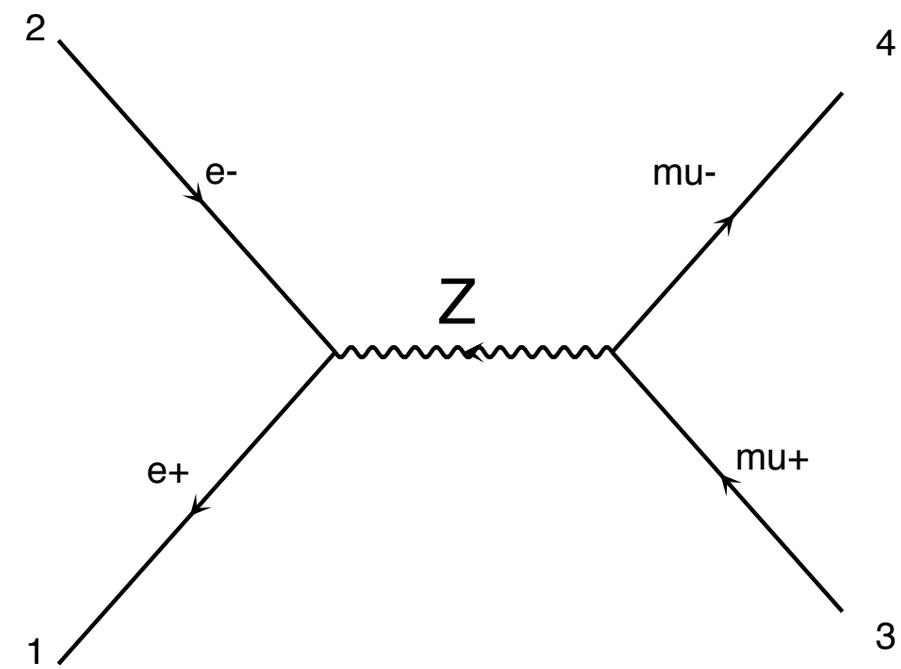
$$\rightarrow \quad \frac{8e^4}{q^4}\left[(p_1.p_3)(p_2.p_4) + (p_1.p_4)(p_2.p_3)\right]$$

Very Efficient
(few computation to perform to get that number)

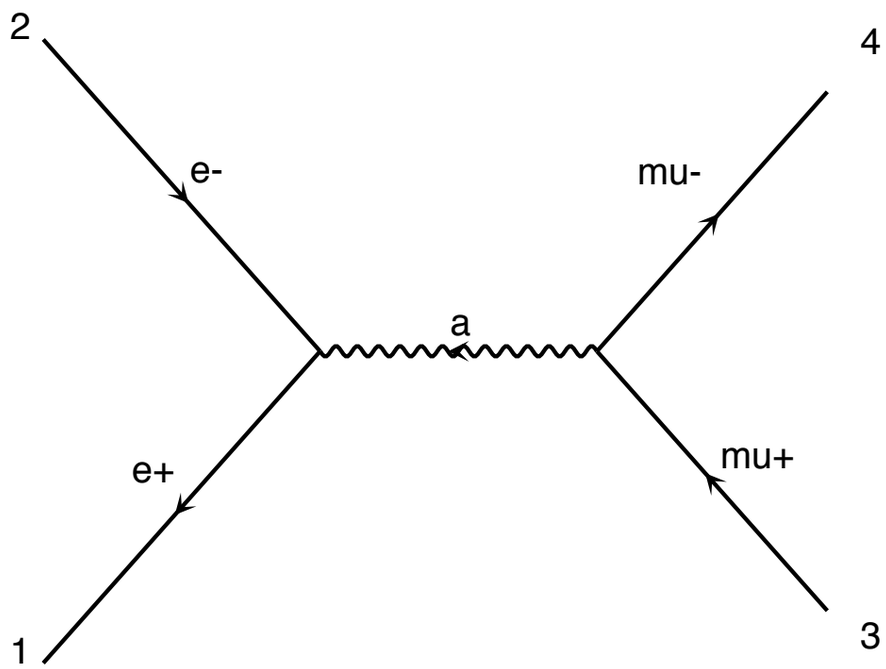

2
4
e-
mu-
a
e+
mu+
1
3

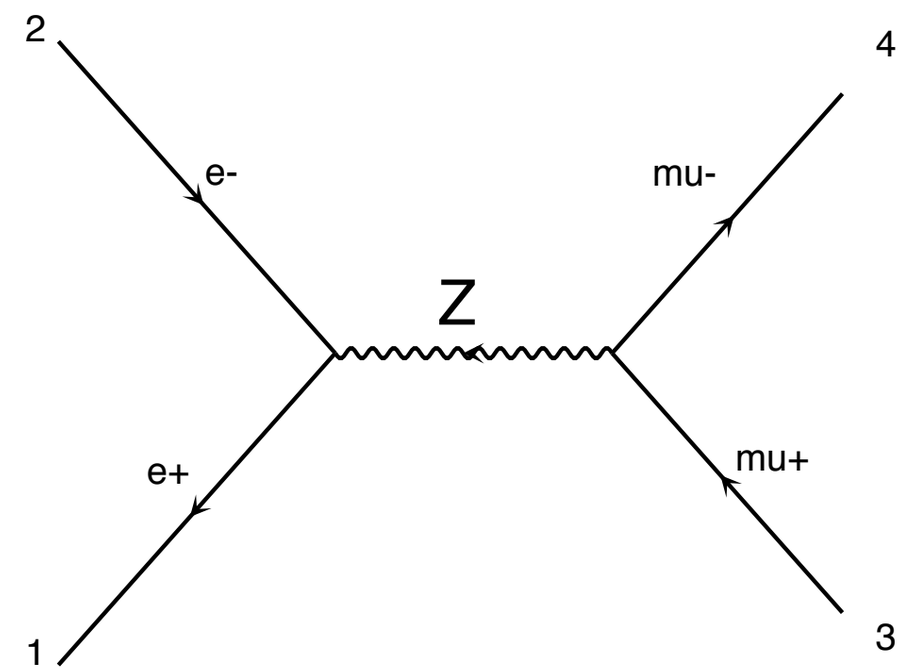

2
4
e-
mu-
Z
e+
mu+
1
3





Need to compute $|M_a|^2$ $|M_z|^2$ $2Re(M_a^* M_z)$





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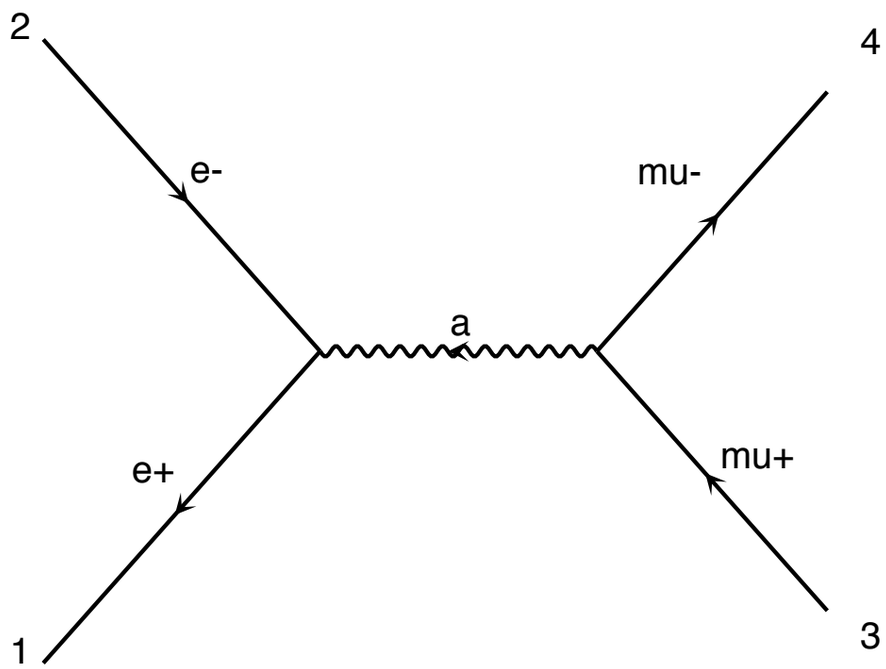
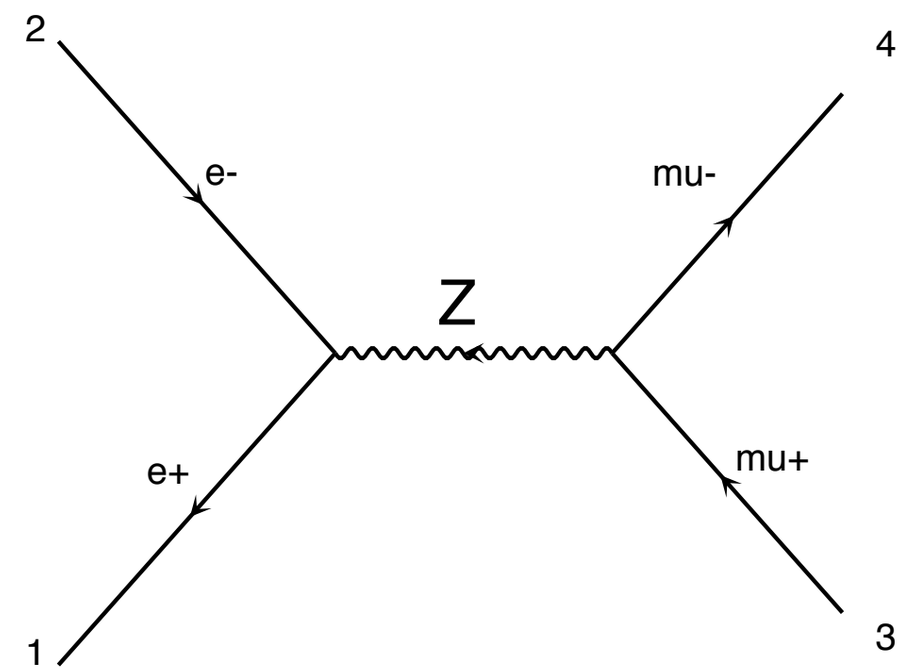
So for M Feynman diagram we need to compute M^2 different term





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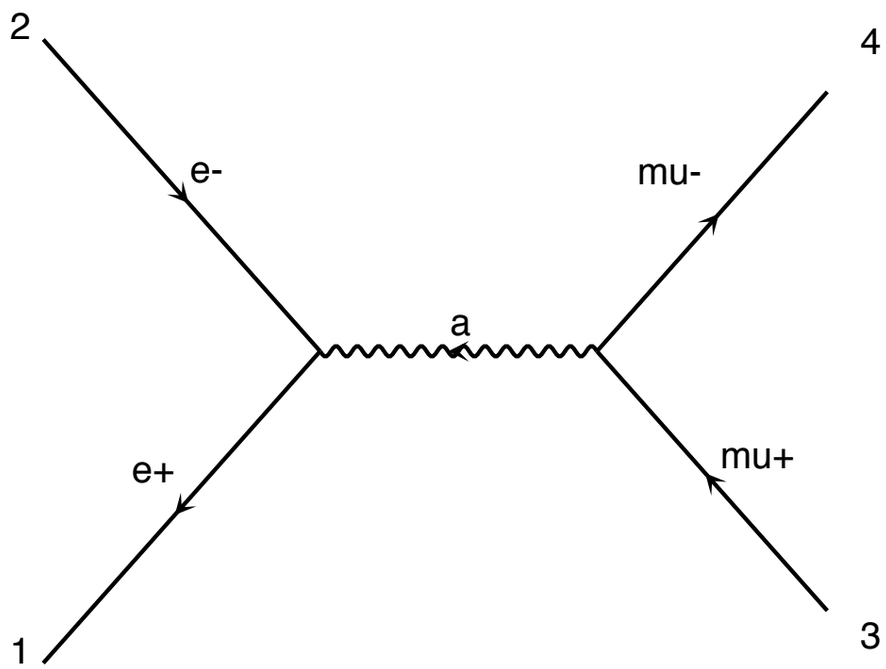
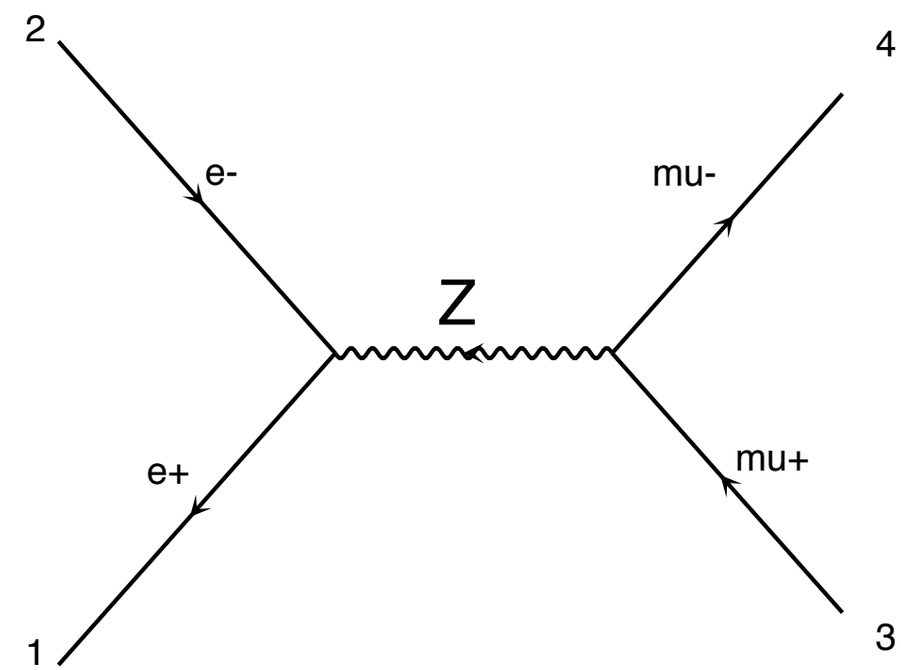
The number of diagram scales factorially with the number of particle





Need to compute $|M_a|^2$ $|M_z|^2$ $2Re(M_a^* M_z)$

So for M Feynman diagram we need to compute M^2 different term

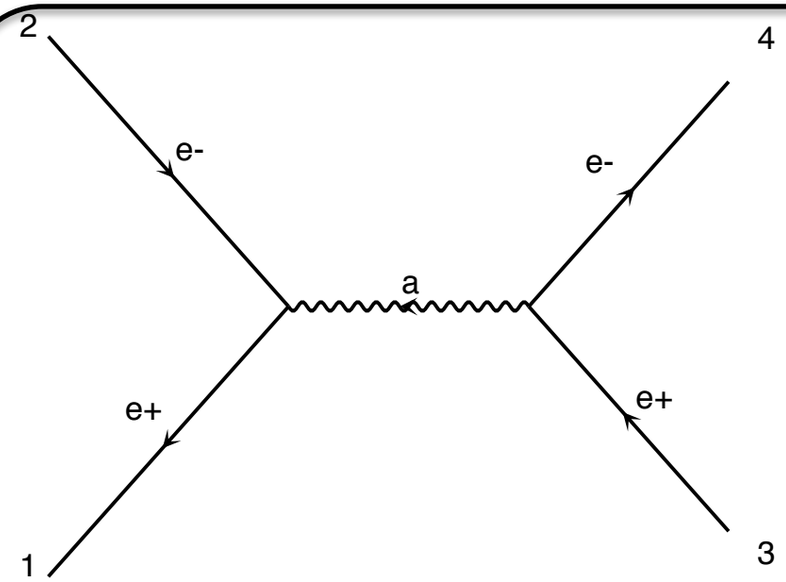
The number of diagram scales factorially with the number of particle

In practise possible up to 2>4

Helicity

Idea

- Evaluate $\mathcal{M}$ for fixed helicity of external particles
  - ➡ Multiply $\mathcal{M}$ with $\mathcal{M}^*$ -> $|\mathcal{M}|$^2
  - ➡ Loop on Helicity and average the results



$$\mathcal{M} = (\bar{u}\, e\, \gamma^\mu v)\frac{g_{\mu\nu}}{q^2}(\bar{v}\, e\, \gamma^\nu u)$$

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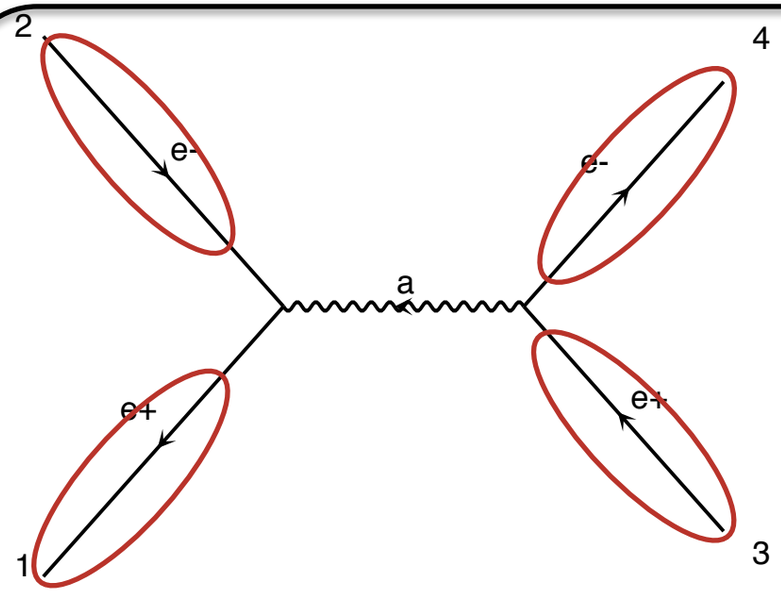

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Numbers for given helicity and momenta

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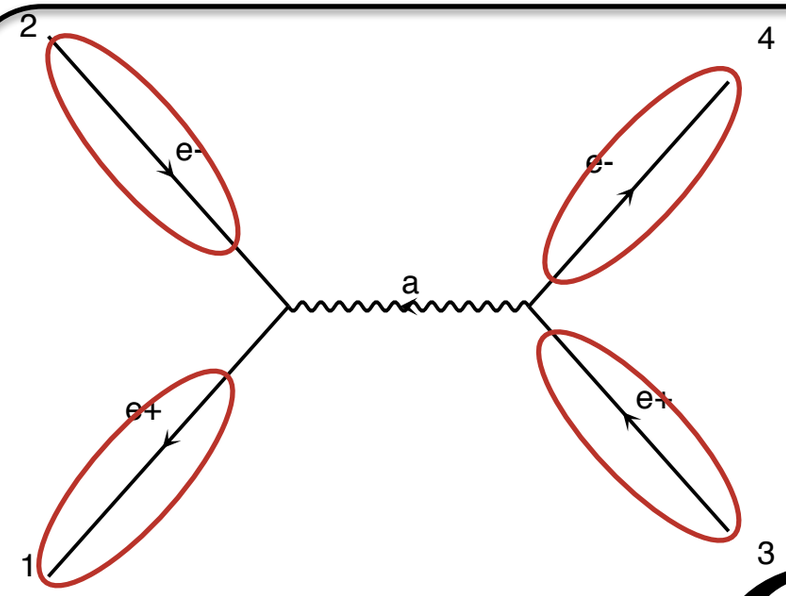

$$\mathcal{M} = (\bar{u}\, e\, \gamma^\mu v)\, \frac{g_{\mu\nu}}{q^2}\, (\bar{v}\, e\, \gamma^\nu u)$$

Numbers for given helicity and momenta

Lines present in the code.

$$\bar{v}_1 = fct(\vec{p}_1, m_1)$$
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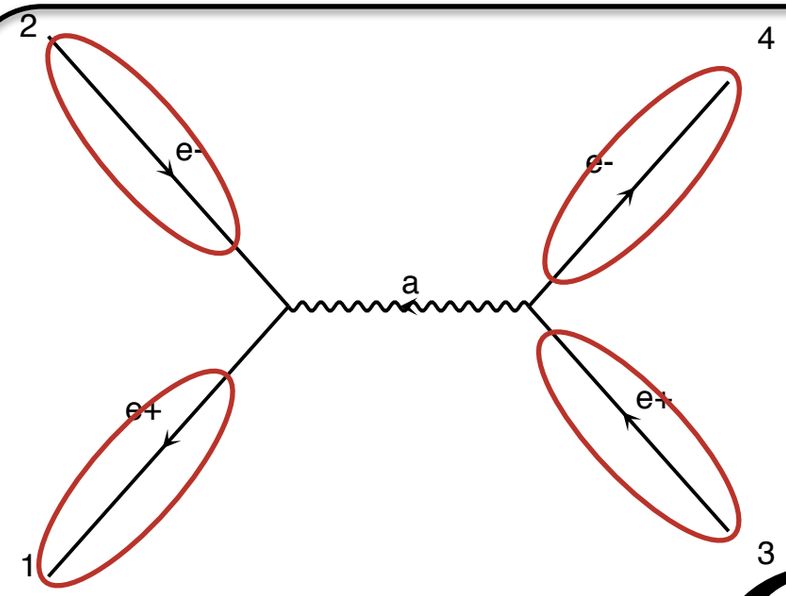

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$$u(p) = \begin{pmatrix} \omega_{-\lambda}(p)\chi_\lambda(\vec{p}) \\ \omega_\lambda(p)\chi_\lambda(\vec{p}) \end{pmatrix}$$

$$\omega_\pm(p) \equiv \sqrt{E \pm |\vec{p}|}.$$

$$\chi_+(\vec{p}) = \frac{1}{\sqrt{2|\vec{p}|(|\vec{p}| + p_z)}} \begin{pmatrix} |\vec{p}| + p_z \\ p_x + ip_y \end{pmatrix},$$

$$\chi_-(\vec{p}) = \frac{1}{\sqrt{2|\vec{p}|(|\vec{p}| + p_z)}} \begin{pmatrix} -p_x + ip_y \\ |\vec{p}| + p_z \end{pmatrix}.$$

Helicity

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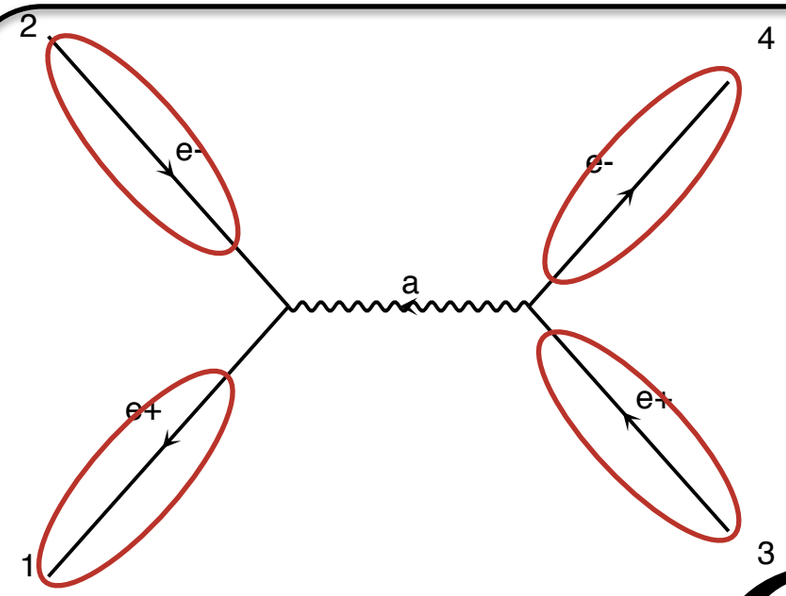

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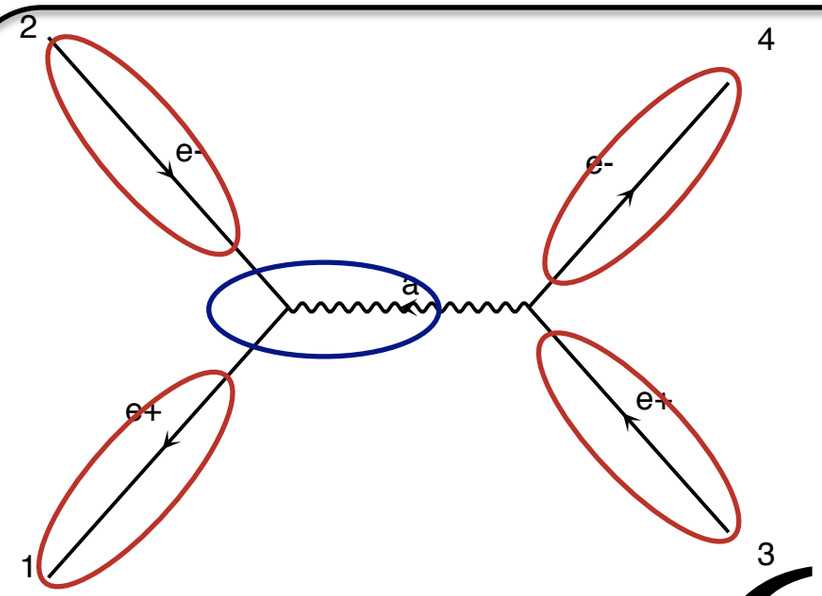

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Numbers for given helicity and momenta

Calculate propagator wavefunctions

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$$W_a = fct(\bar{v}_1, u_2, m_a, \Gamma_a)$$

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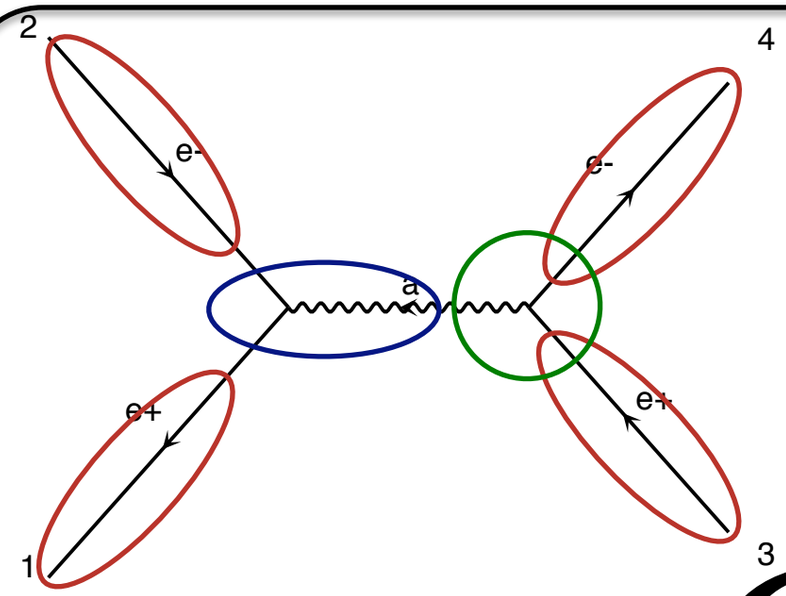


$$\mathcal{M} = (\bar{u}\, e\, \gamma^\mu v)\, \frac{g_{\mu\nu}}{q^2}\, (\bar{v}\, e\, \gamma^\nu u)$$

Numbers for given helicity and momenta

Calculate propagator wavefunctions

Finally evaluate amplitude (c-number)

Lines present in the code.

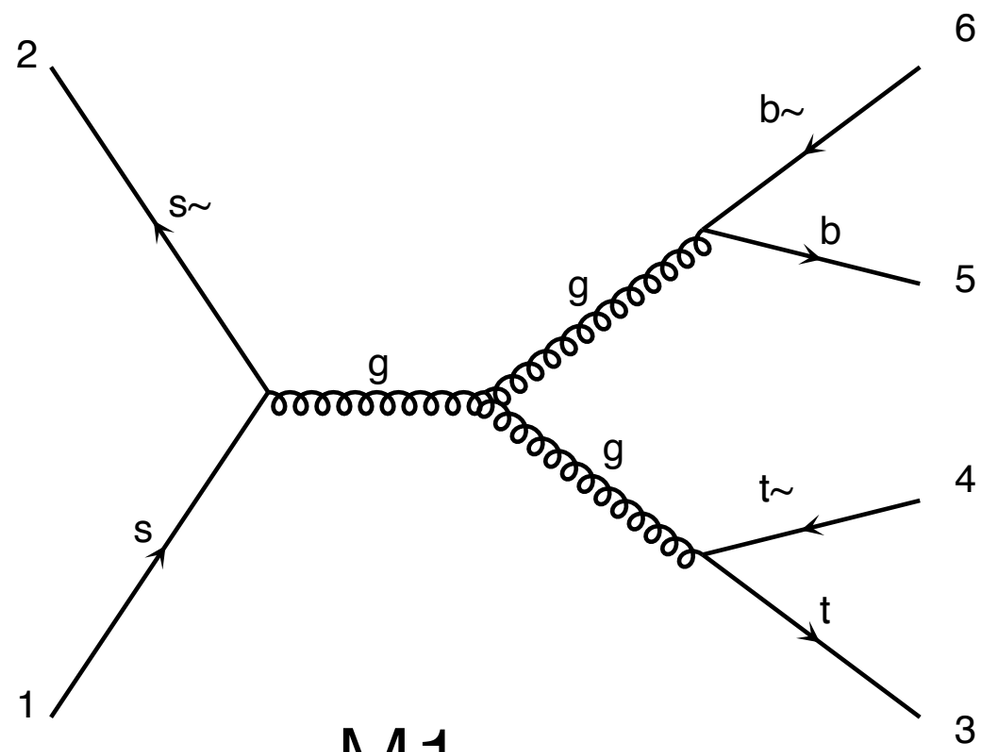
$$\left\{ \begin{aligned} \bar{v}_1 &= fct(\vec{p}_1, m_1) \\ u_2 &= fct(\vec{p}_2, m_2) \\ v_3 &= fct(\vec{p}_3, m_3) \\ \bar{u}_4 &= fct(\vec{p}_4, m_4) \\ W_a &= fct(\bar{v}_1, u_2, m_a, \Gamma_a) \\ \mathcal{M} &= fct(v_3, \bar{u}_4, W_a) \end{aligned} \right.$$

Comparison

	M diag	N particle
Analytical	M^2	$(N!)^2$
Helicity	M	$(N!)\,2^N$

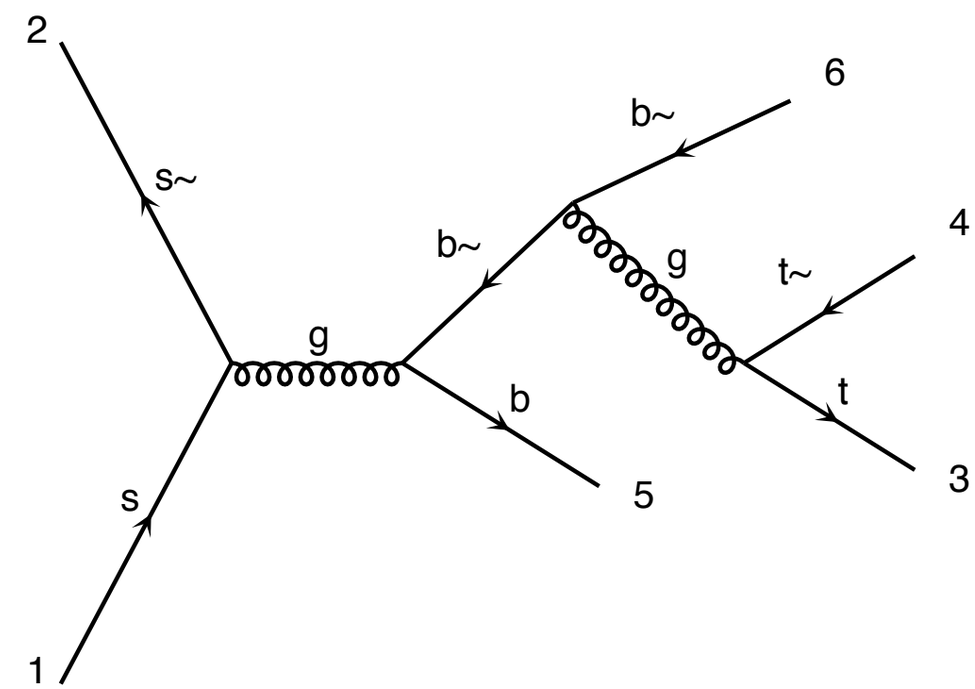
Real case

Known



M1

Number of routines: 0



M2

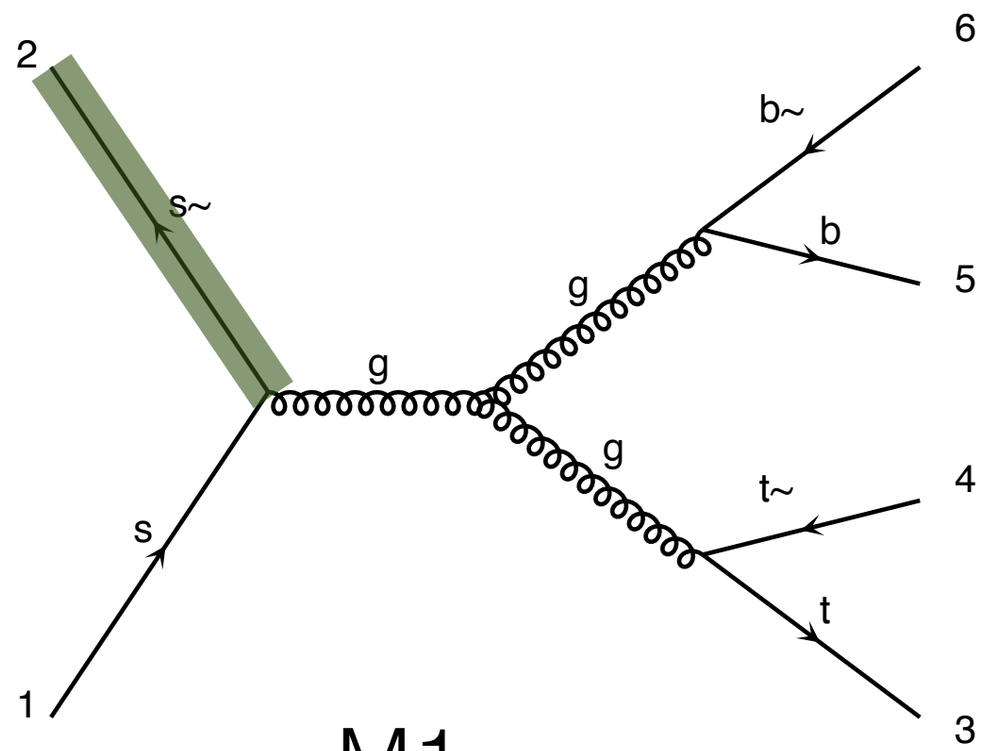
Number of routines: 0

Number of routines for both: 0

$$|M|^2 = |M_1 + M_2|^2$$

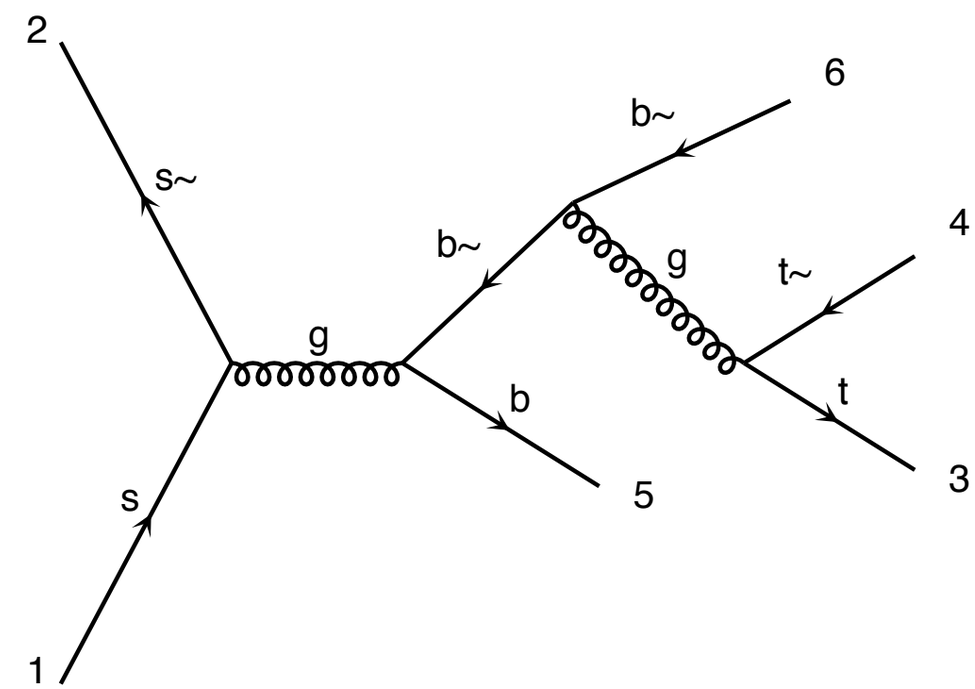
Real case

Known



M1

Number of routines: 1



M2

Number of routines: 0

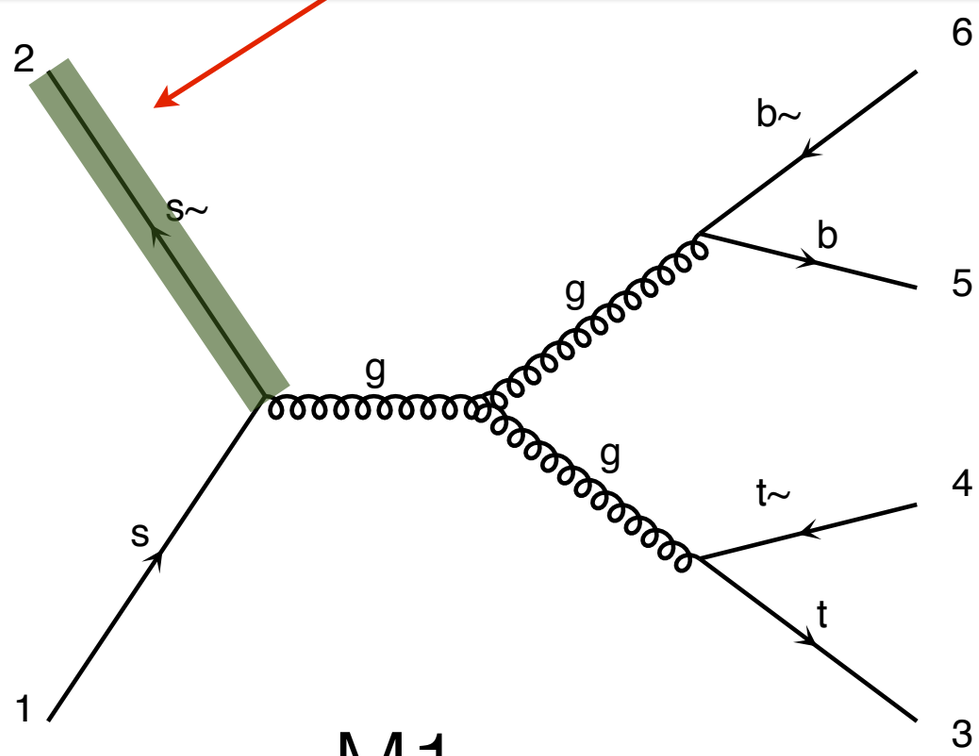
Number of routines for both: 1

$$|M|^2 = |M_1 + M_2|^2$$

Real case

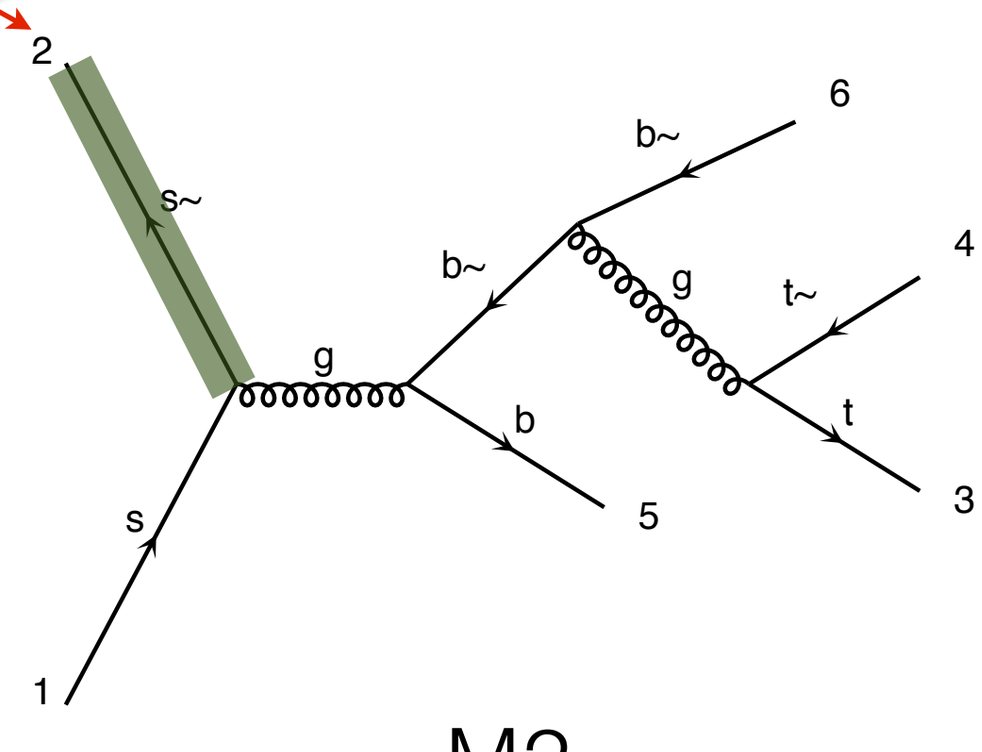
Identical

Known



M1

Number of routines: 1



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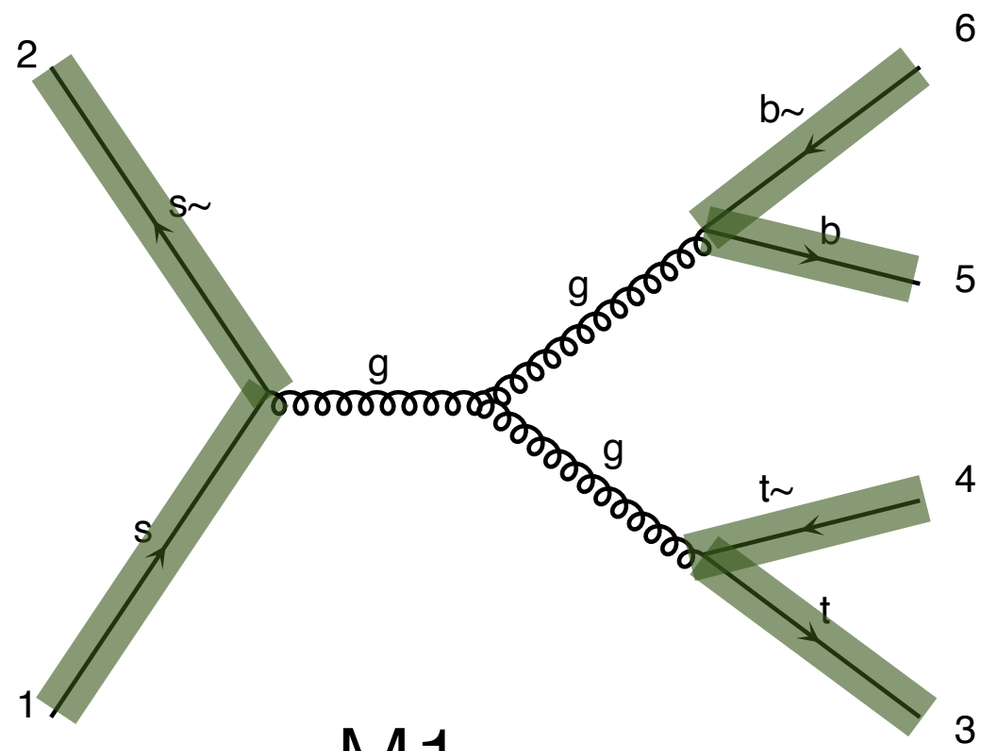
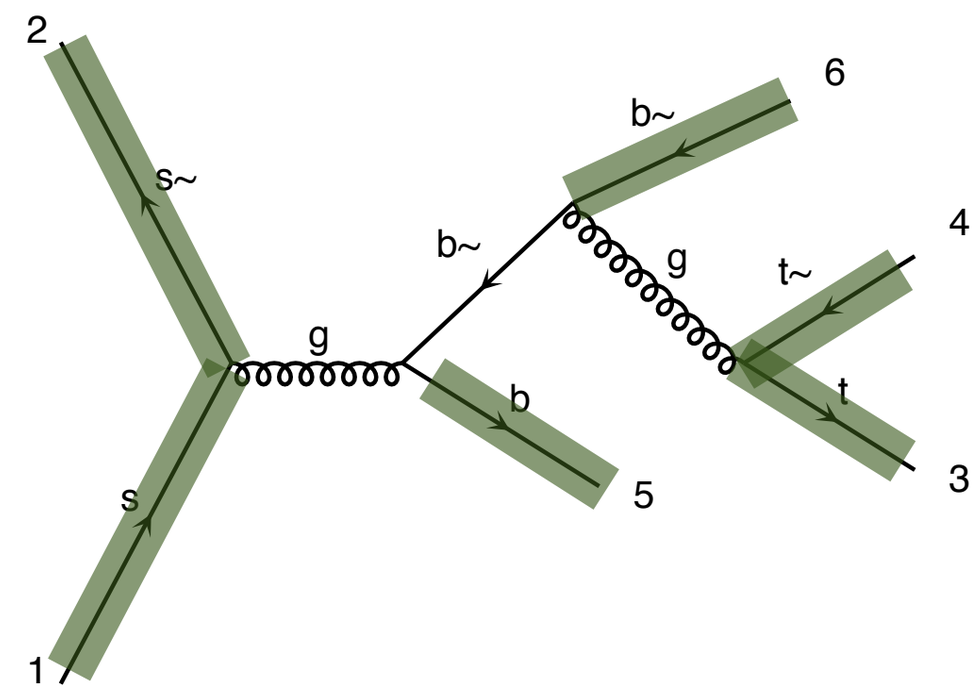
Real case

Known



M1

Number of routines: 6



M2

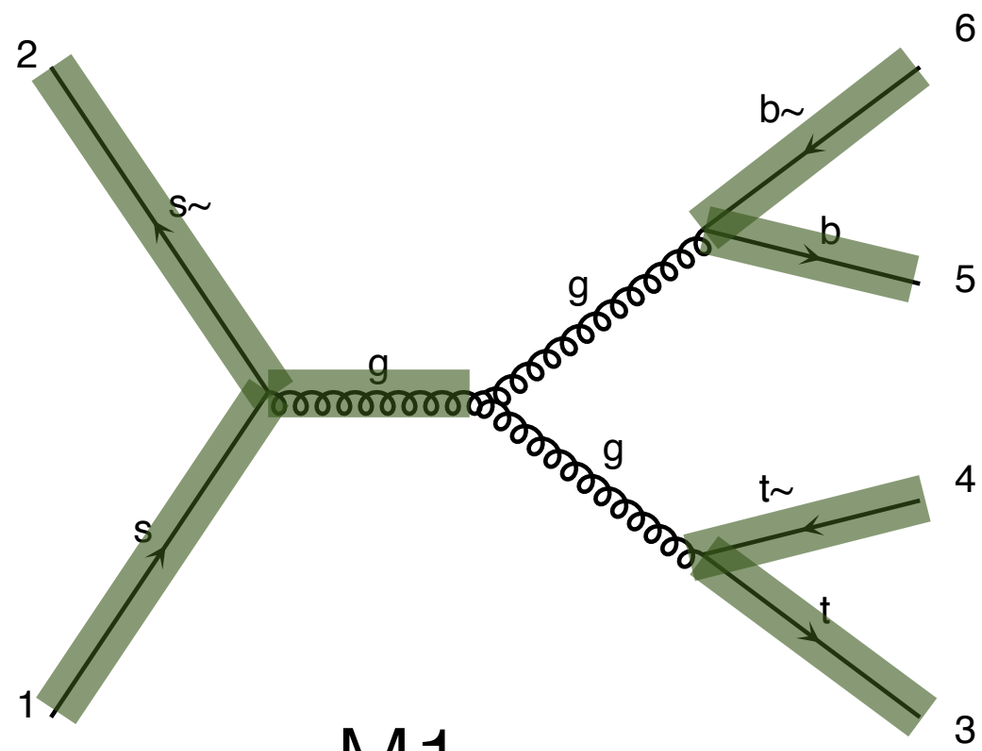
Number of routines: 6

Number of routines for both: 6

$$|M|^2 = |M_1 + M_2|^2$$

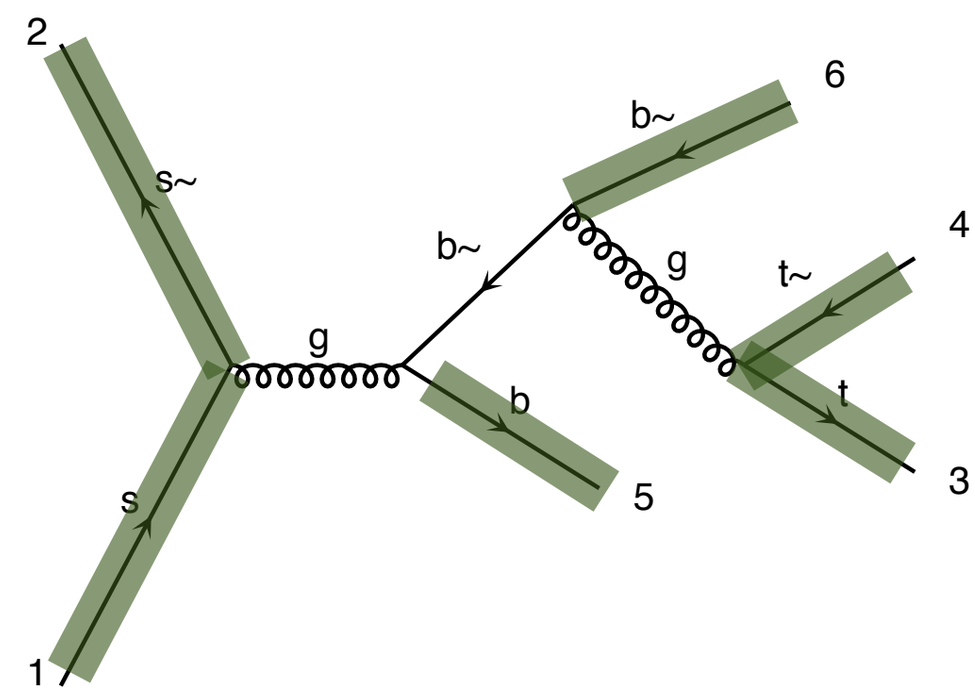
Real case

Known



M1

Number of routines: 7



M2

Number of routines: 6

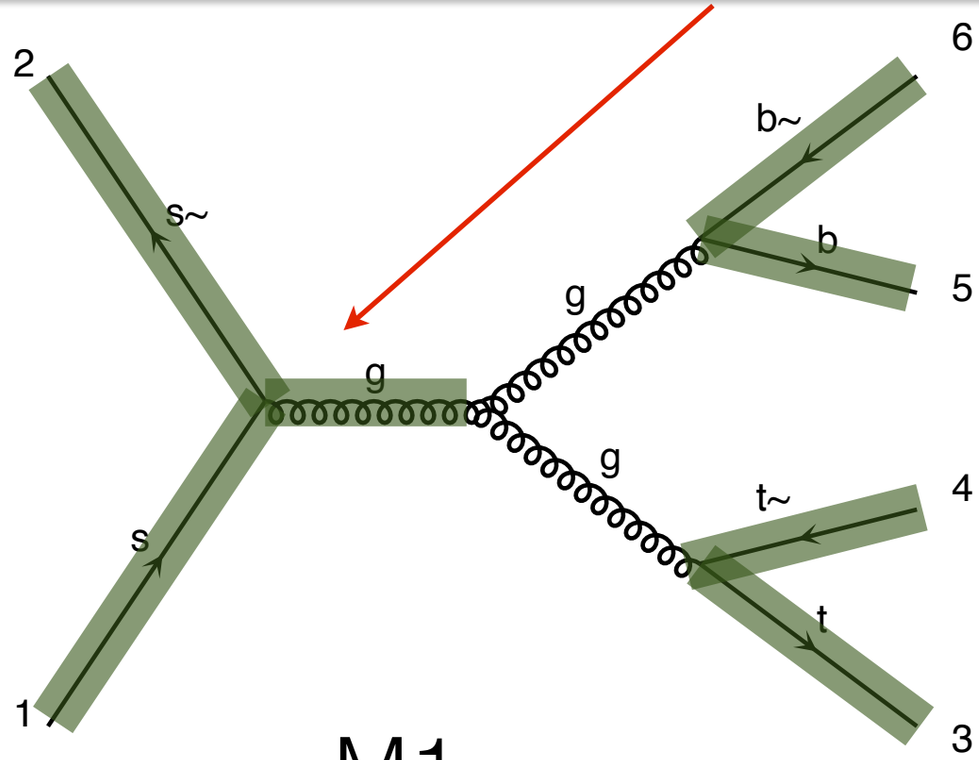
Number of routines for both: 7

$$|M|^2 = |M_1 + M_2|^2$$

Real case

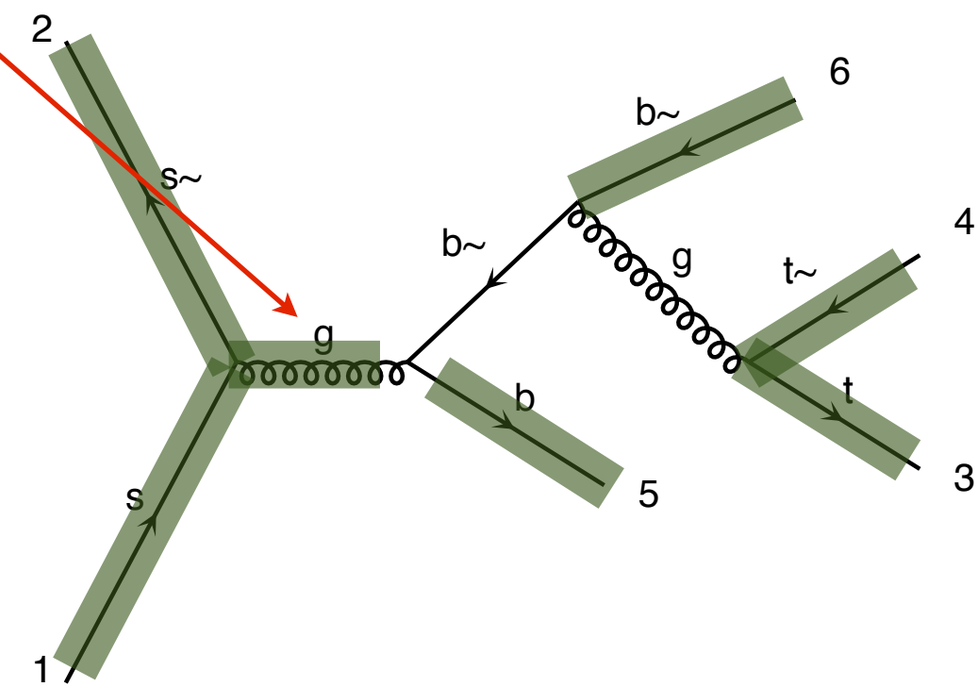
Known

Identical



M1

Number of routines: 7



M2

Number of routines: 7

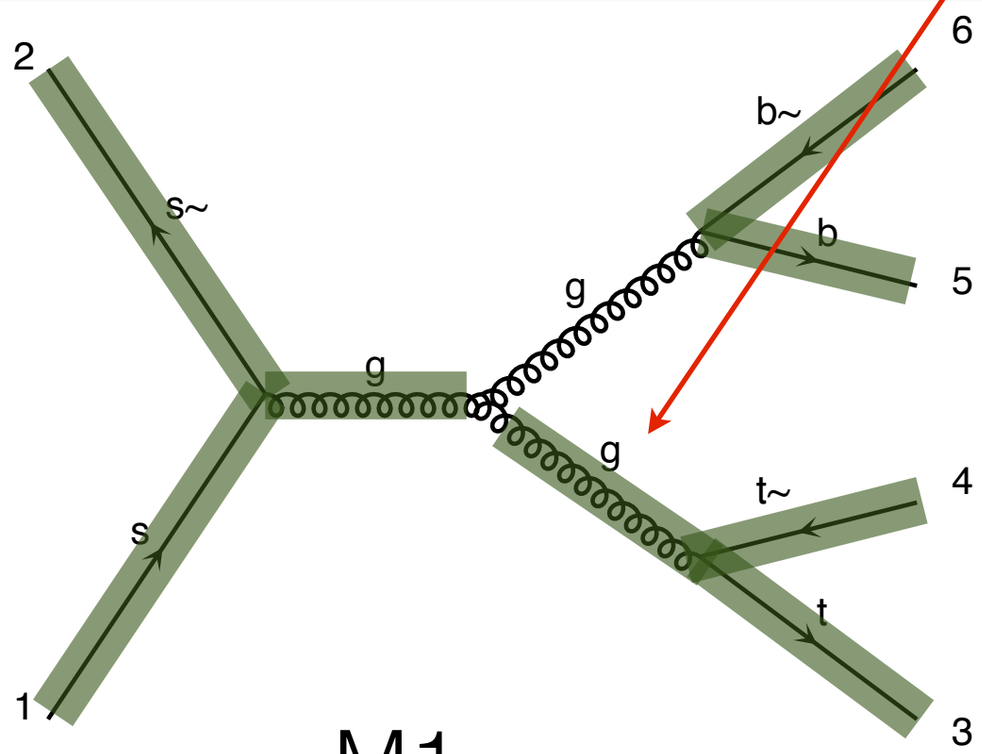
Number of routines for both: 7

$$|M|^2 = |M_1 + M_2|^2$$

Real case

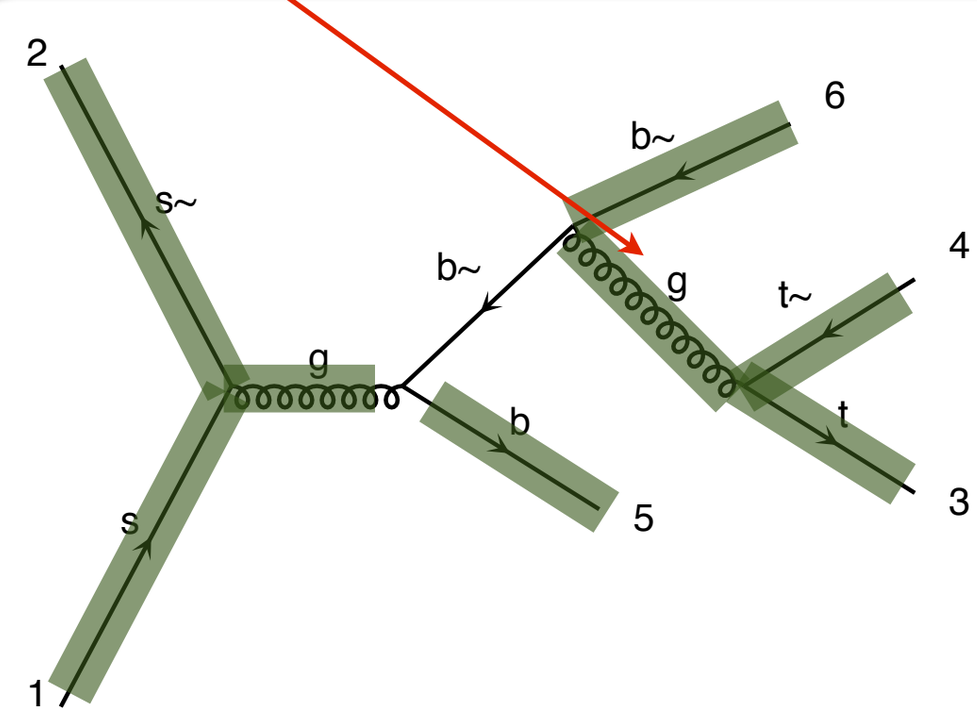
Identical

Known



M1

Number of routines: 8



M2

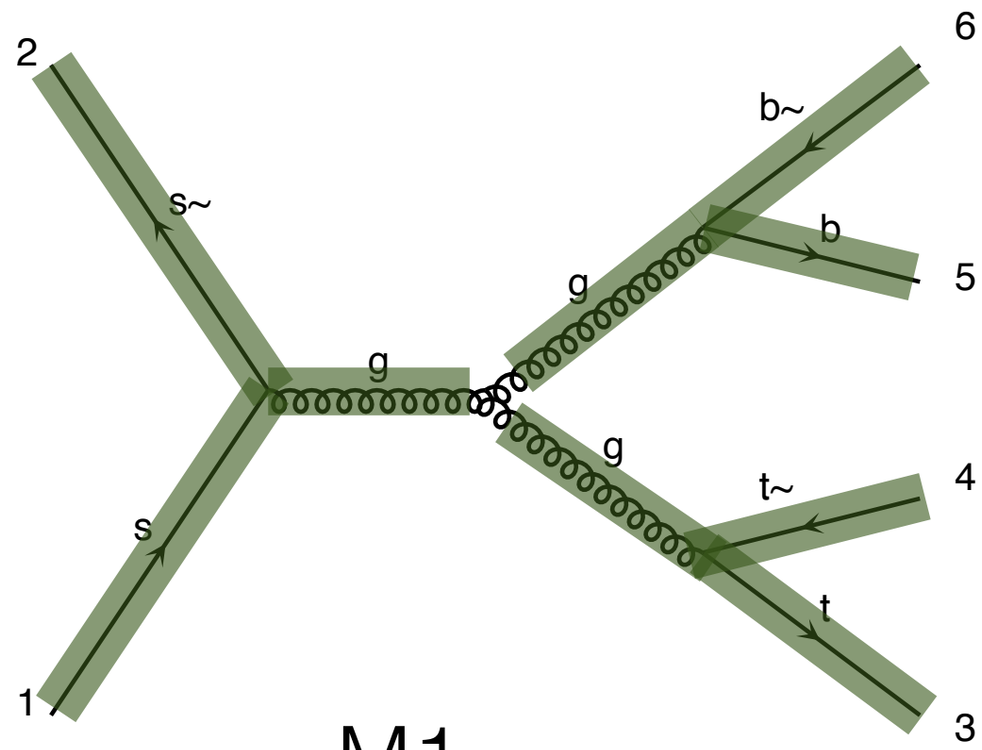
Number of routines: 8

Number of routines for both: 8

$$|M|^2 = |M_1 + M_2|^2$$

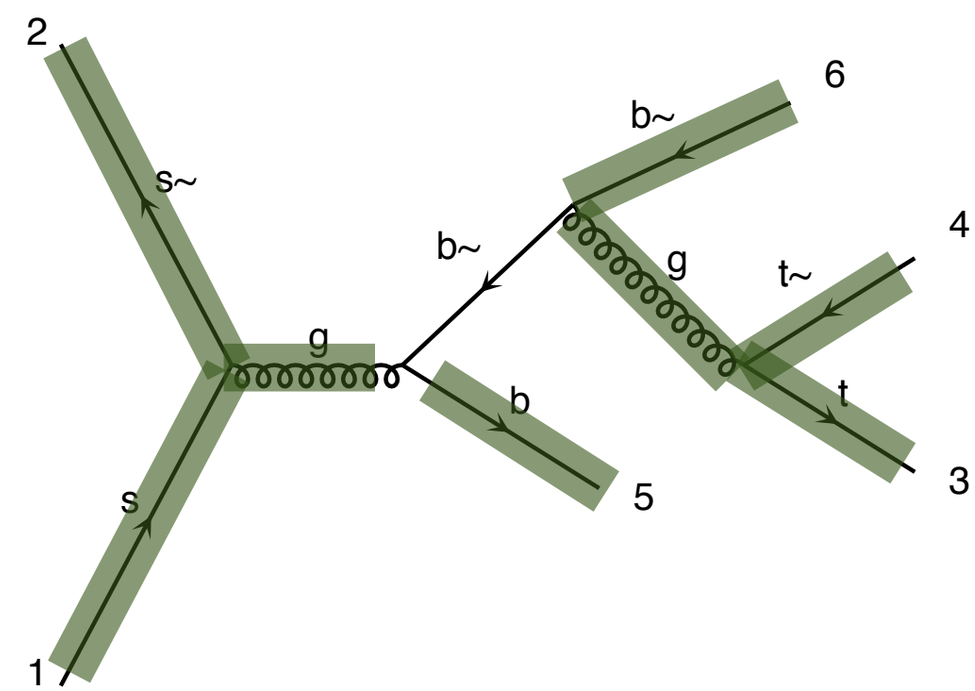
Real case

Known



M1

Number of routines: 9



M2

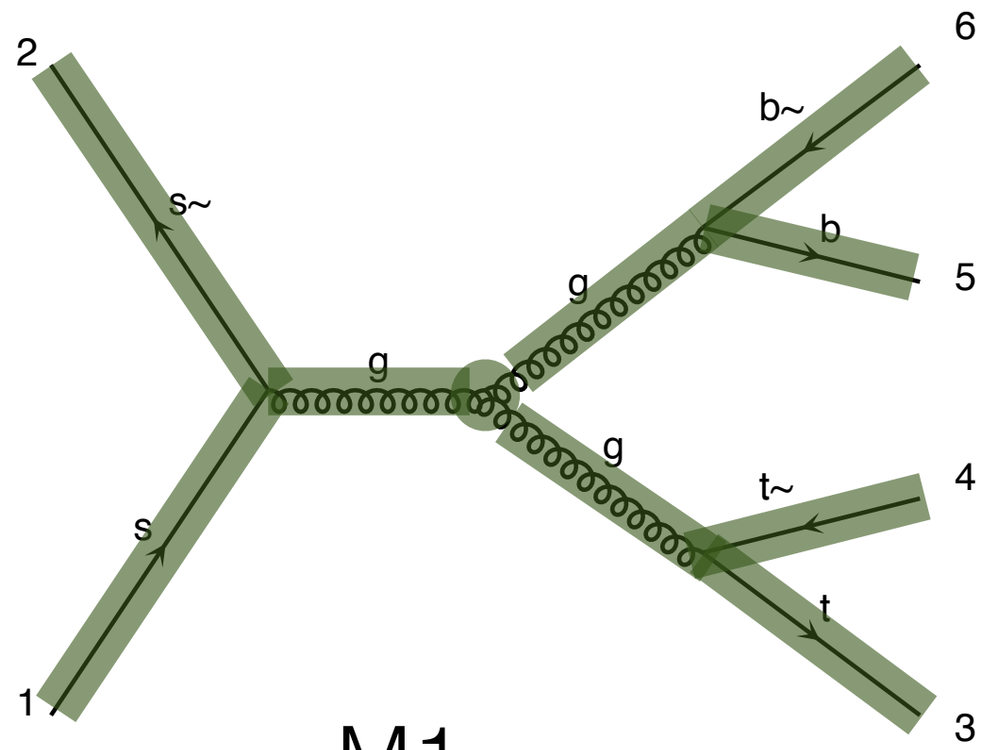
Number of routines: 8

Number of routines for both: 9

$$|M|^2 = |M_1 + M_2|^2$$

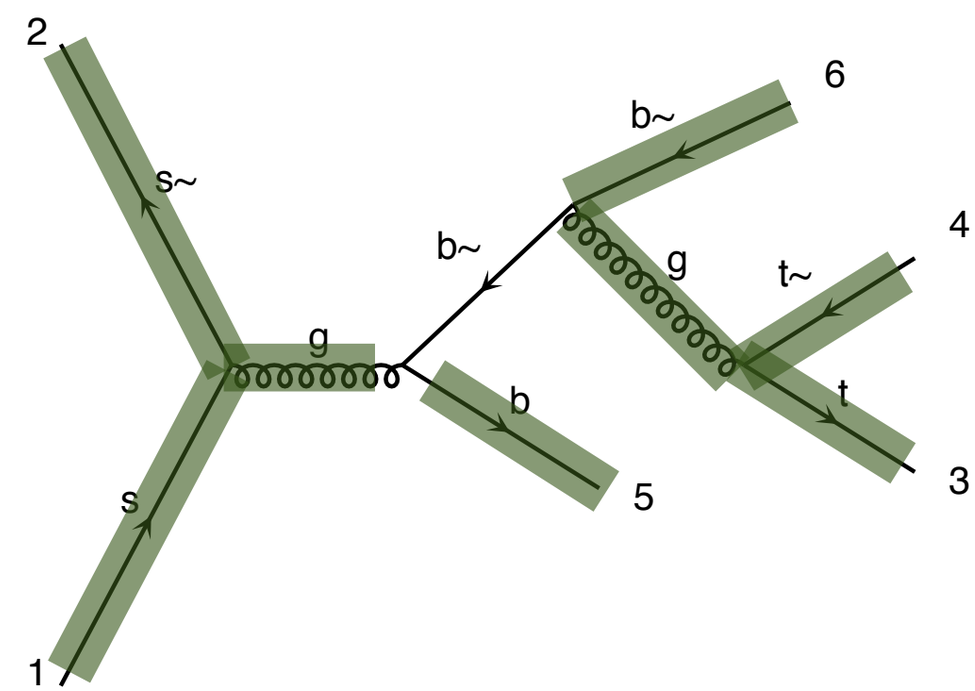
Real case

Known



M1

Number of routines: 10



M2

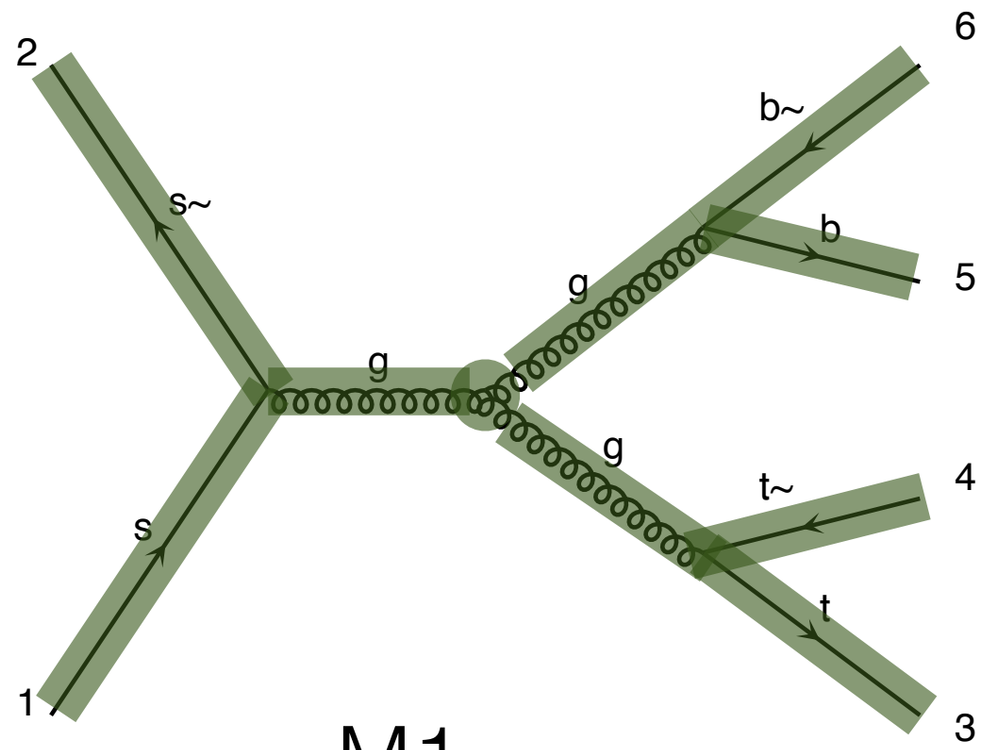
Number of routines: 8

Number of routines for both: 10

$$|M|^2 = |M_1 + M_2|^2$$

Real case

Known



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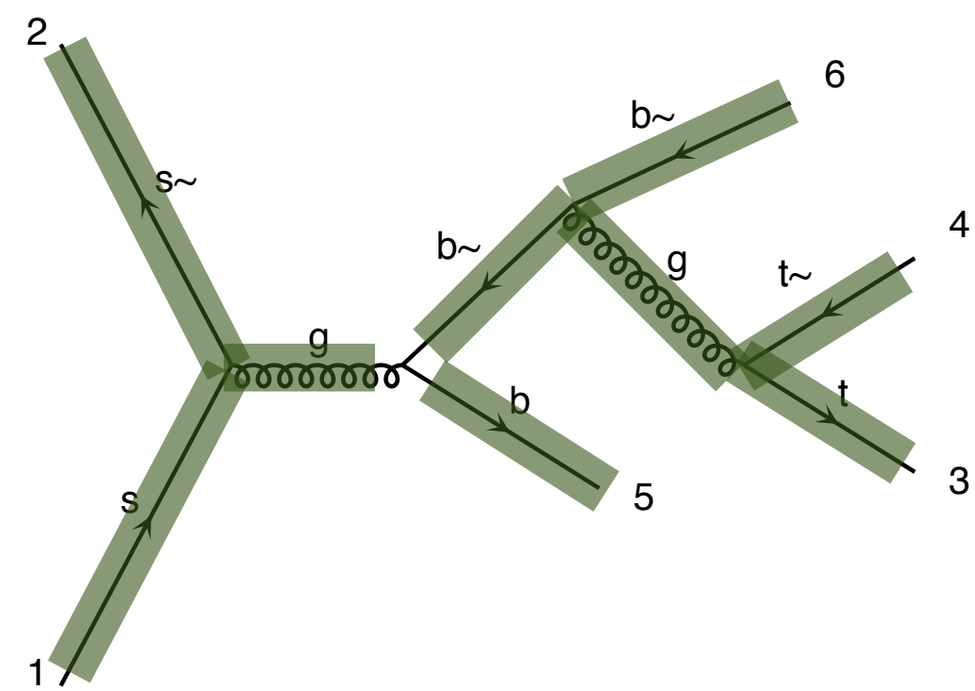
Number of routines: 10



M2

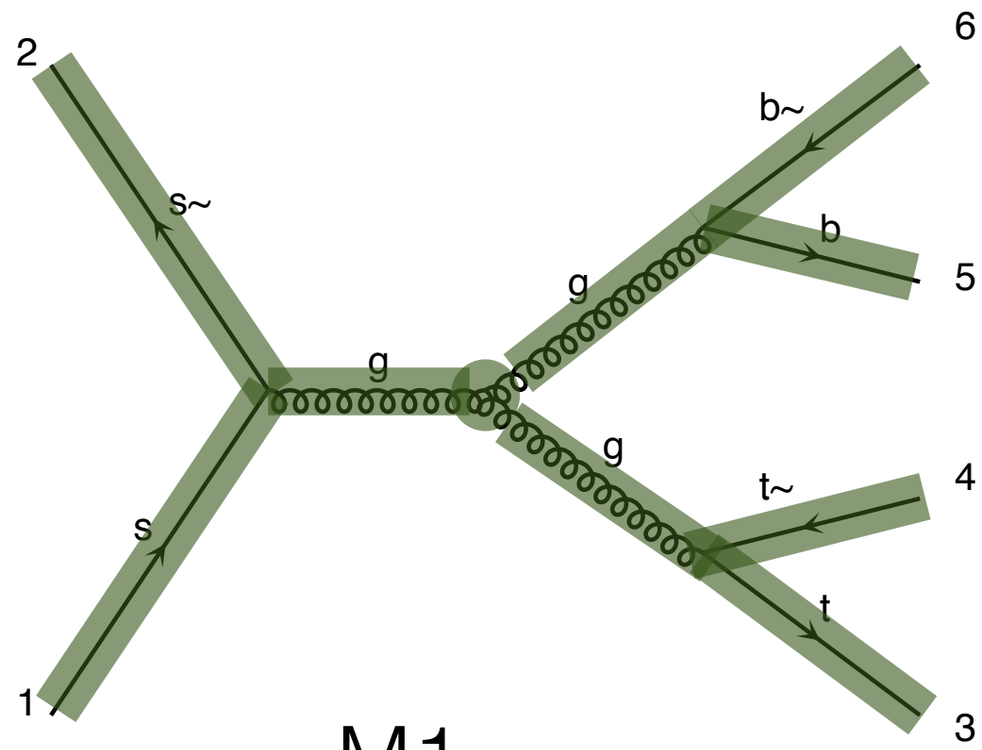
Number of routines: 9

Number of routines for both: 11

$$|M|^2 = |M_1 + M_2|^2$$

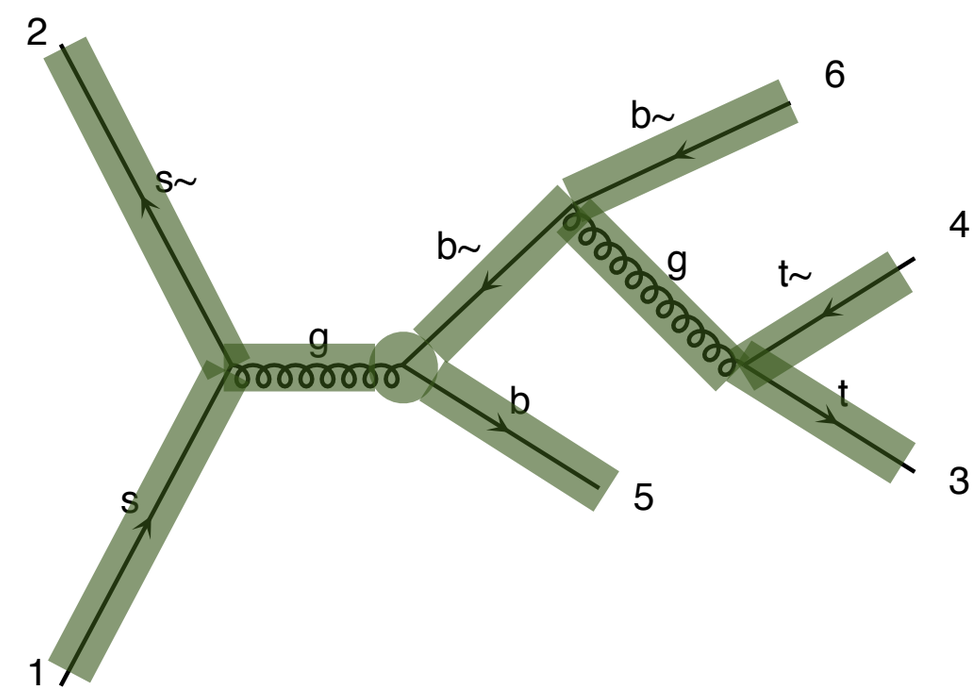
Real case

Known



M1

Number of routines: 10



M2

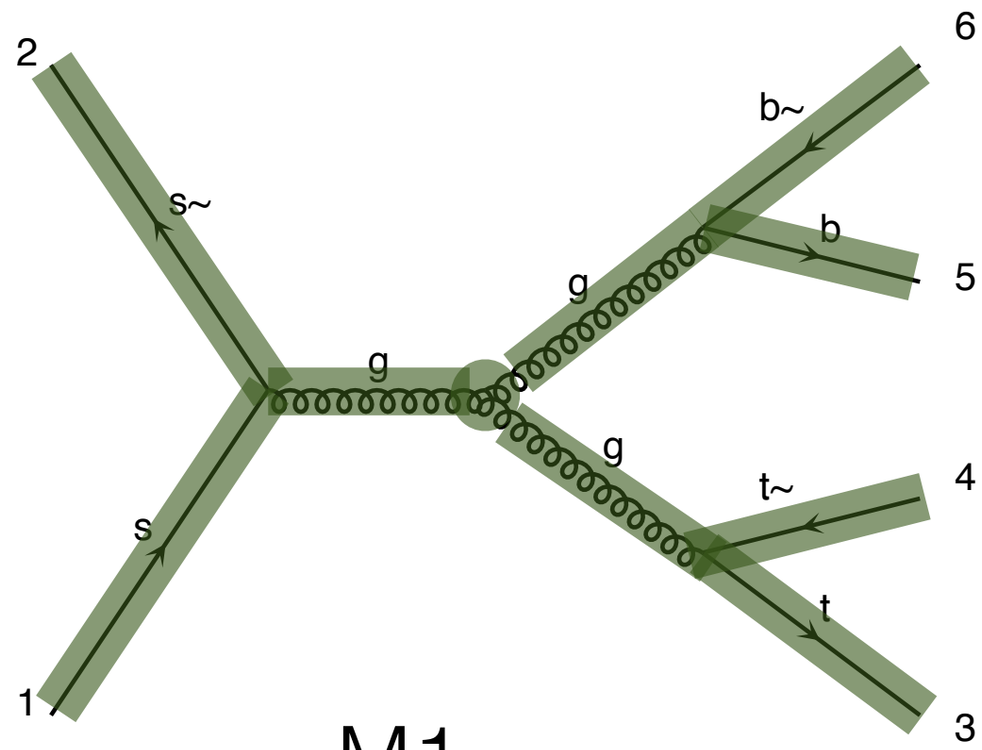
Number of routines: 10

Number of routines for both: 12

$$|M|^2 = |M_1 + M_2|^2$$

Real case

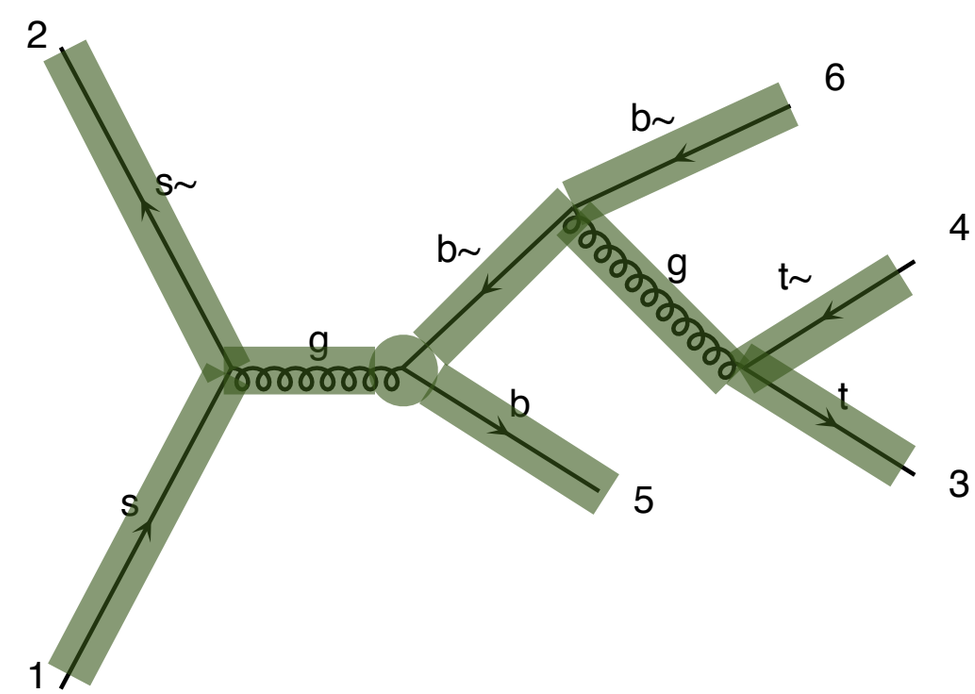
Known



M1

Number of routines: 10

2(N+1)



M2

Number of routines: 10

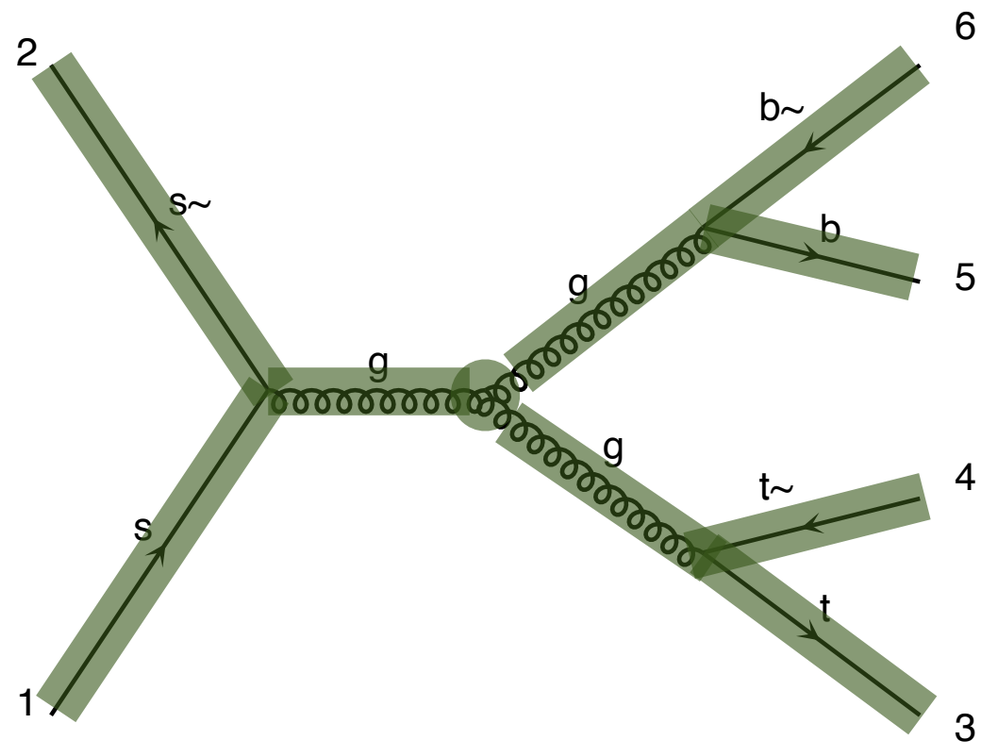
2(N+1)

Number of routines for both: 12

$$|M|^2 = |M_1 + M_2|^2$$

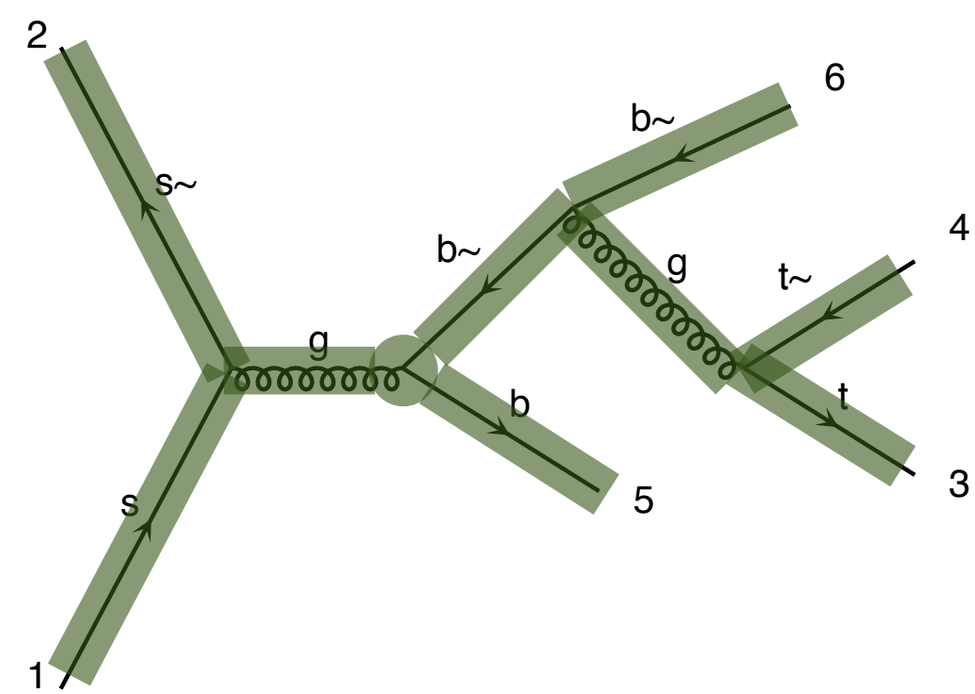
Real case

Known



Number of routines: 10

2(N+1)



Number of routines: 10

2(N+1)

Number of routines for both: 12

N!*2(N+1) ⟶ N!

Comparison

	M diag	N particle
Analytical	M^2	$(N!)^2$
Helicity	M	$(N!)\,2^N$
Recycling	M	$(N-1)!\,2^{(N-1)}$

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Recursion Relation	$log(M)$	$2^N\,2^{(N-1)}$	Not used in Madgraph

Comparison

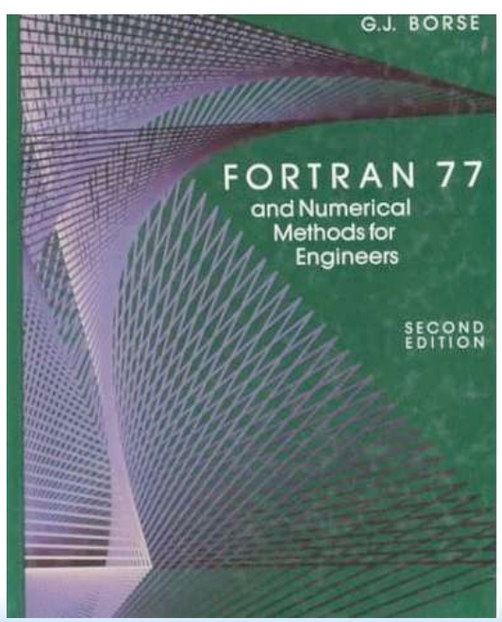
	M diag	N particle	2 > 6
Analytical	M^2	$(N!)^2$	1.6e9
Helicity	M	$(N!)\,2^N$	1.0e7
Recycling	M	$(N-1)!\,2^{(N-1)}$	6.5e5
Recursion Relation	$log(M)$	$2^N\,2^{(N-1)}$	3.2e4

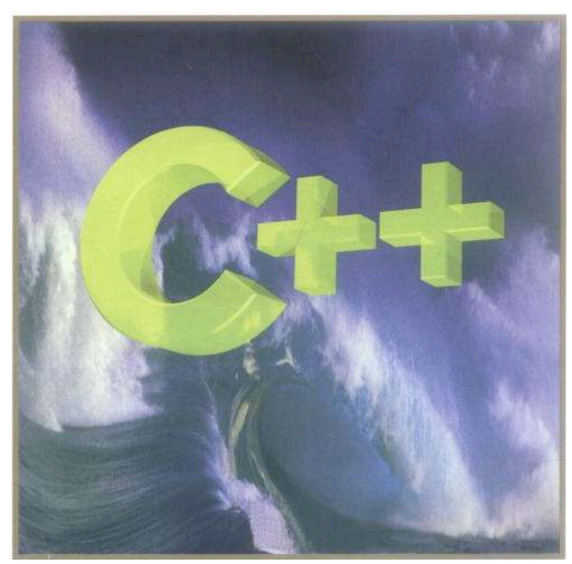
ALOHA

ALOHA
~~Google~~ translate

From: UFO To: Helicity Translate

Type text or a website address or translate a document.





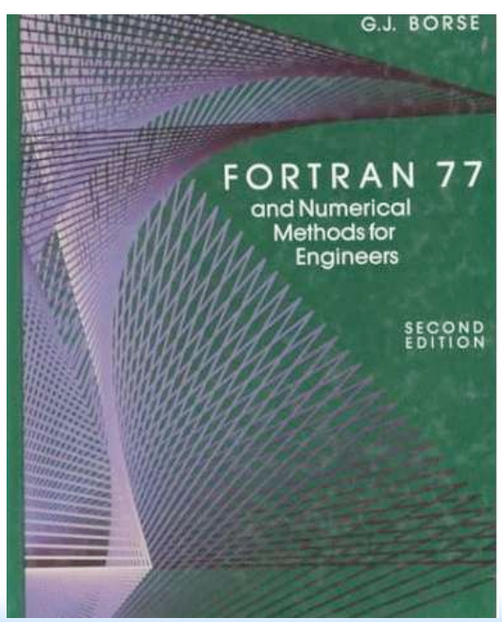
ALOHA

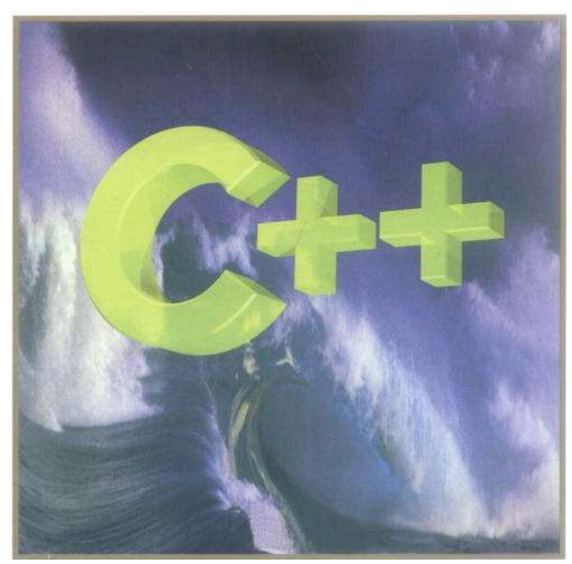
ALOHA
~~Google~~ translate

From: UFO To: Helicity Translate

Basically, any new operator can be handle by MG5/Pythia8 out of the box!

Type text or a website address or translate a document.





To Remember

- Numerical computation faster than analytical computation
- We are able to compute matrix-element
  - ➡ for large number of final state
  - ➡ for any BSM theory

Plan

- Details of the computation
  - Evaluation of matrix-element
  - Phase-Space integration
- What is MG5_aMC?

Monte Carlo Integration

Calculations of cross section or decay widths involve integrations over high-dimension phase space of very peaked functions:

$$\sigma = \frac{1}{2s} \int |\mathcal{M}|^2 d\Phi(n)$$

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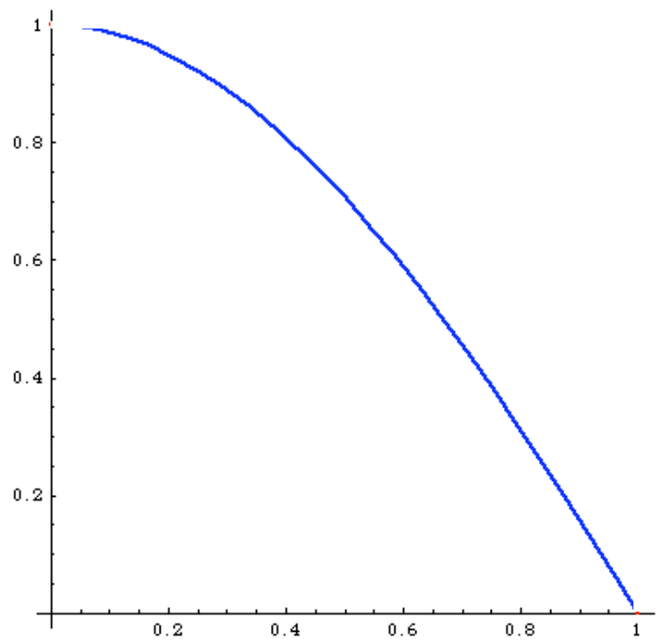
$$Dim[\Phi(n)] \sim 3n$$

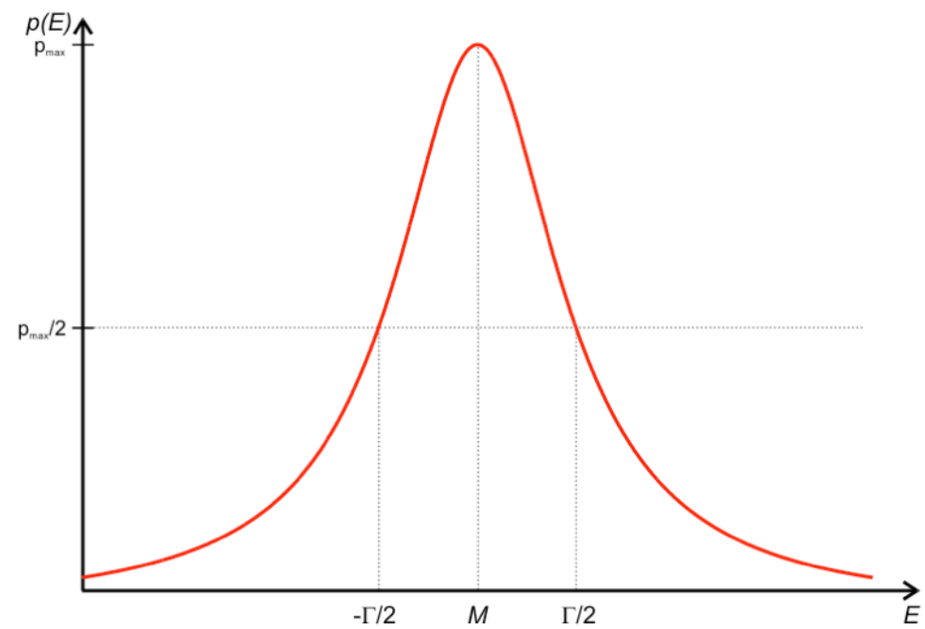
General and flexible method is needed

Integration

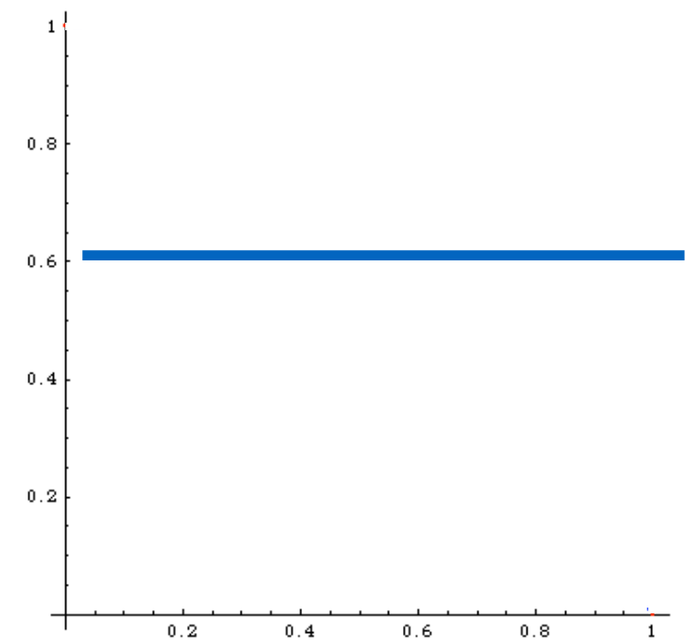
$$I = \int_0^1 dx \cos\frac{\pi}{2}x$$



$$\int \frac{dq^2}{(q^2 - M^2 + iM\Gamma)^2}$$

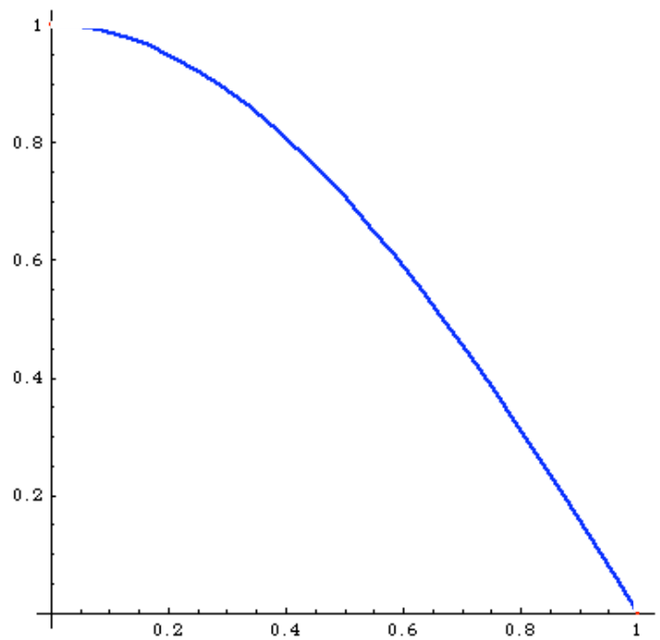


$$\int dx\, C$$



Integration

$$I = \int_0^1 dx \cos\frac{\pi}{2}x$$



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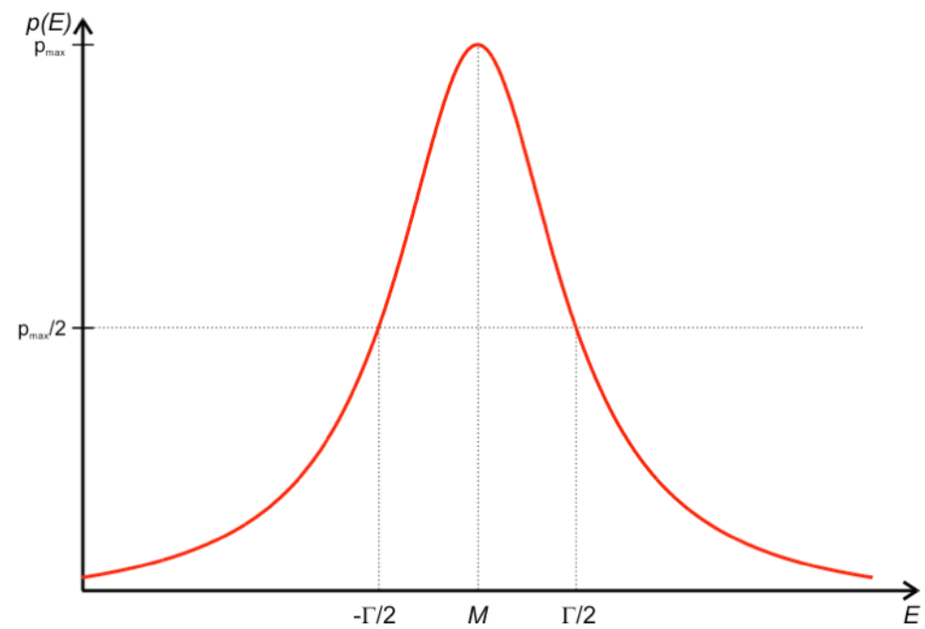

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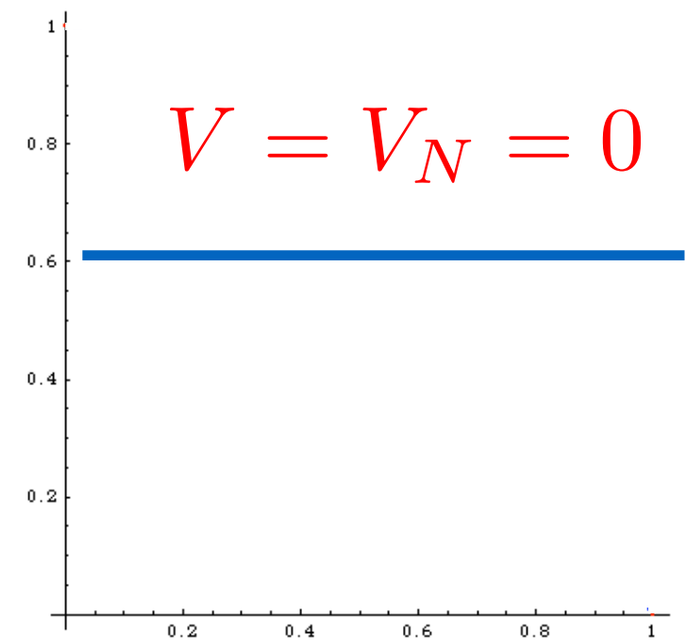


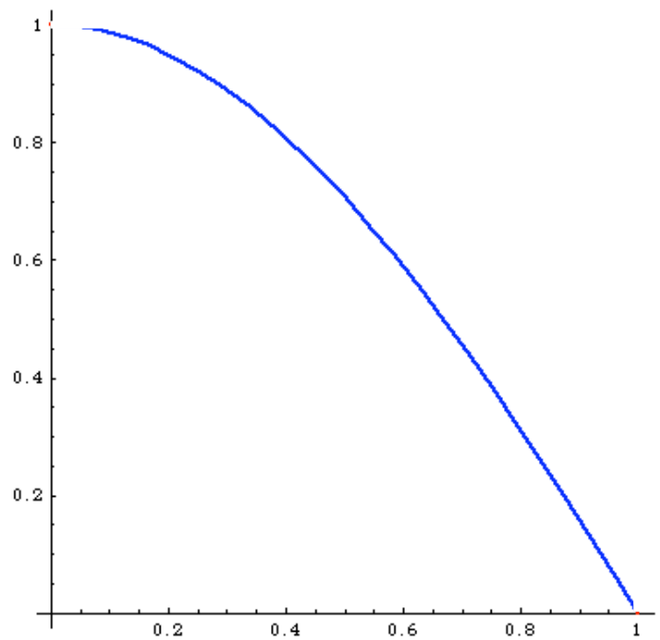
$$V = V_N = 0$$

Method of evaluation

- MonteCarlo $1/\sqrt{N}$
- Trapezium $1/N^2$
- Simpson $1/N^4$

Integration

$$I = \int_0^1 dx \cos\frac{\pi}{2}x$$



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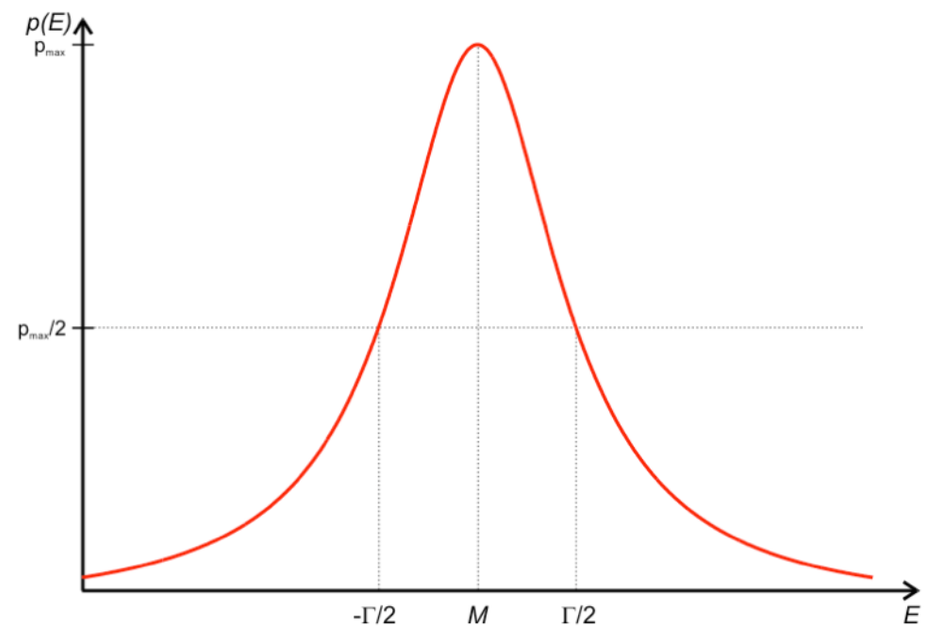

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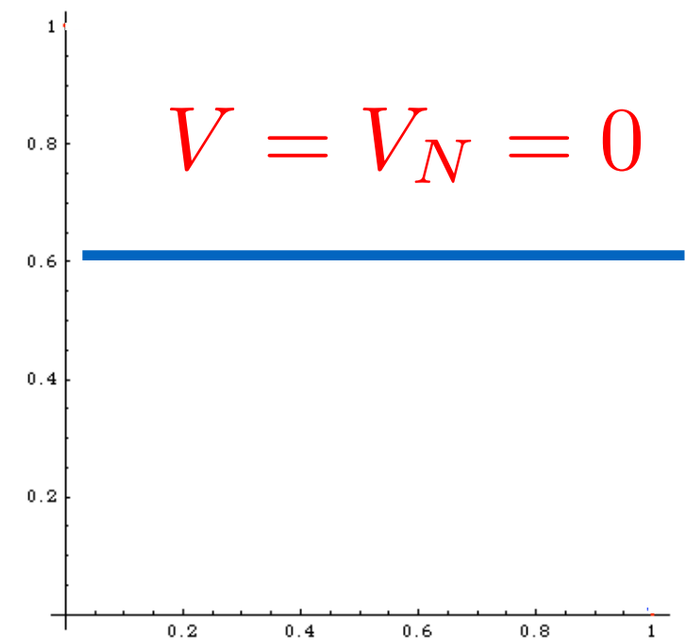

$$V = V_N = 0$$

	simpson	MC
3	0,638	0,3
5	0,6367	0,8
20	0,63662	0,6
100	0,636619	0,65
1000	0,636619	0,636

Method of evaluation

- MonteCarlo $1/\sqrt{N}$
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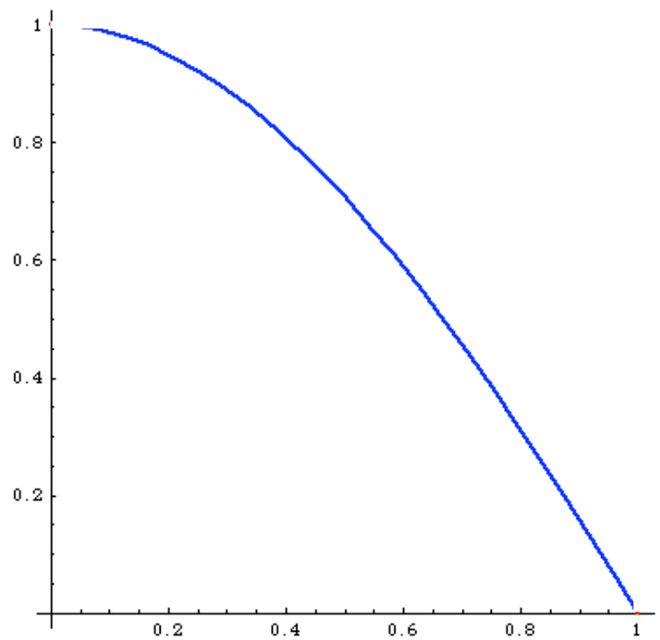
Integration

$$I = \int_0^1 dx \cos\frac{\pi}{2}x$$



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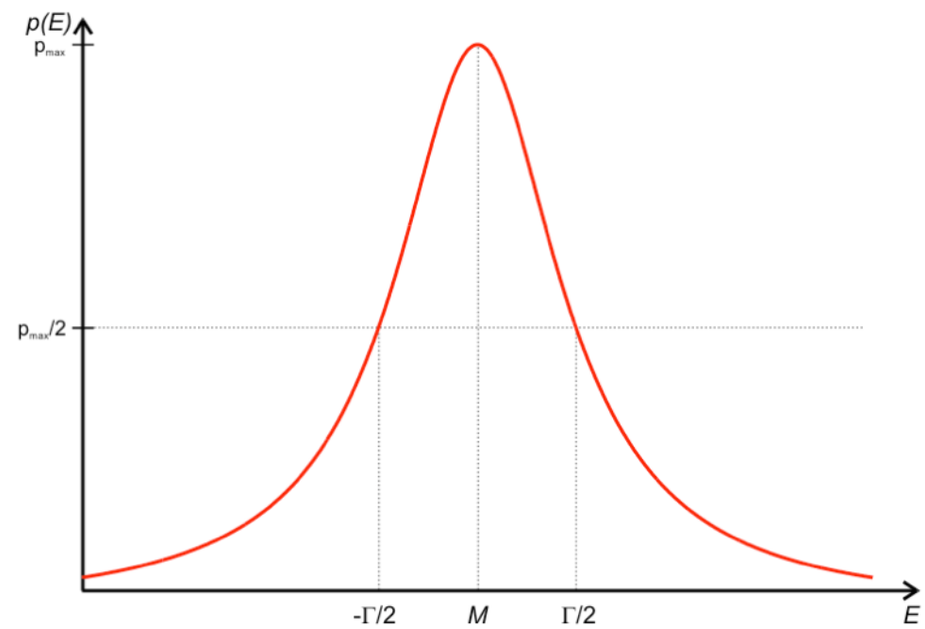

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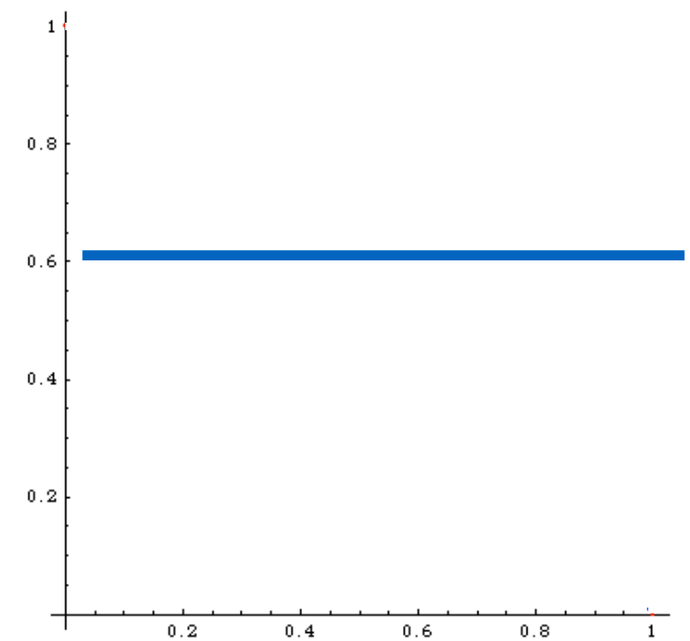

Method of evaluation

- MonteCarlo $1/\sqrt{N}$
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More Dimension →

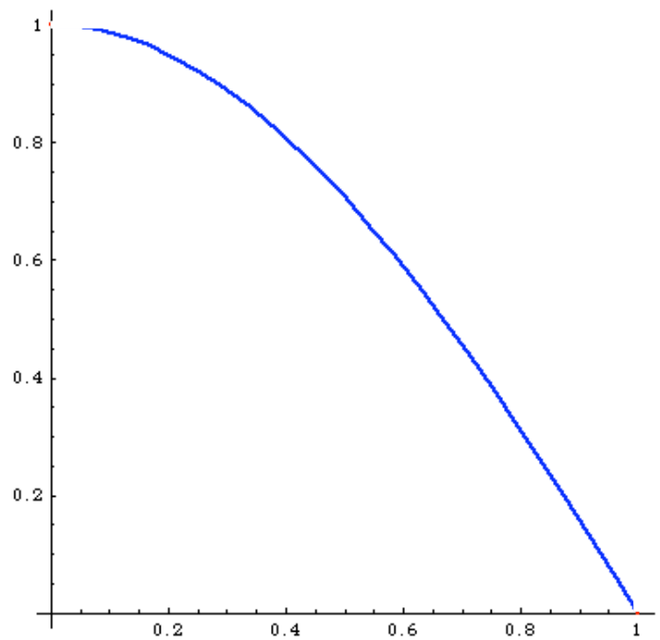
$1/\sqrt{N}$

$1/N^{2/d}$

$1/N^{4/d}$

Integration

$$I = \int_0^1 dx \cos\frac{\pi}{2}x$$



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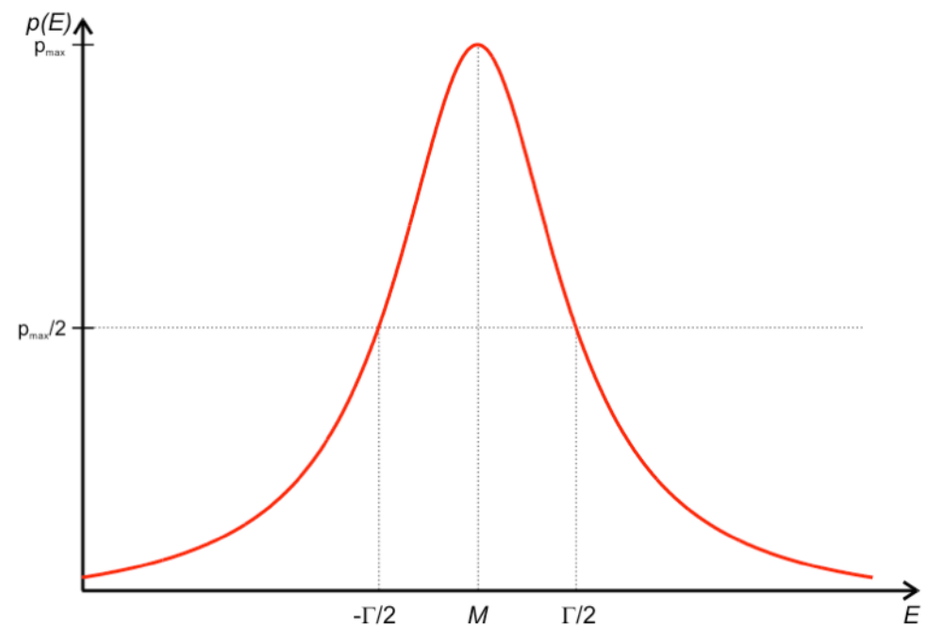

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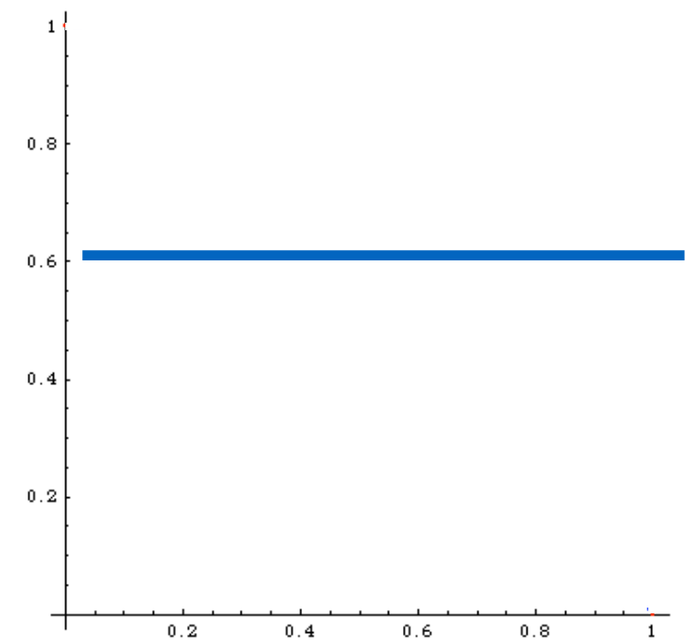

$$I = \int_{x_1}^{x_2} f(x)dx \quad \Rightarrow \quad I_N = (x_2 - x_1)\frac{1}{N}\sum_{i=1}^{N} f(x)$$

$$V = (x_2 - x_1)\int_{x_1}^{x_2} [f(x)]^2 dx - I^2 \quad \Rightarrow \quad V_N = (x_2 - x_1)^2 \frac{1}{N}\sum_{i=1}^{N}[f(x)]^2 - I_N^2$$

Integration

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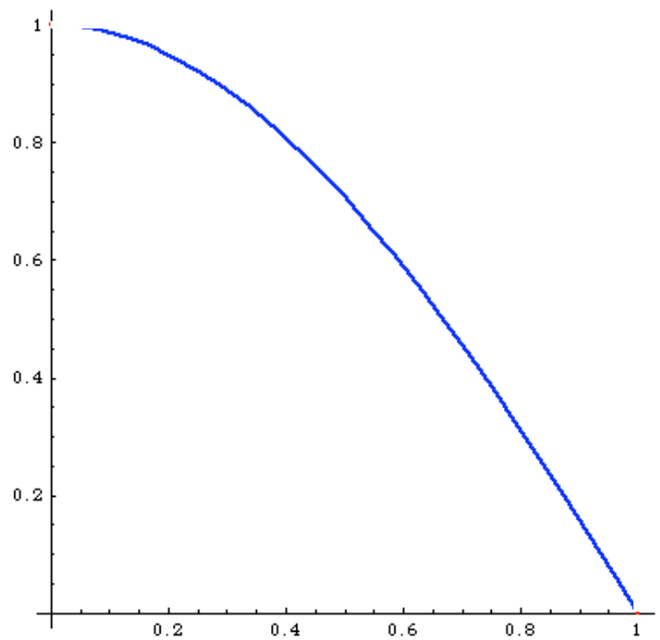

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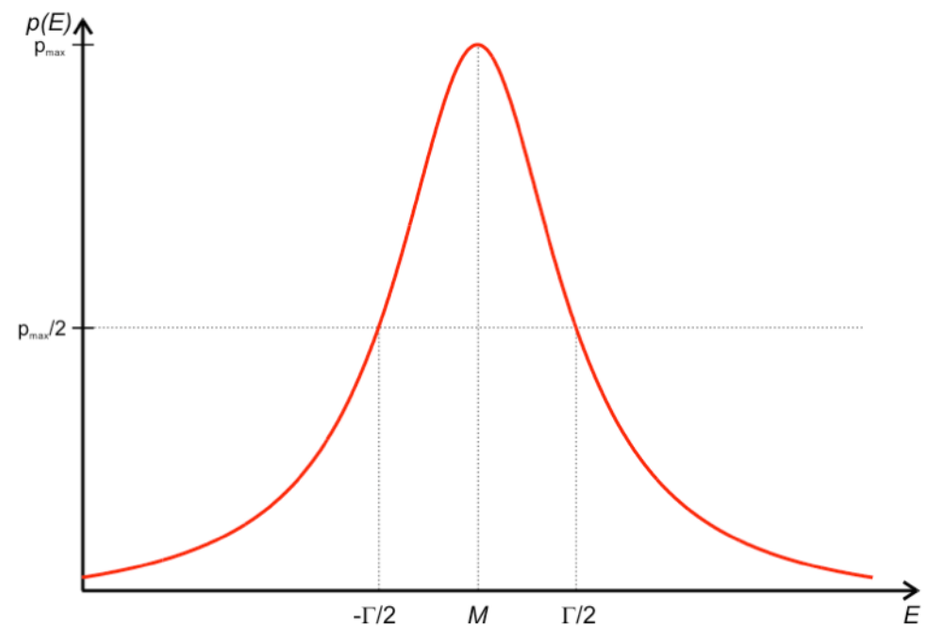

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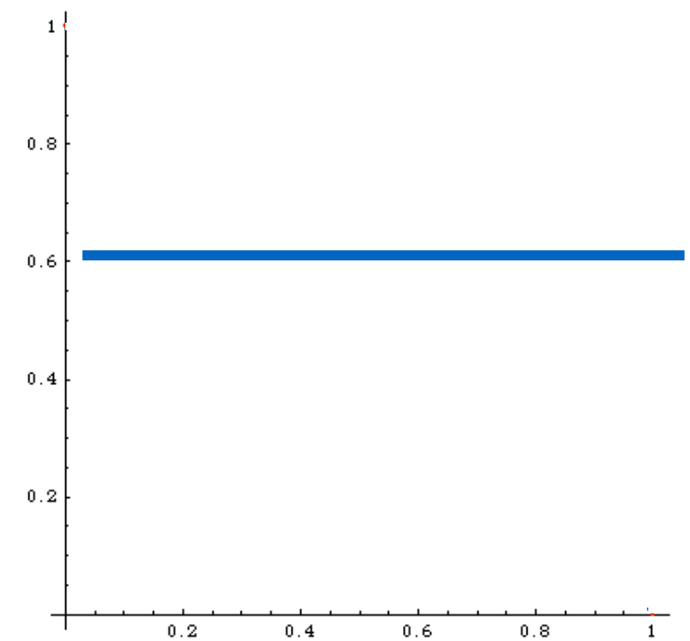

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$$I = I_N \pm \sqrt{V_N/N}$$

Integration

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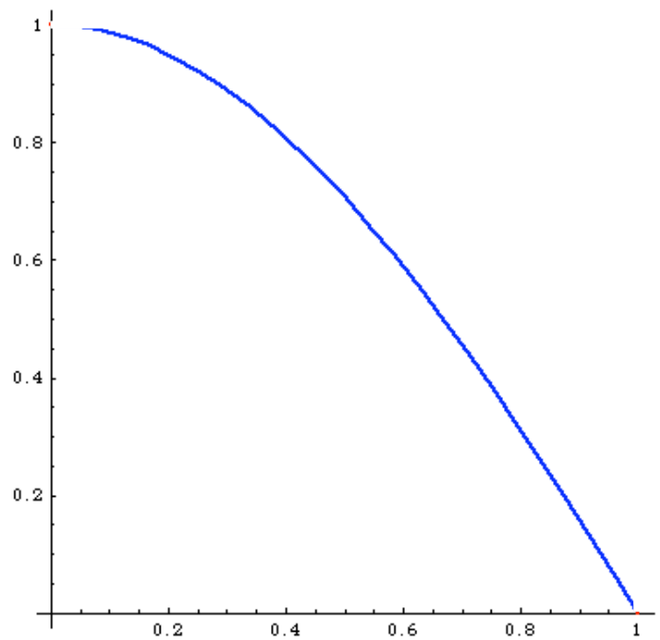

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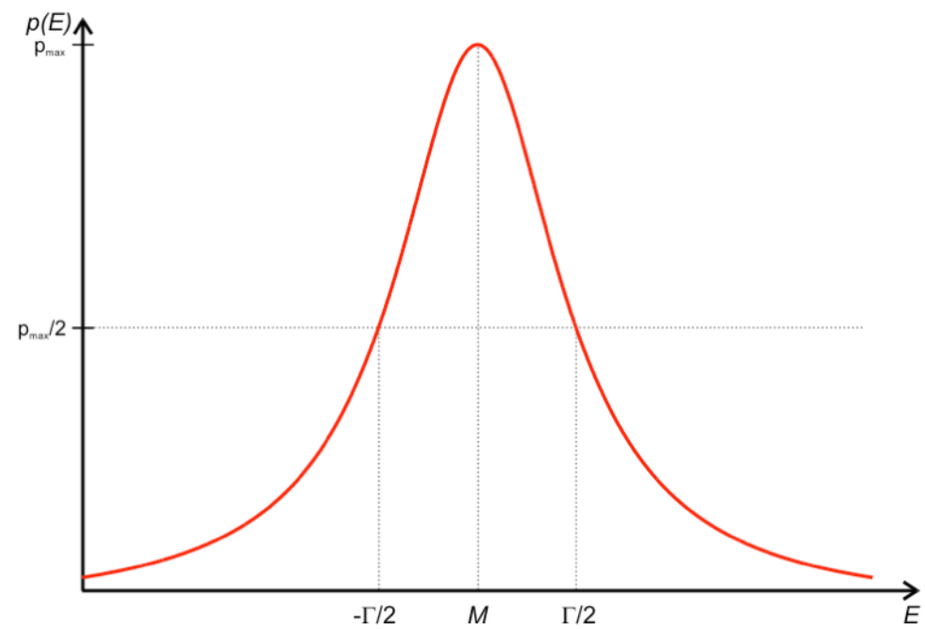

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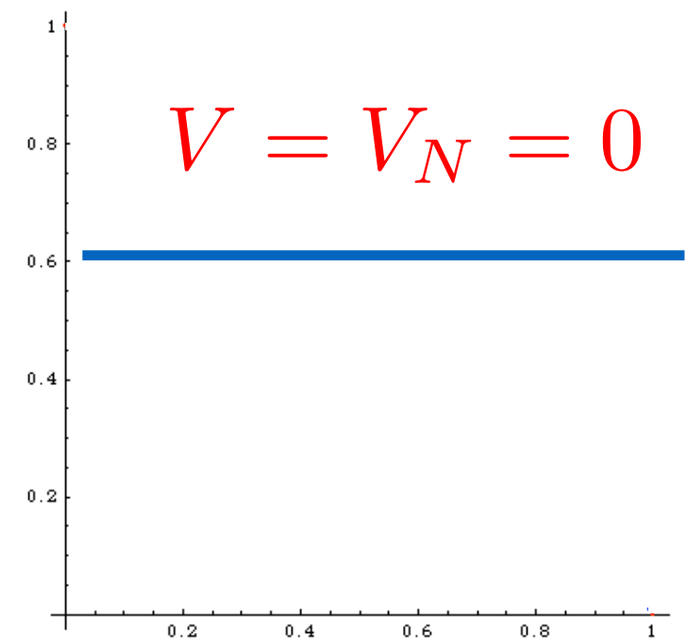

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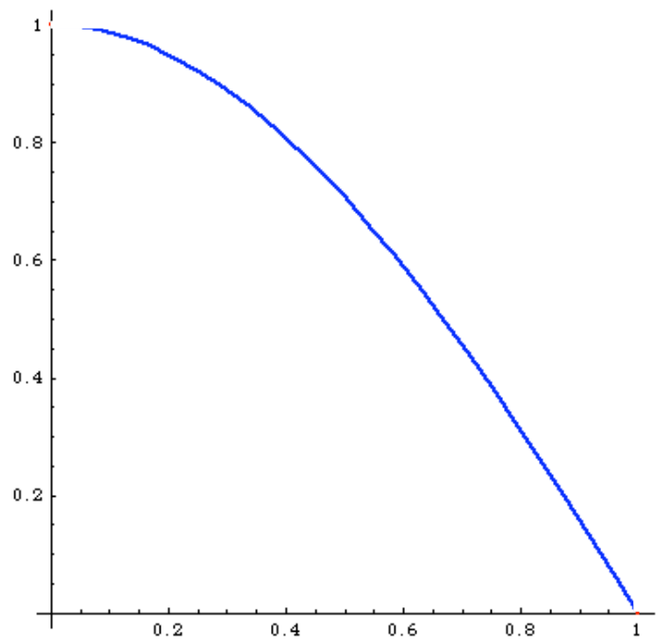

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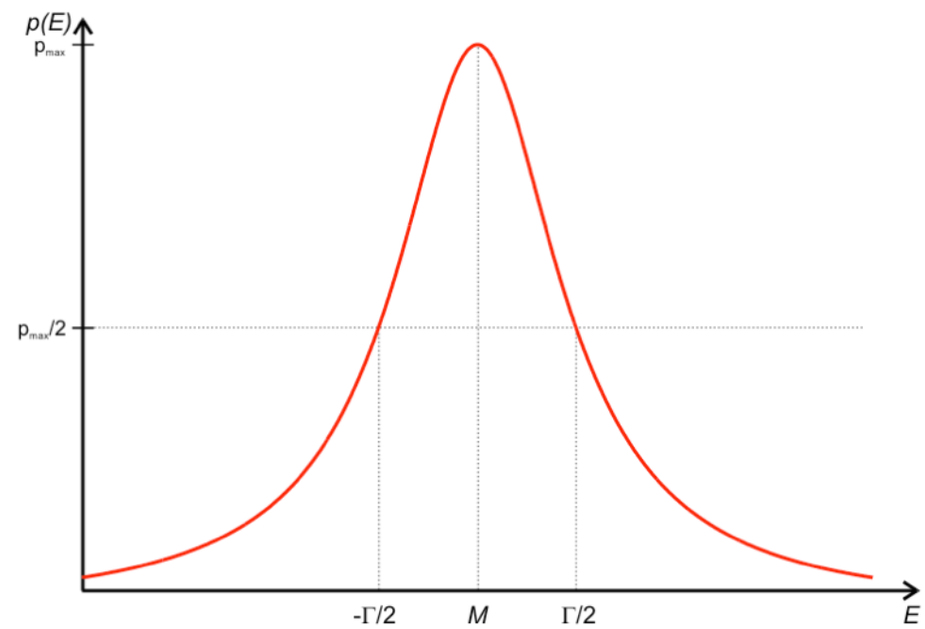

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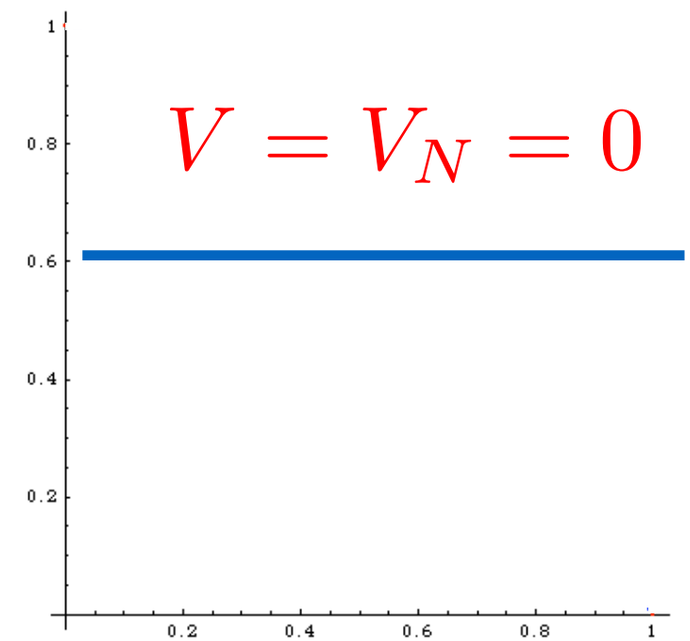

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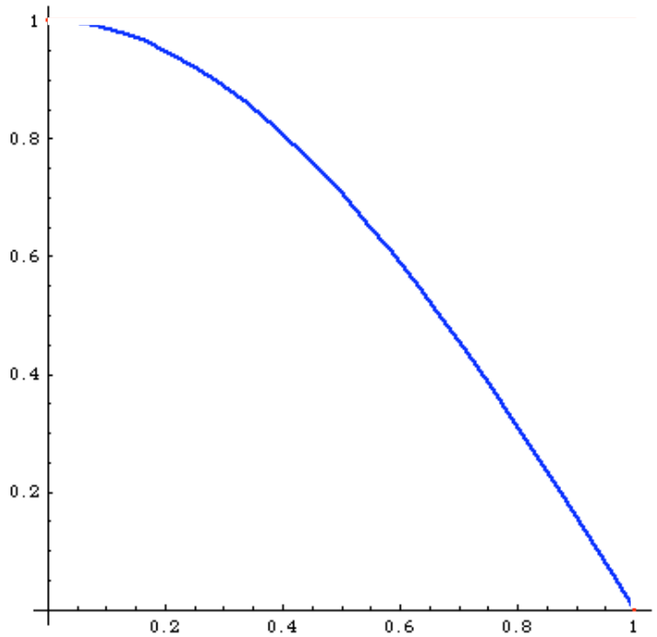
Can be minimized!

Importance Sampling



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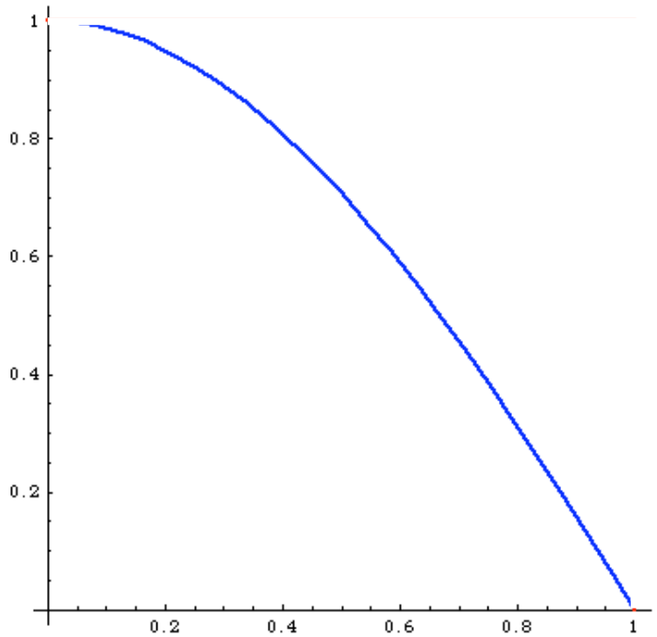

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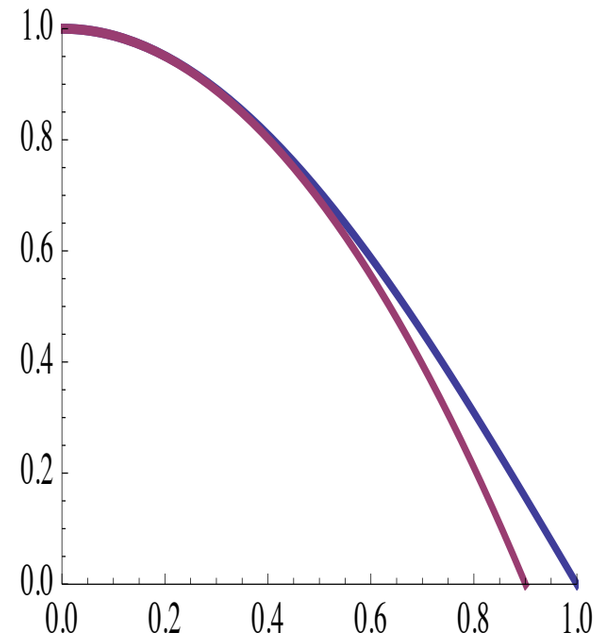

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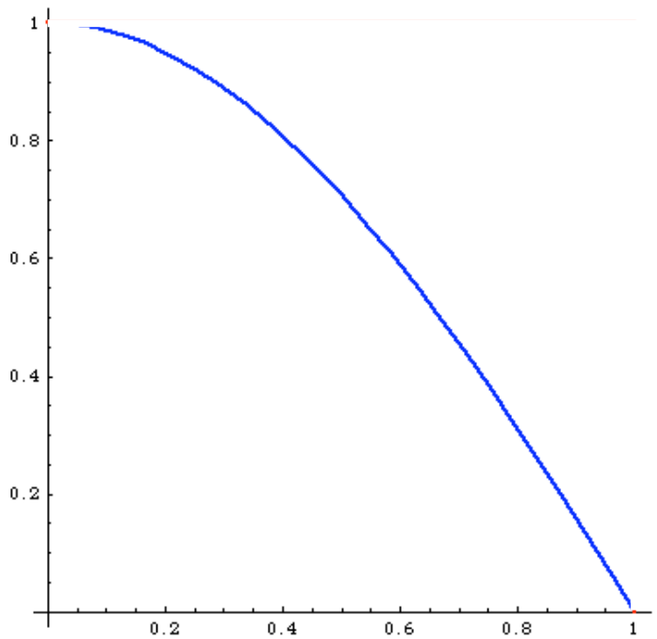

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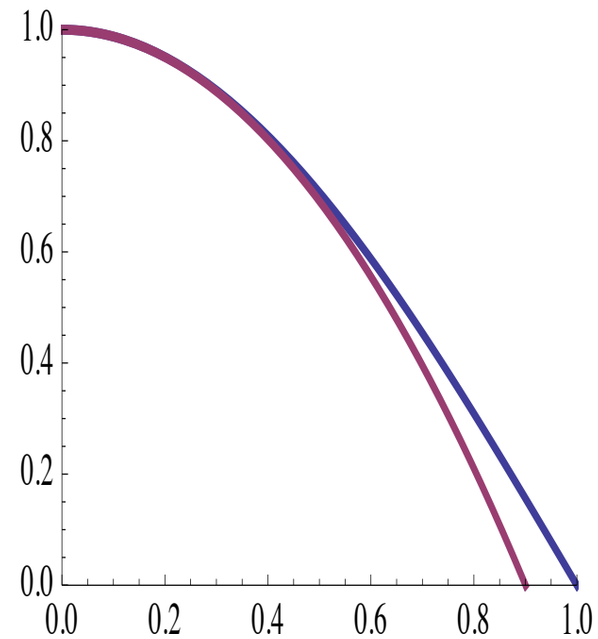

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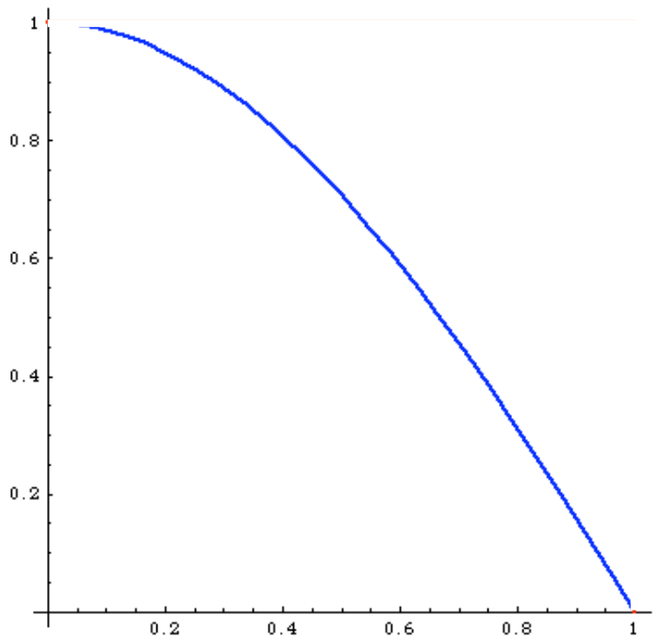

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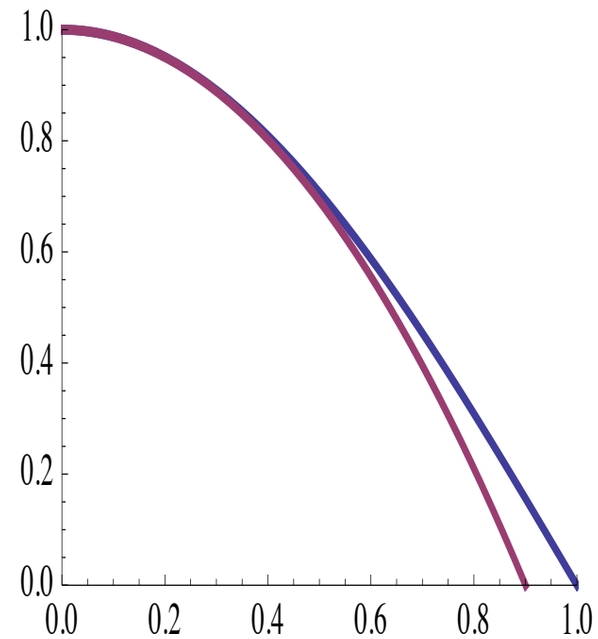

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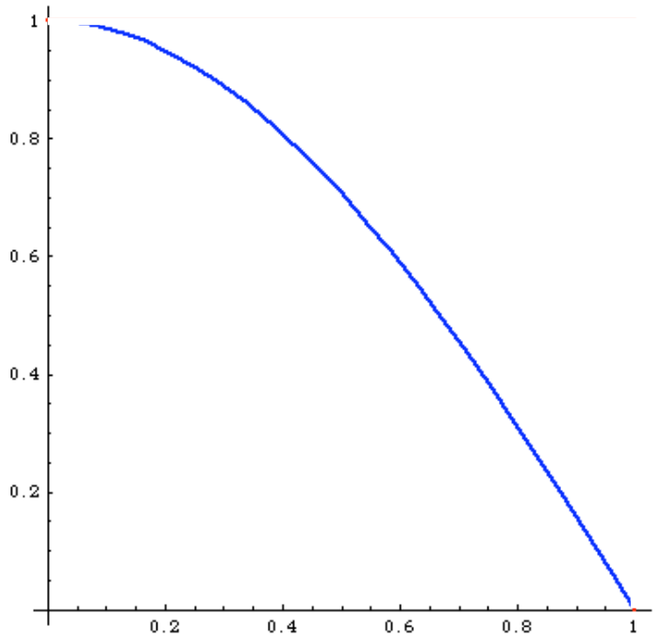
$$\Rightarrow \simeq 1$$

Importance Sampling



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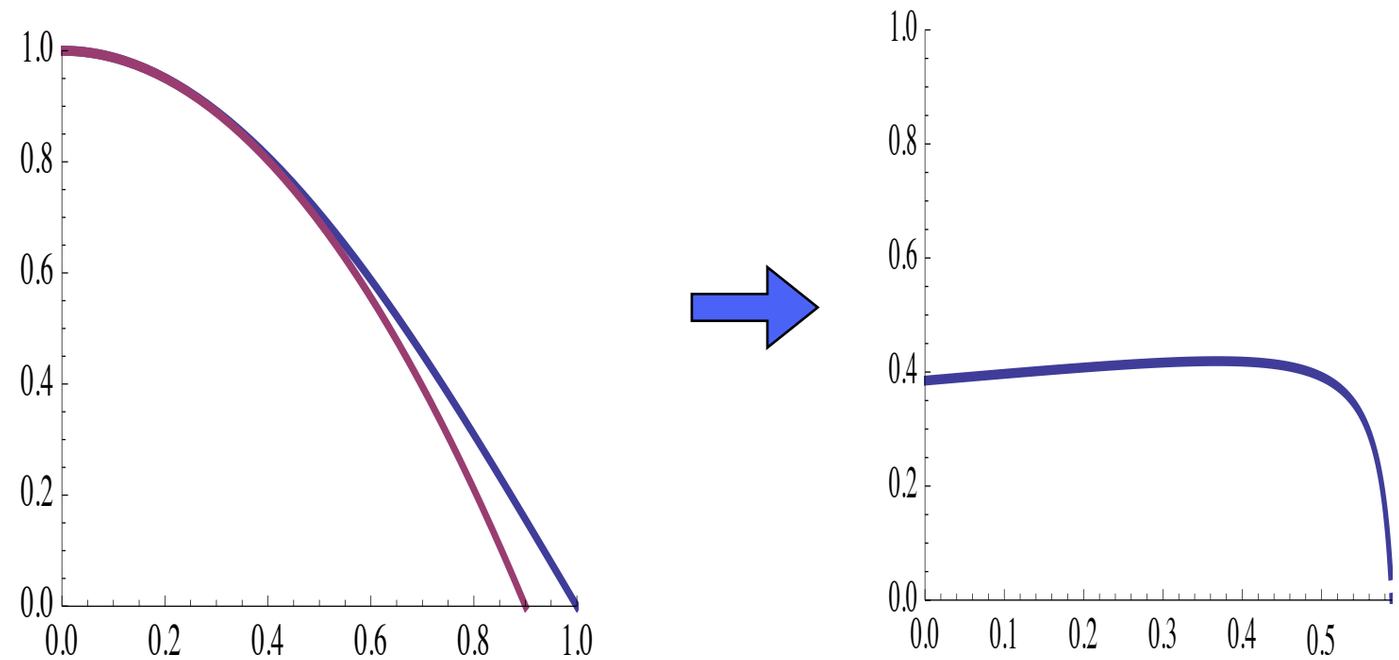

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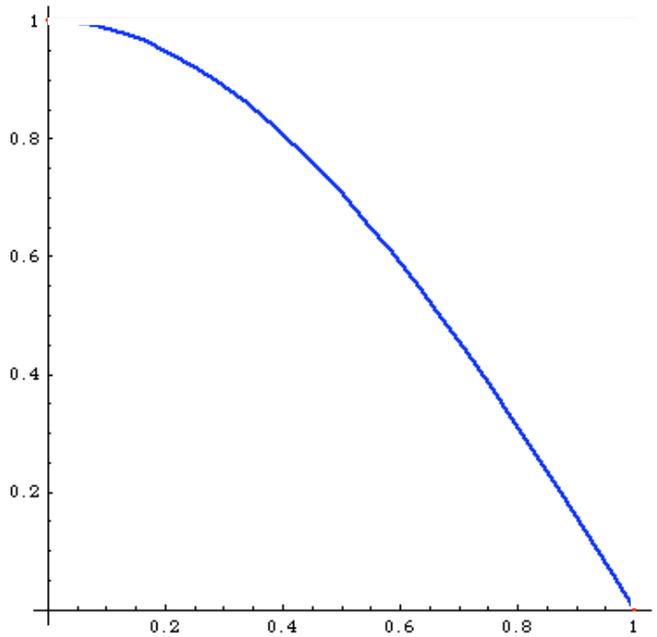

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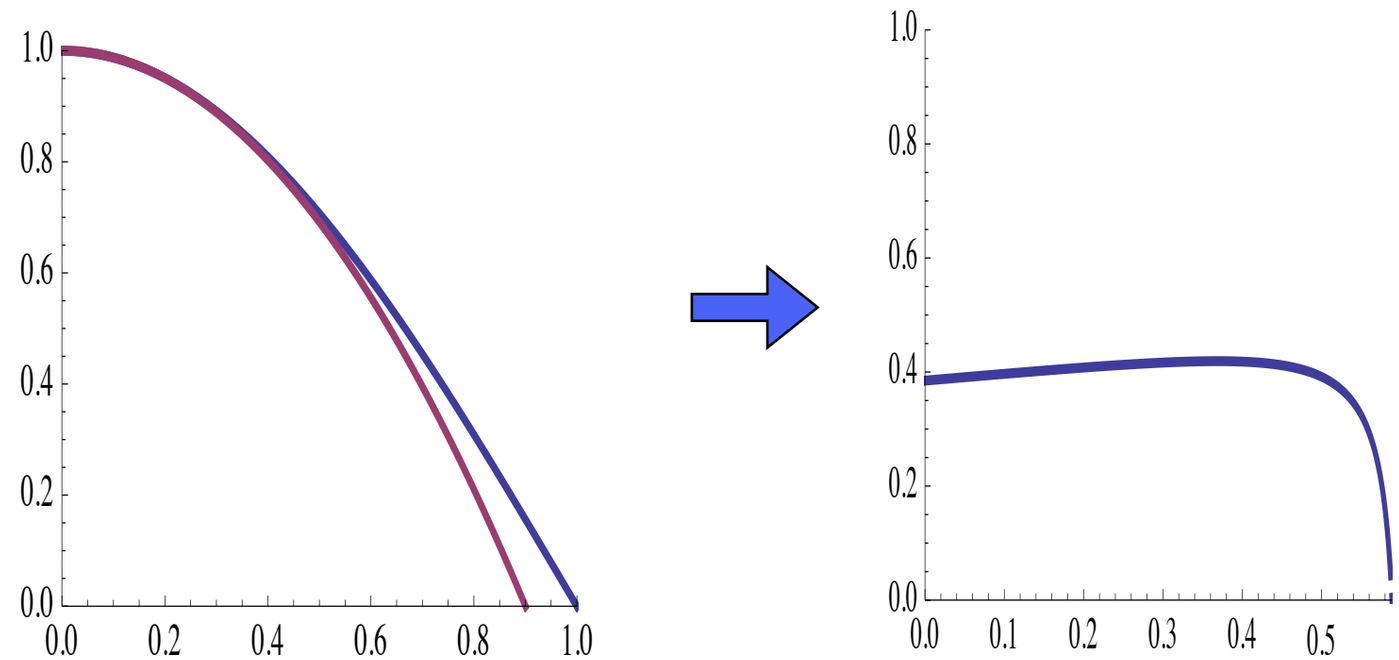

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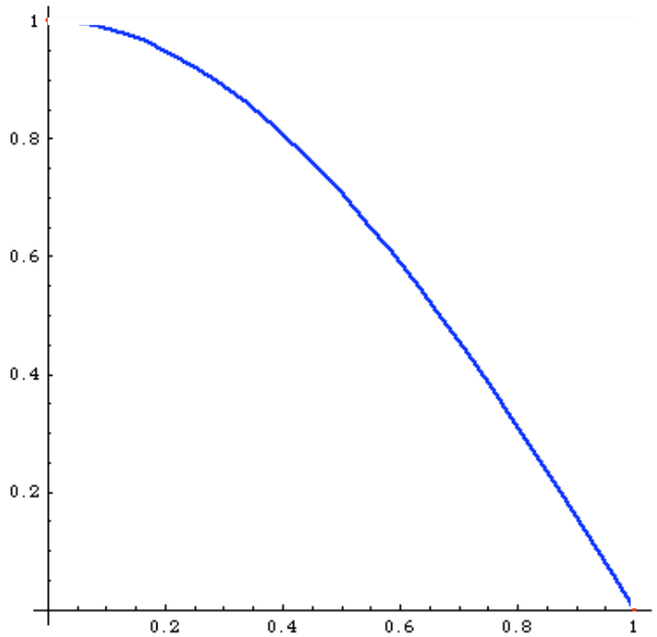

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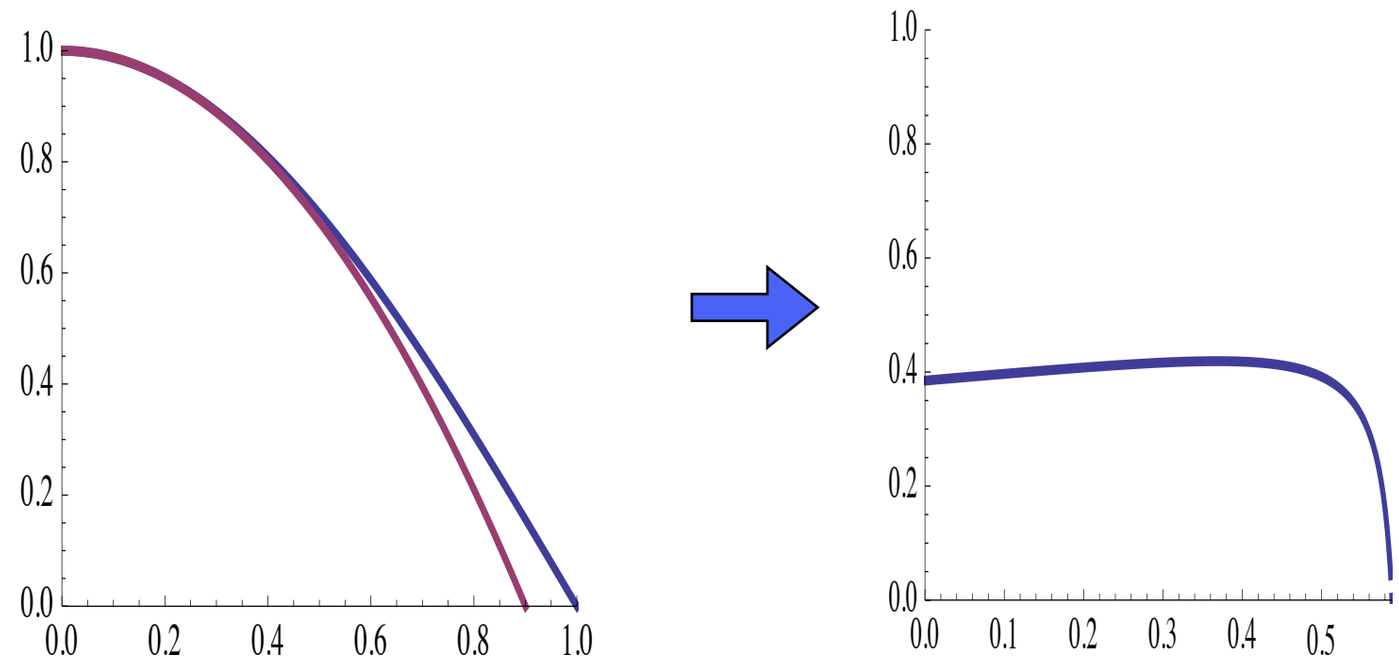

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$$I_N = 0.637 \pm 0.031/\sqrt{N}$$

The Phase-Space parametrization is important to have an efficient computation!

Importance Sampling

Key Point

- Generate the random point in a distribution which is close to the function to integrate.
- This is a change of variable, such that the function is flatter in this new variable.
- Needs to know an approximate function.

Adaptative Monte-Carlo

- Create an approximation of the function on the flight!

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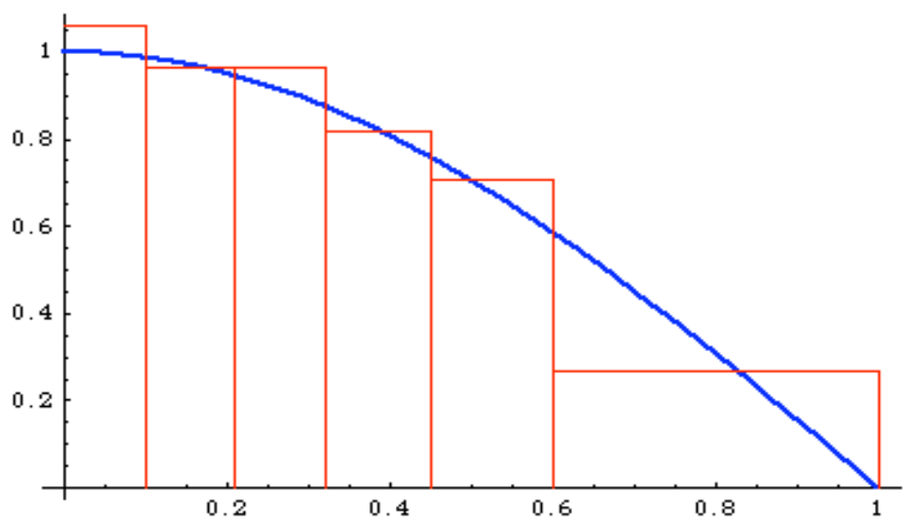


Algorithm

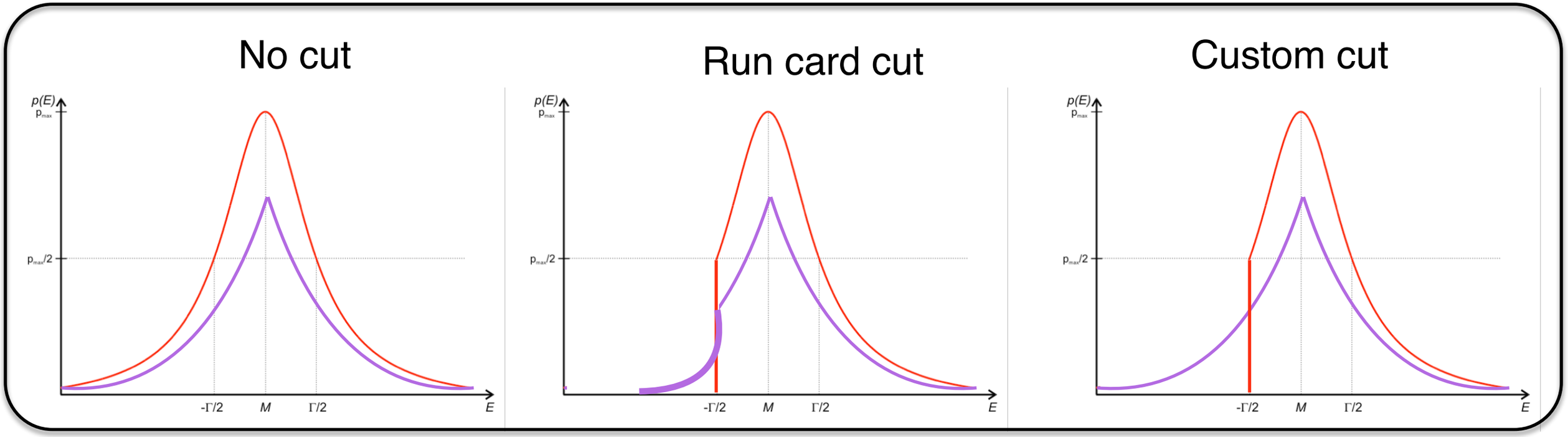
1. Creates bin such that each of them have the same contribution.

   ➡Many bins where the function is large

2. Use the approximate for the importance sampling method.

Cut Impact

- Events are generated according to our best knowledge of the function
  - ➡Basic cut include in this “best knowledge”
  - ➡Custom cut are ignored



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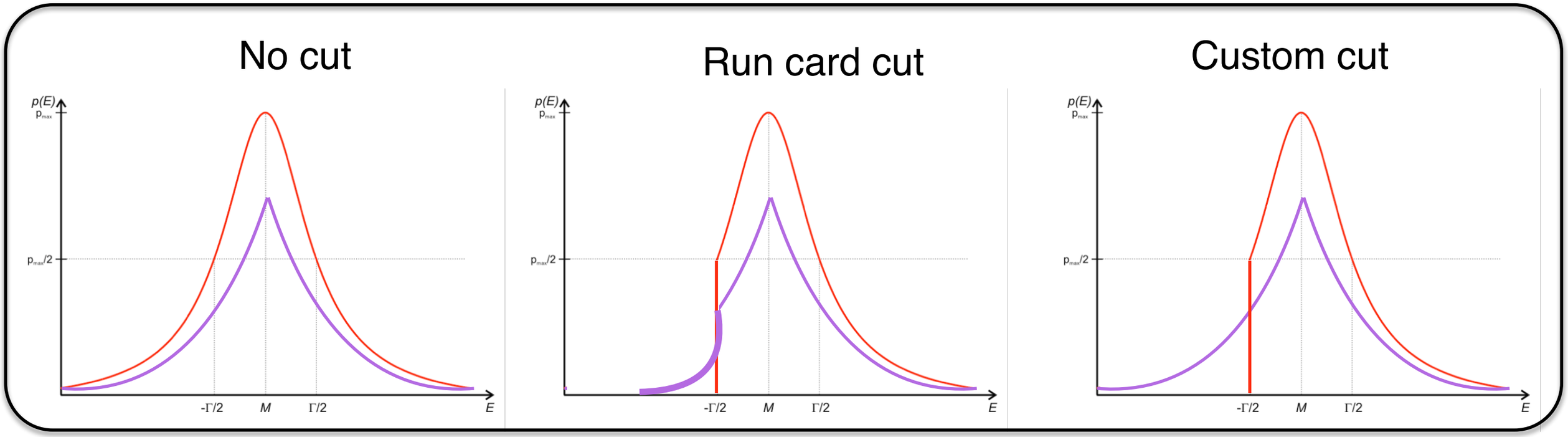
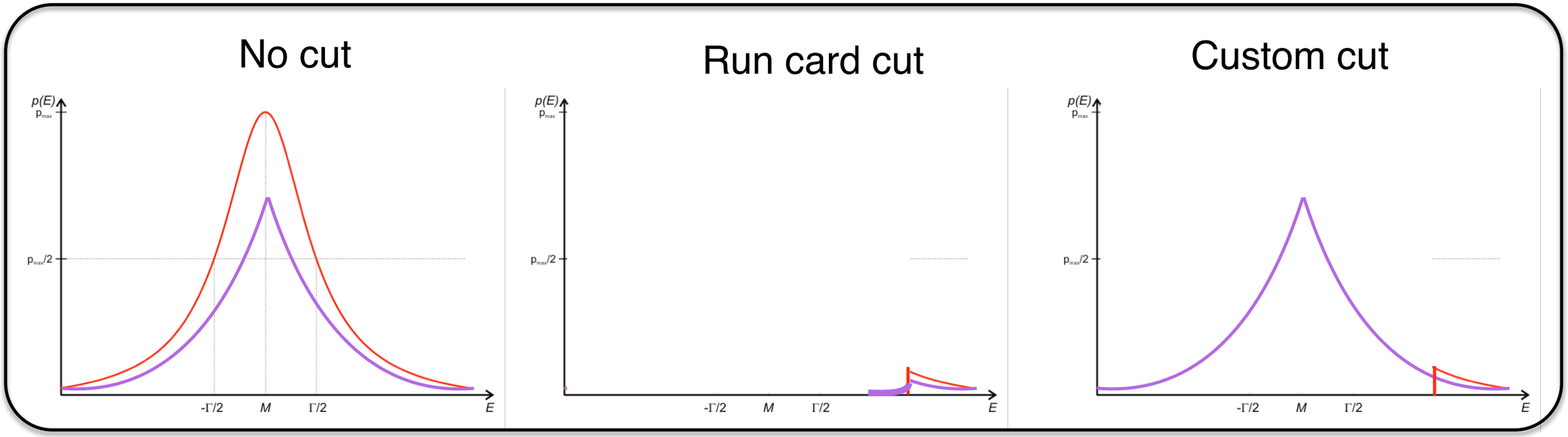
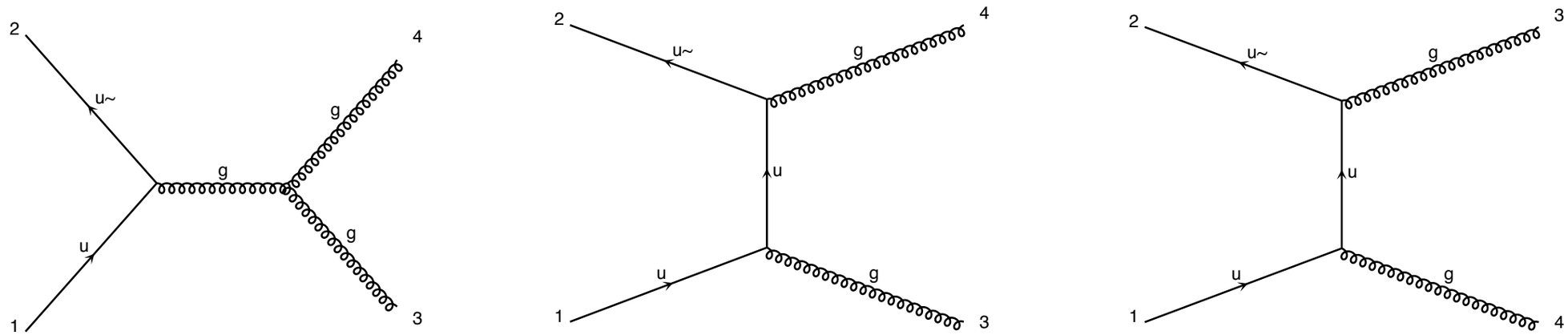




Might miss the contribution and think it is just zero.

Example: QCD 2 → 2



$$\propto \frac{1}{\hat{s}} = \frac{1}{(p_1 + p_2)^2} \qquad \propto \frac{1}{\hat{t}} = \frac{1}{(p_1 - p_3)^2} \qquad \propto \frac{1}{\hat{u}} = \frac{1}{(p_1 - p_4)^2}$$

Three very different pole structures contributing to the same matrix element.

Let's cut the problem in piece

$$|M_T|^2 = \frac{|M_1|^2 + |M_2|^2}{|M_1|^2 + |M_2|^2} |M_T|^2$$

$$\int |M_{tot}|^2 = \int \frac{\sum_i |M_i|^2}{\sum_j |M_j|^2} |M_{tot}|^2 = \sum_i \int \frac{|M_i|^2}{\sum_j |M_j|^2} |M_{tot}|^2$$

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Key Idea

- One diagram is manageable
- All other peaks taken care of by denominator sum

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- One diagram is manageable
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N Integral

- Errors add in quadrature so no extra cost
- Parallel in nature

$$\int |M_{tot}|^2 = \int \frac{\sum_i |M_i|^2}{\sum_j |M_j|^2} |M_{tot}|^2 = \sum_i \int \frac{|M_i|^2}{\sum_j |M_j|^2} |M_{tot}|^2$$

P1_qq_wpwm

s= 725.73 ± 2.07 (pb)

Graph	Cross-Section ↓	Error	Events (K)	Unwgt	Luminosity
G2.2	377.6	1.67	142.285	7941.0	21
G3	239	1.16	220.04	10856.0	45.5
G1	109.1	0.378	70.88	3793.0	34.8

P1_gg_wpwm

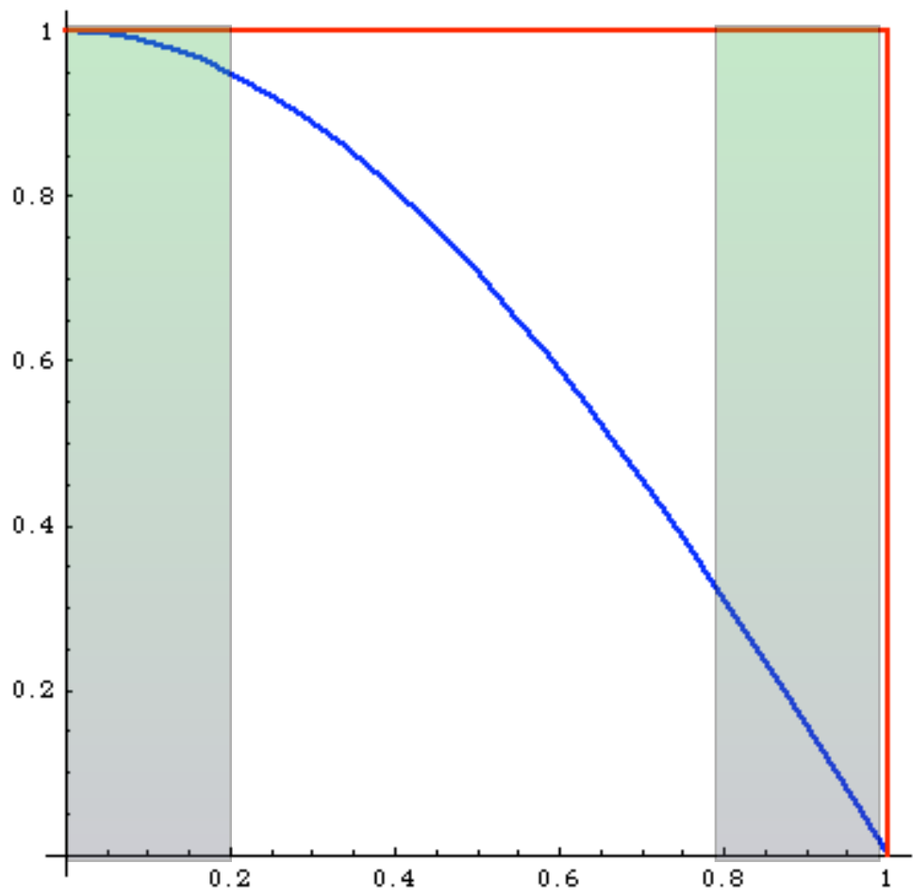
s= 20.714 ± 0.332 (pb)

Graph	Cross-Section ↓	Error	Events (K)	Unwgt	Luminosity
G1.2	20.71	0.332	7.01	373.0	18

term of the above sum.

each term might not be gauge invariant

Event generation

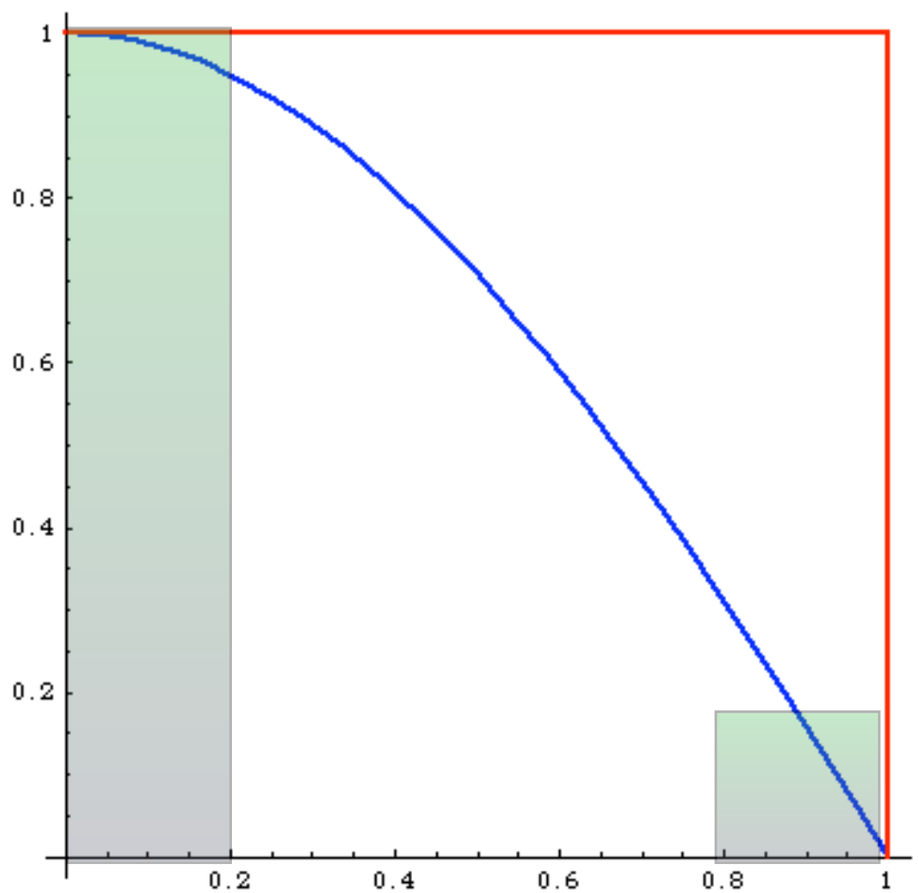


What's the difference between weighted and unweighted?

Weighted:

Same # of events in areas of phase space with very different probabilities: events must have different weights

Event generation



What's the difference between weighted and unweighted?

Unweighted:

events is proportional to the probability of areas of phase space:
events have all the same weight ("unweighted")

Events distributed as in nature

Event generation

$$\int f(x)dx = \frac{1}{N}\sum_{i=1}^{N} f(x_i)$$

Event generation

$$\int f(x)dx = \frac{1}{N}\sum_{i=1}^{N} f(x_i) = \frac{1}{N}\sum_{i=1}^{N} \frac{f(x_i)}{max(f)} max(f)$$

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Number between 0 and 1 (assuming positive function)
-> re-interpret as the probability to keep the events

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For each events throw the dice and see if we keep or reject the events

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Event generation

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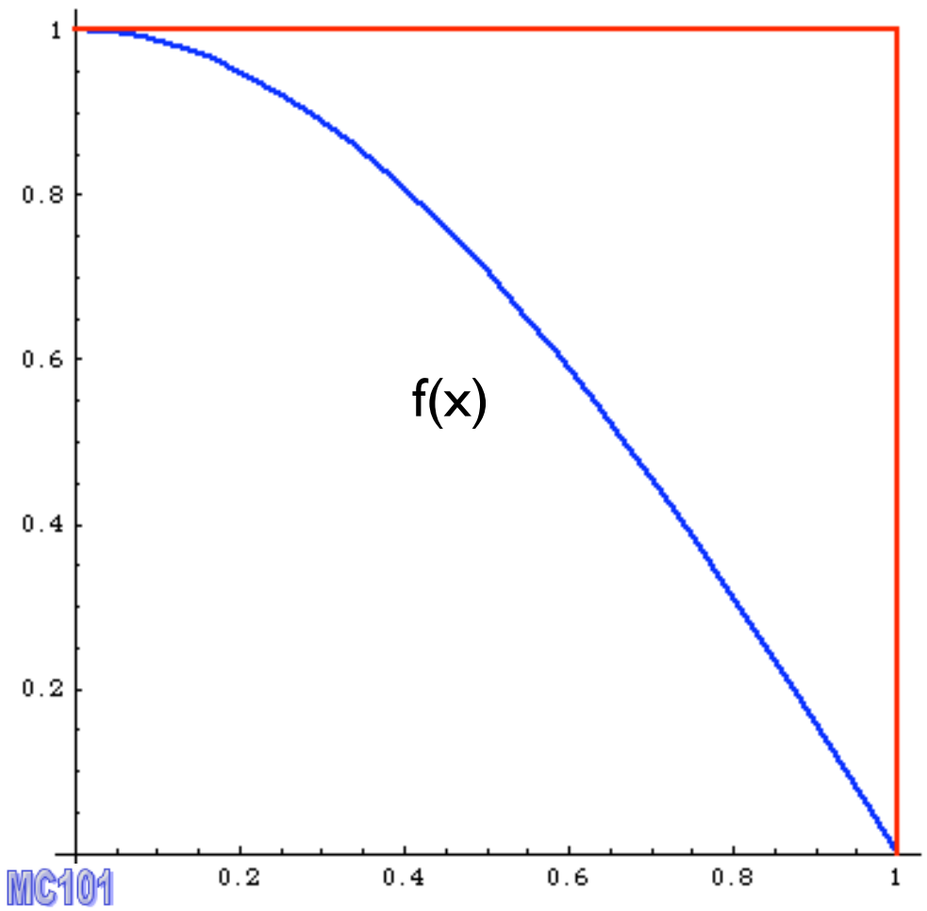

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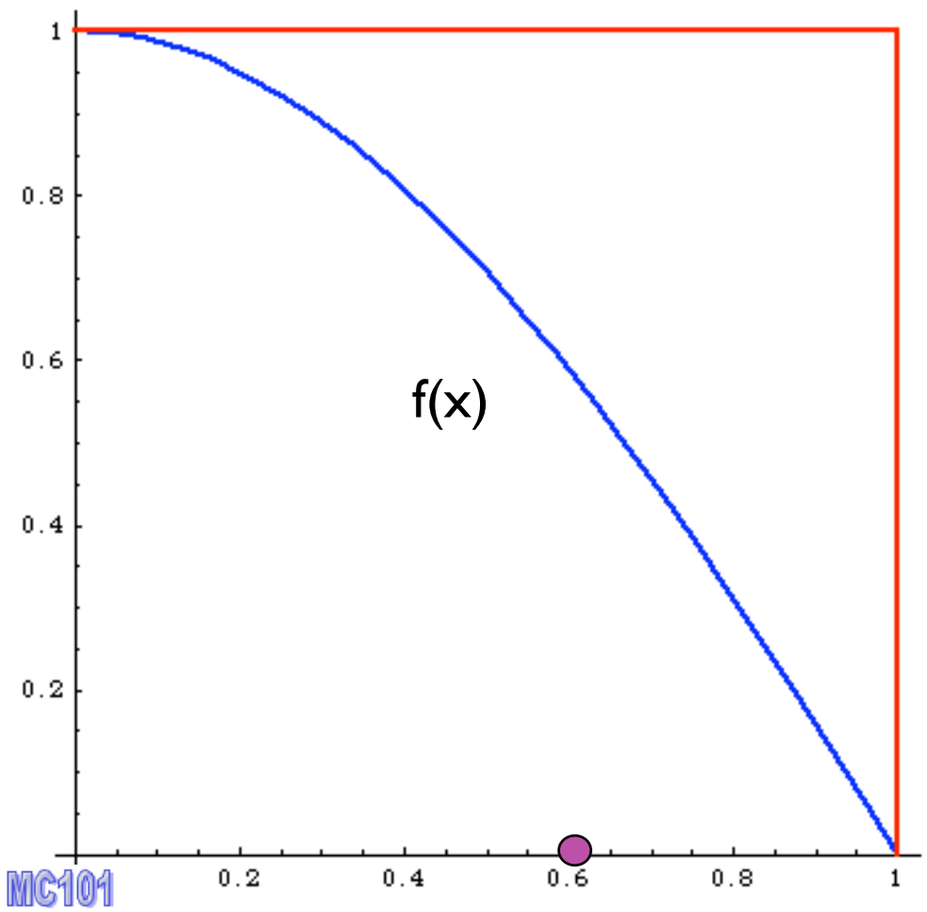

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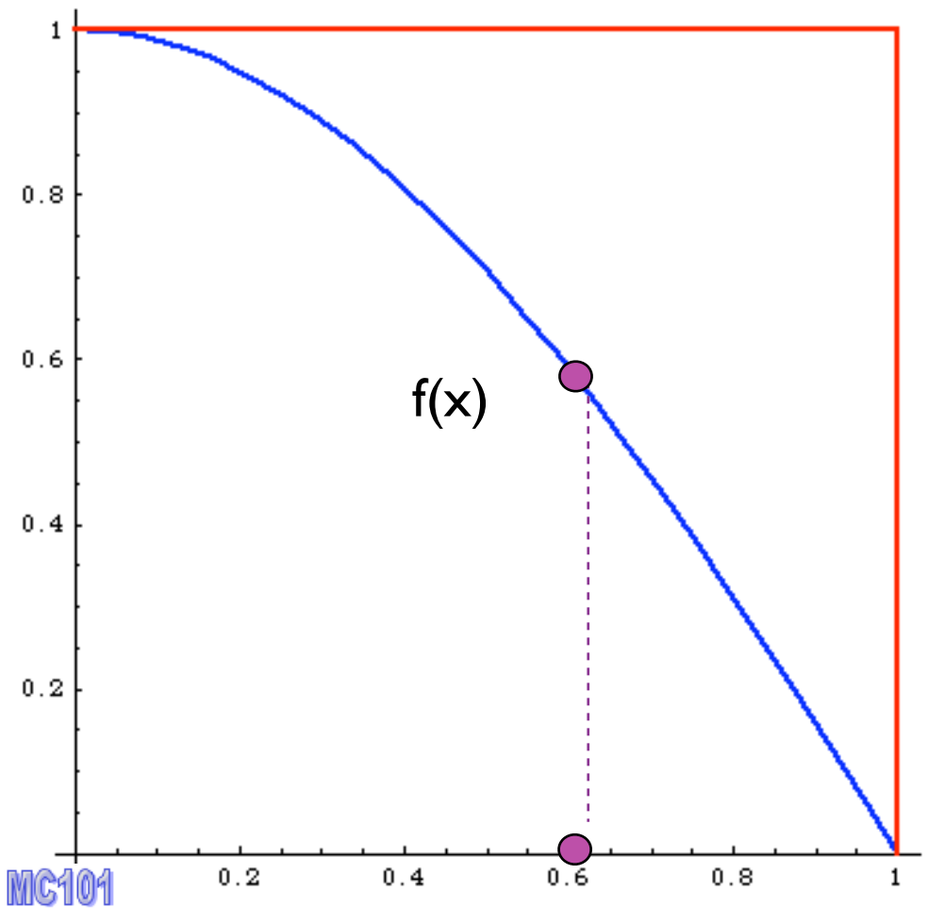

1. pick x_i
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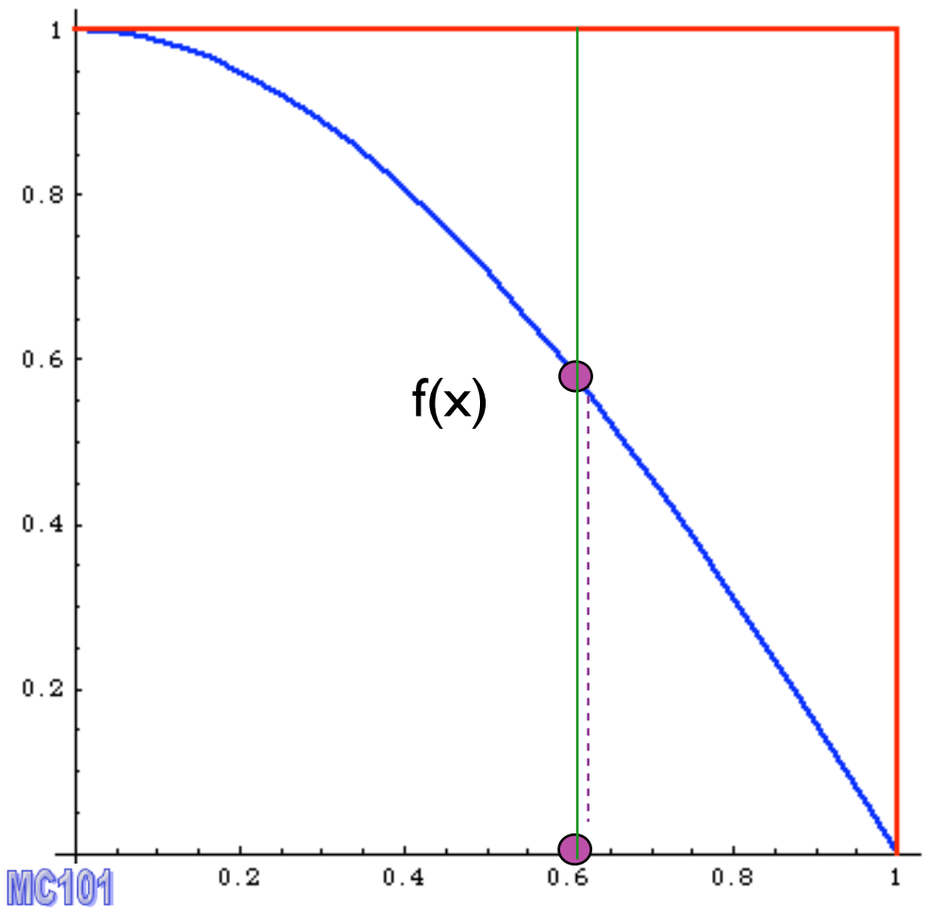

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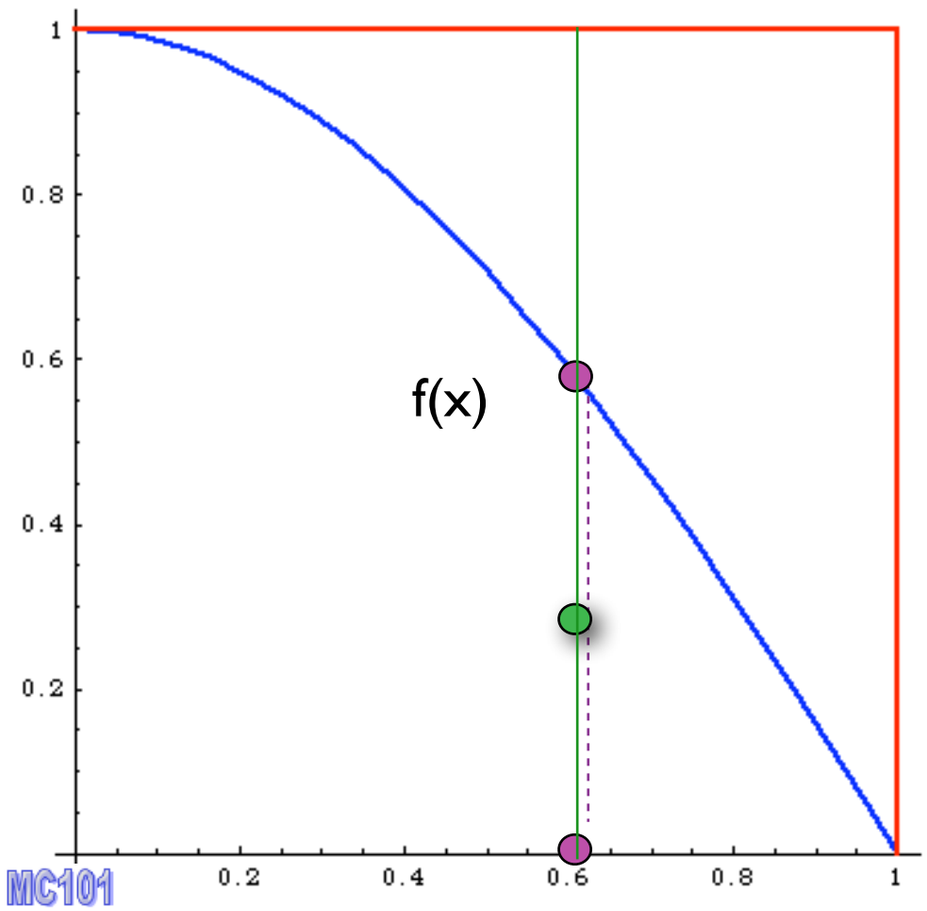

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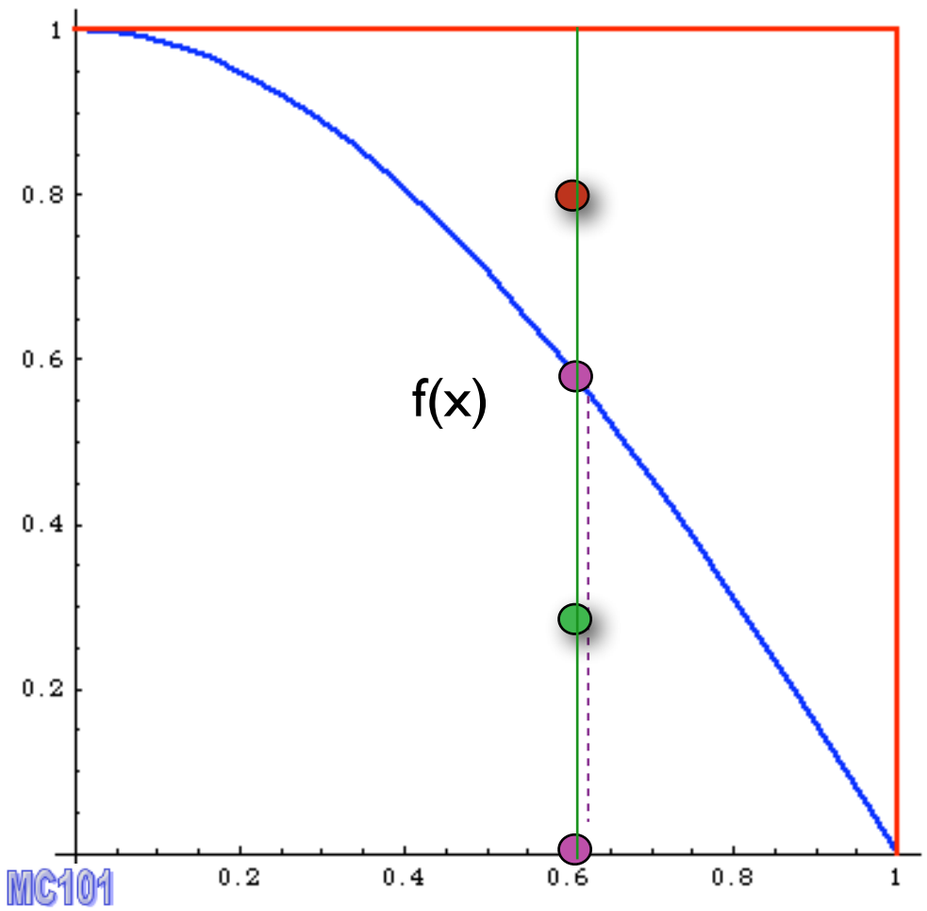

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MC integrator

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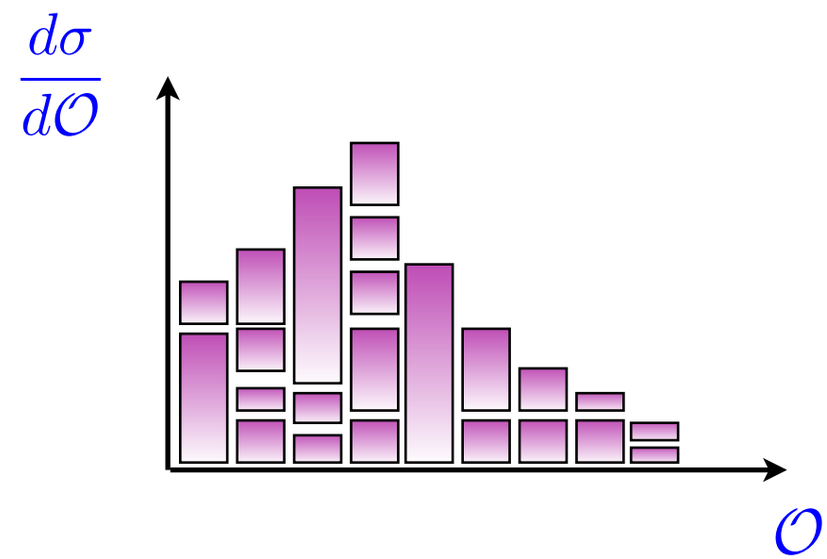

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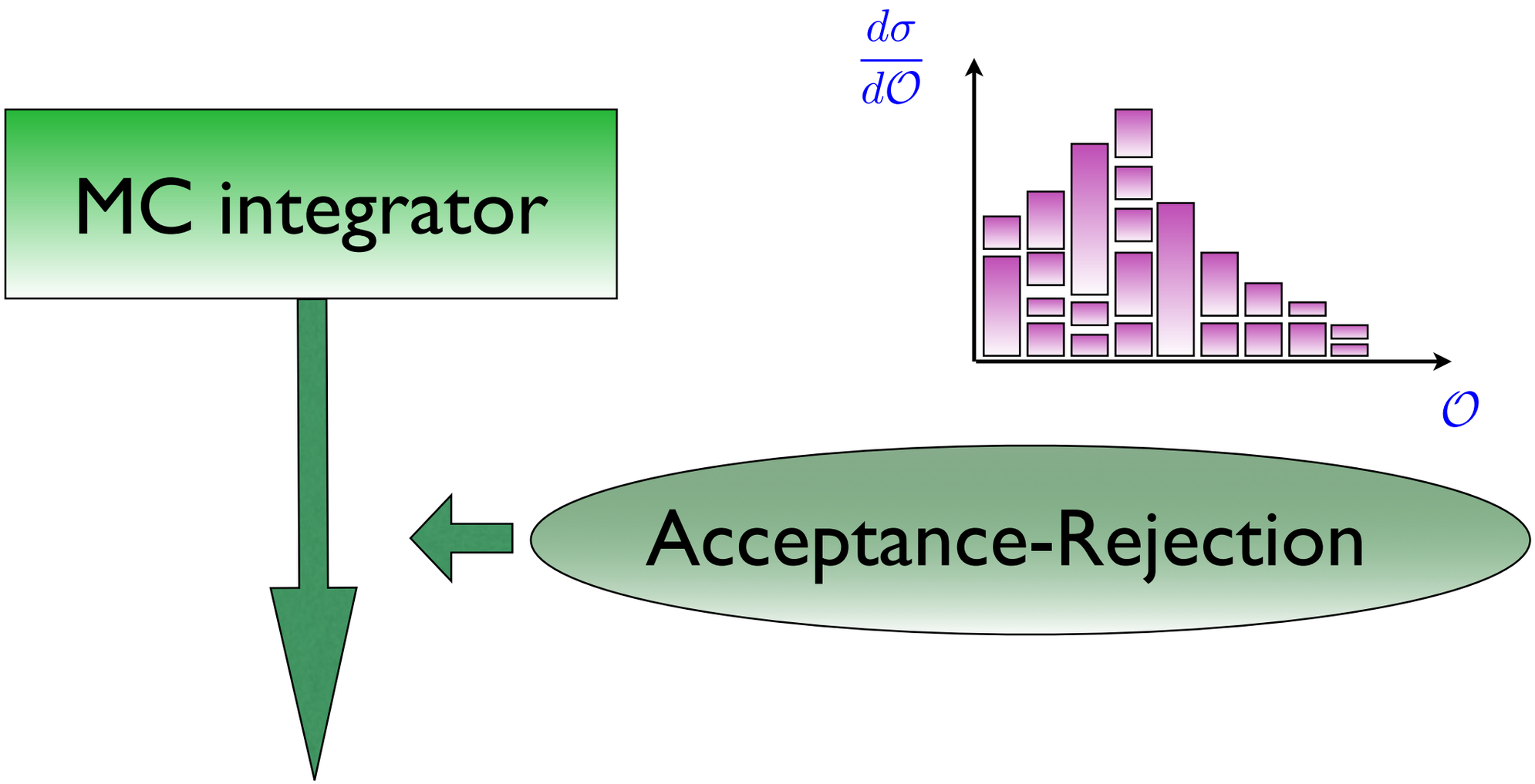

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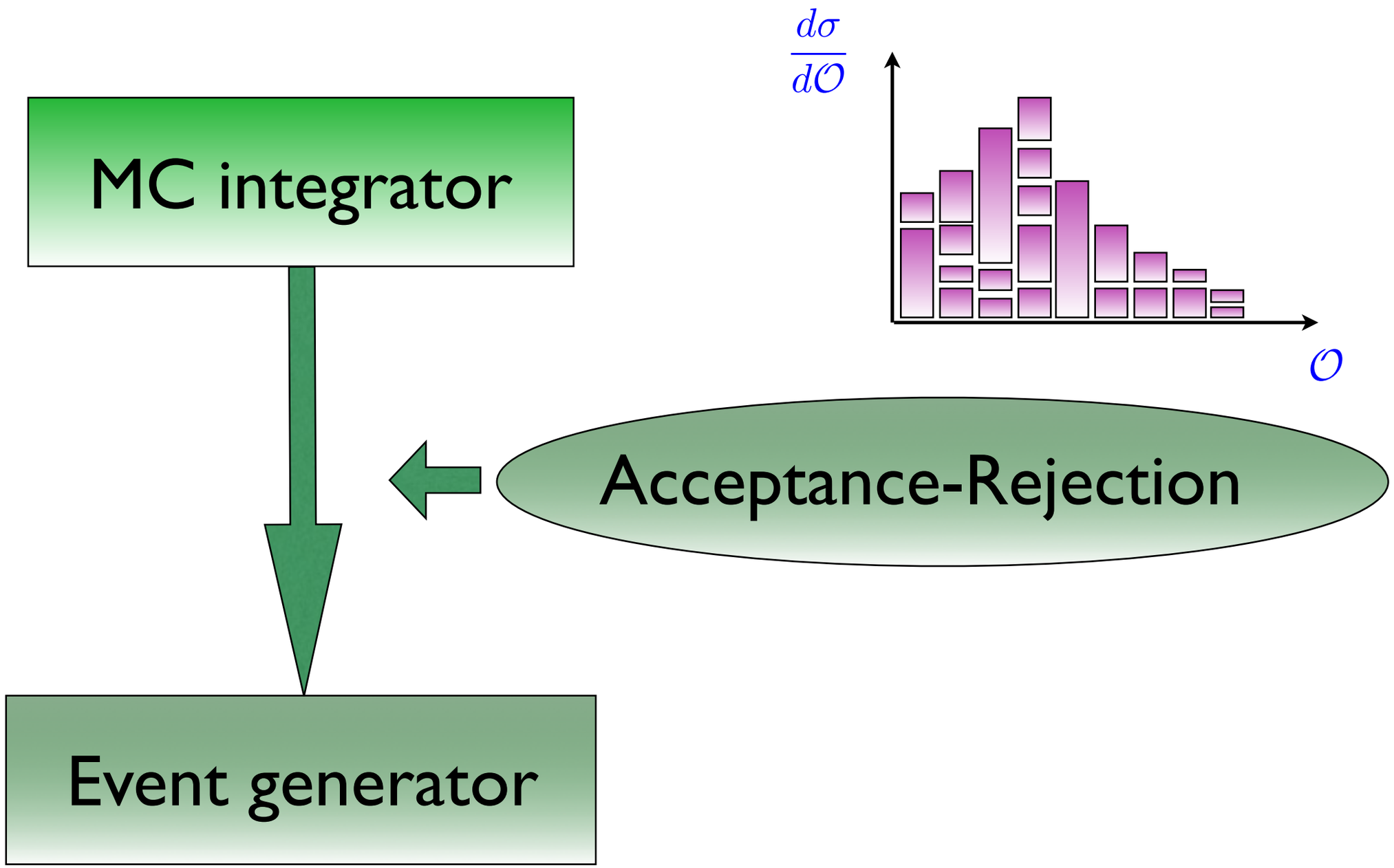

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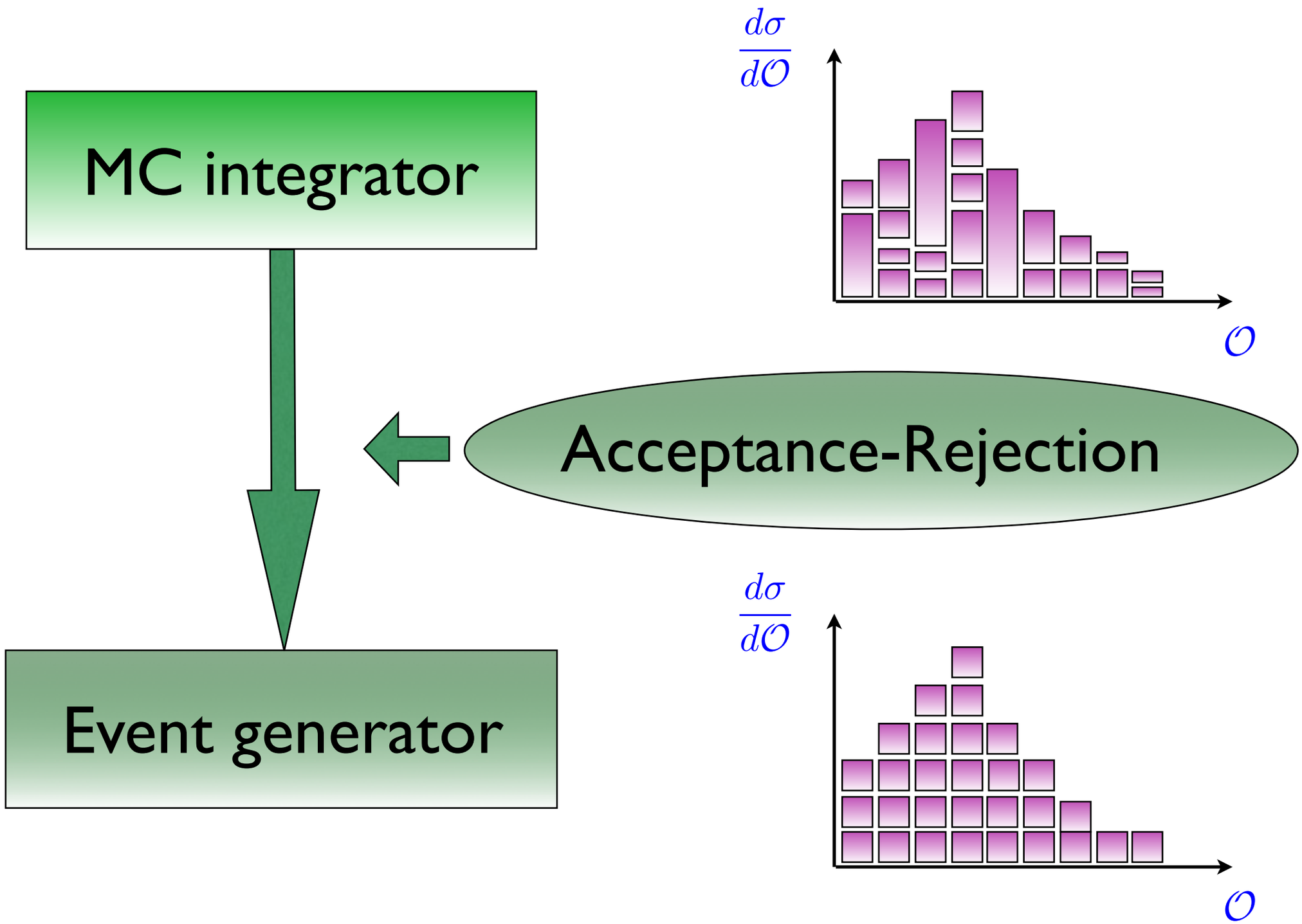

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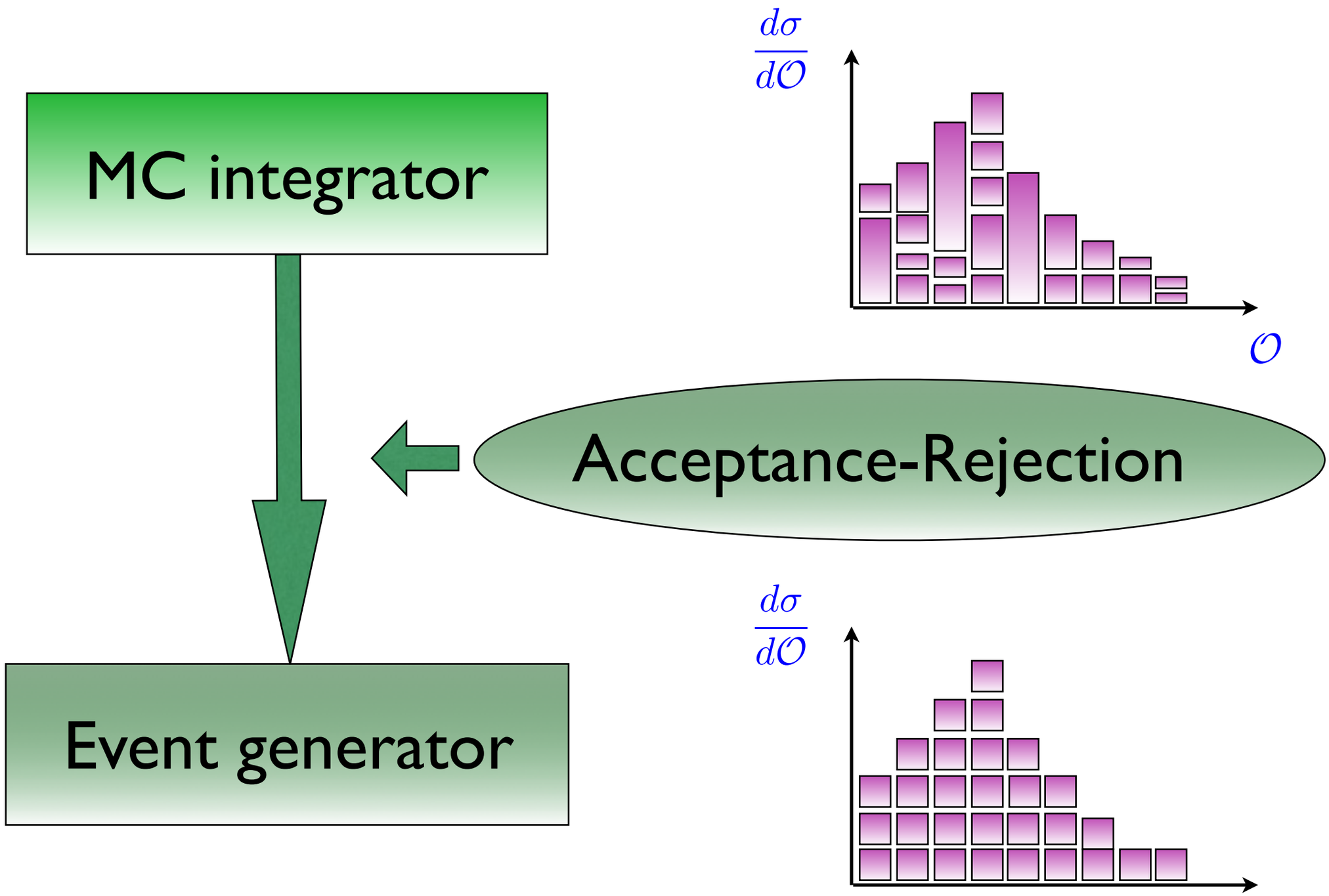

☞ **This is possible only if f(x)<∞ AND has definite sign!**

Monte-Carlo Summary

Bad Point

- Slow Convergence (especially in low number of Dimension)
- Need to know the function
  - Impact on cut

Monte-Carlo Summary

Bad Point

- Slow Convergence (especially in low number of Dimension)
- Need to know the function
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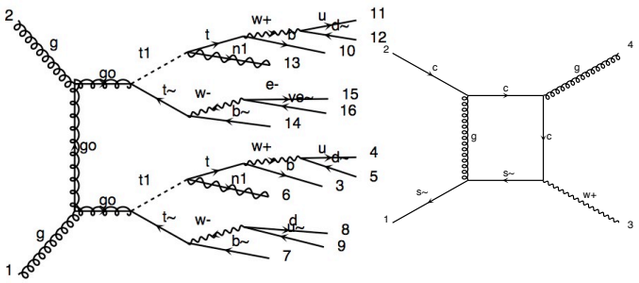
Good Point

- Complex area of Integration
- Easy Error estimate
- quick estimation of the integral
- Possibility to have unweighted events

Type of generation

	Tree (B)SM	NLO (QCD) (SM)	NLO (QCD) (BSM)	NLO (EW) (SM)	Loop Induced (B)SM
Fix Order	✓	✓	✓	✓	✓



$$\hat{\sigma} = \sigma^{\mathrm{Born}}\left(1 + \frac{\alpha_s}{2\pi}\sigma^{(1)} + \left(\frac{\alpha_s}{2\pi}\right)^2\sigma^{(2)} + \left(\frac{\alpha_s}{2\pi}\right)^3\sigma^{(3)} + \ldots\right)$$

LO predictions

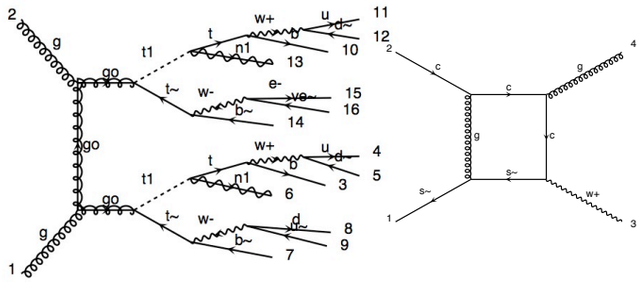
NLO corrections

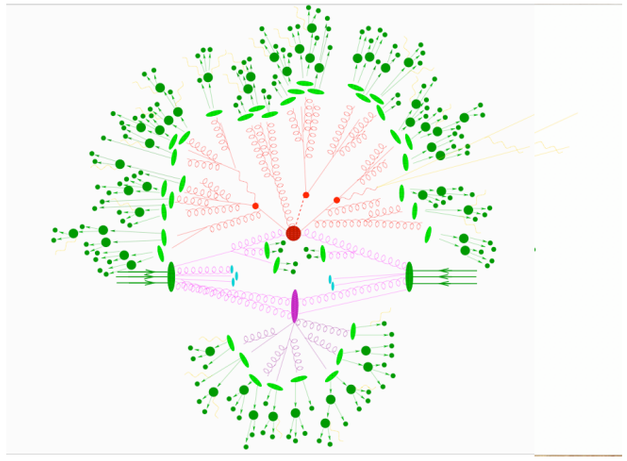
NNLO corrections

N3LO or NNNLO corrections

Type of generation

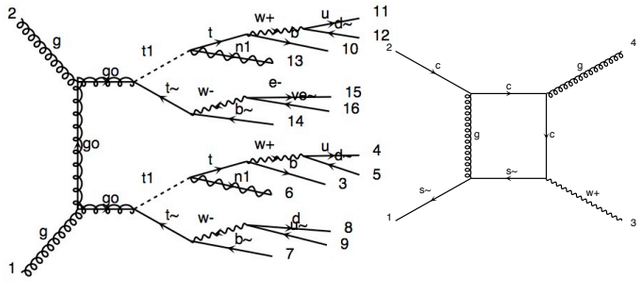
	Tree (B)SM	NLO (QCD) (SM)	NLO (QCD) (BSM)	NLO (EW) (SM)	Loop Induced (B)SM
Fix Order	✓	✓	✓	✓	✓
+Parton Shower	✓	✓	✓	✗	✓

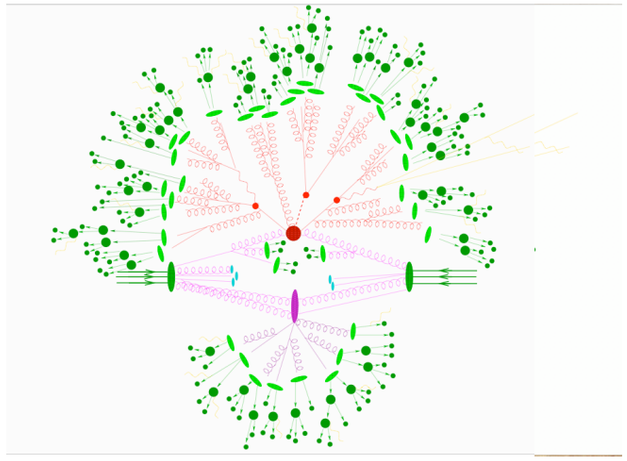




Type of generation

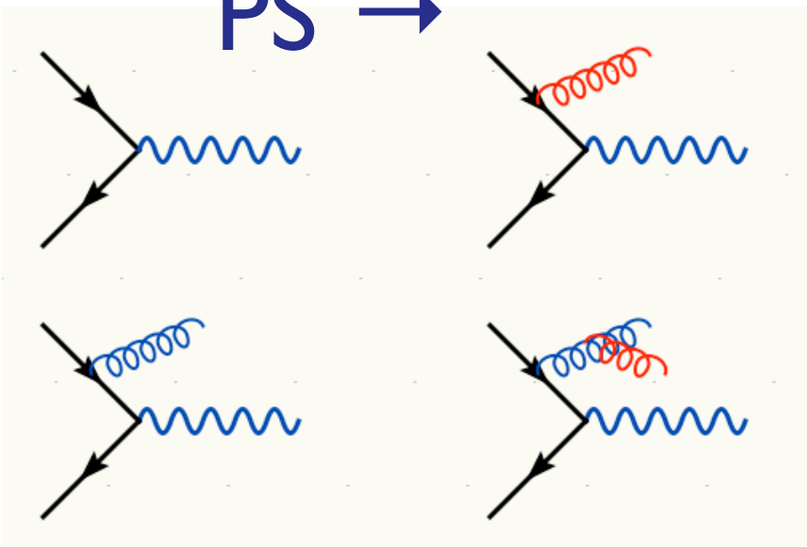
	Tree (B)SM	NLO (QCD) (SM)	NLO (QCD) (BSM)	NLO (EW) (SM)	Loop Induced (B)SM
Fix Order	✓	✓	✓	✓	✓
+Parton Shower	✓	✓	✓	✗	✓
Merged Sample	✓	✓	?	✗	✓





PS →

ME ↓



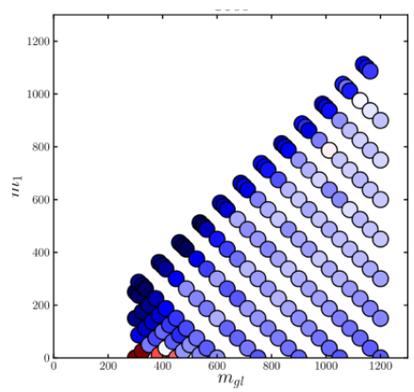
LO Feature

LO Feature

Auto-Width

$$\Gamma = ?$$

Parameter scan



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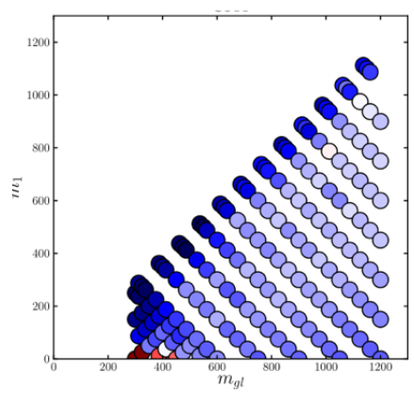
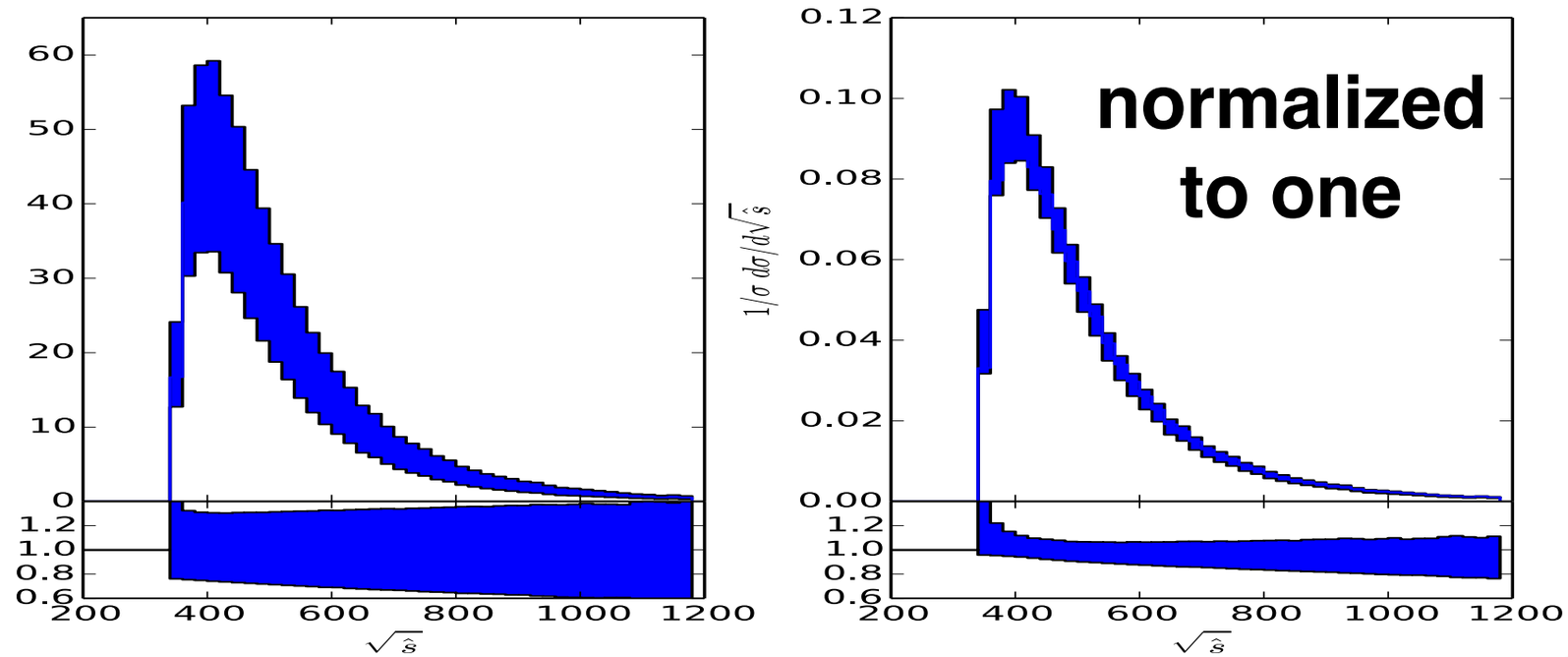


Systematics



BSM re-weighting

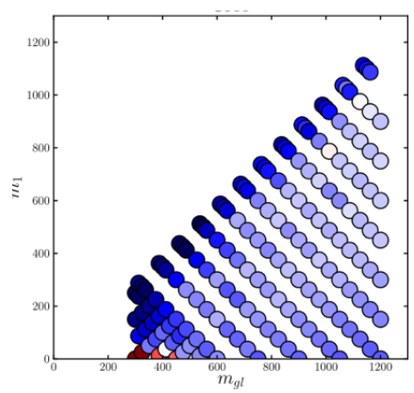
$$|M_{new}|^2 / |M_{old}|^2$$

LO Feature

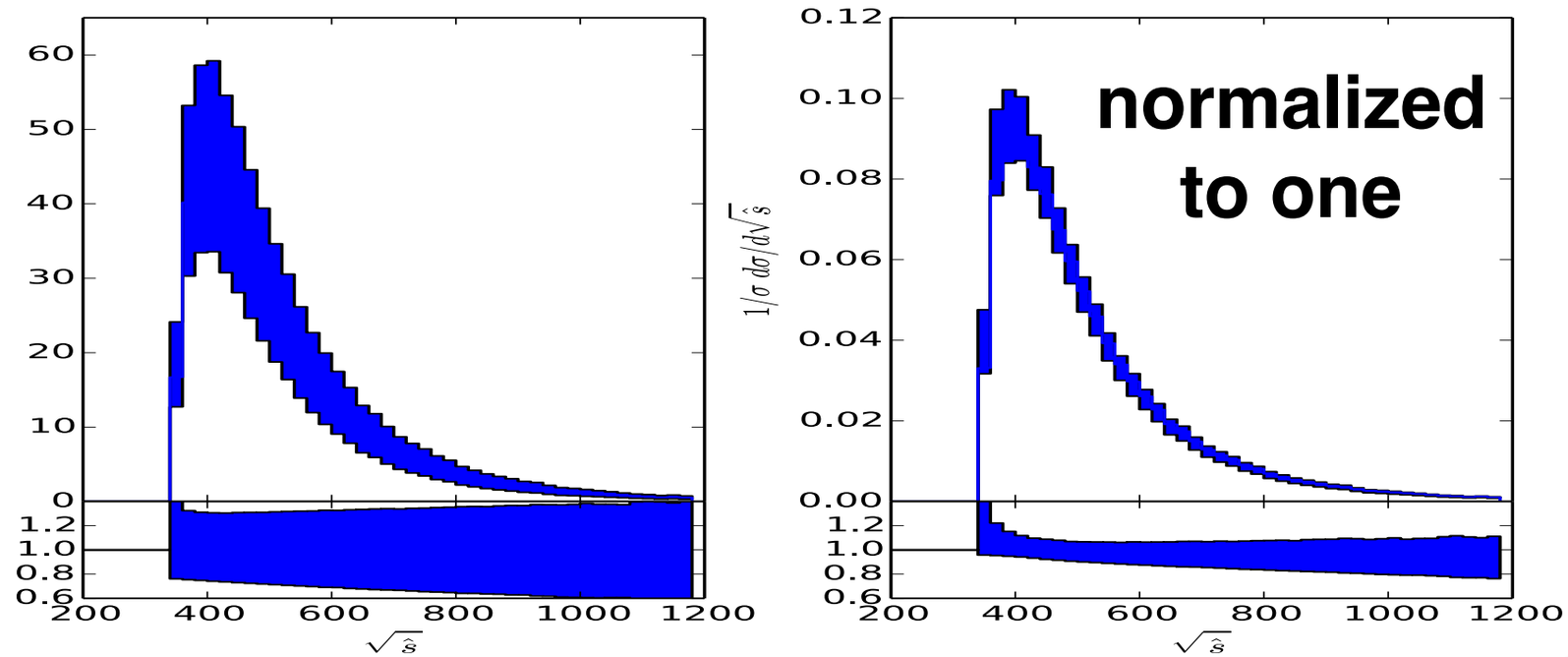
Auto-Width

$$\Gamma = ?$$

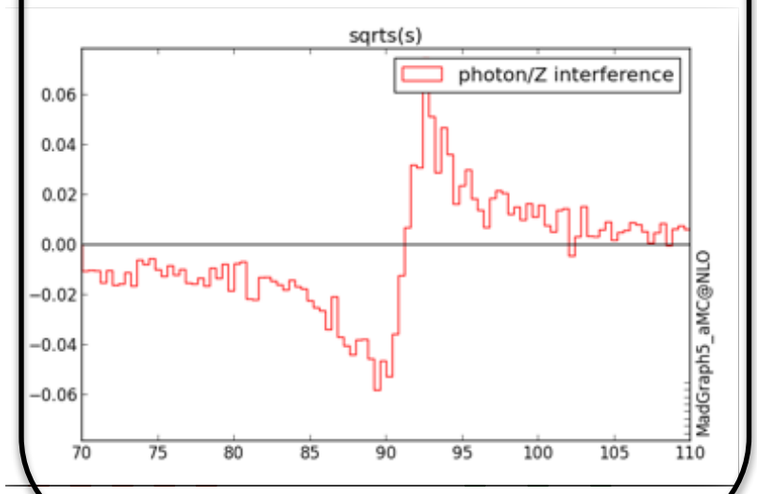
Parameter scan



Systematics



Interference



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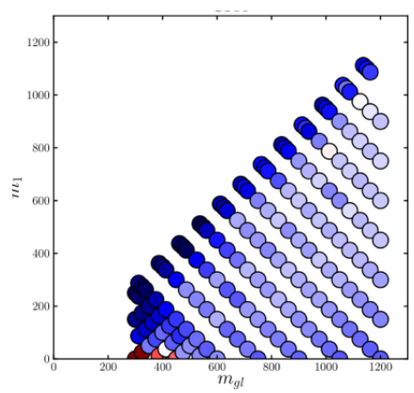

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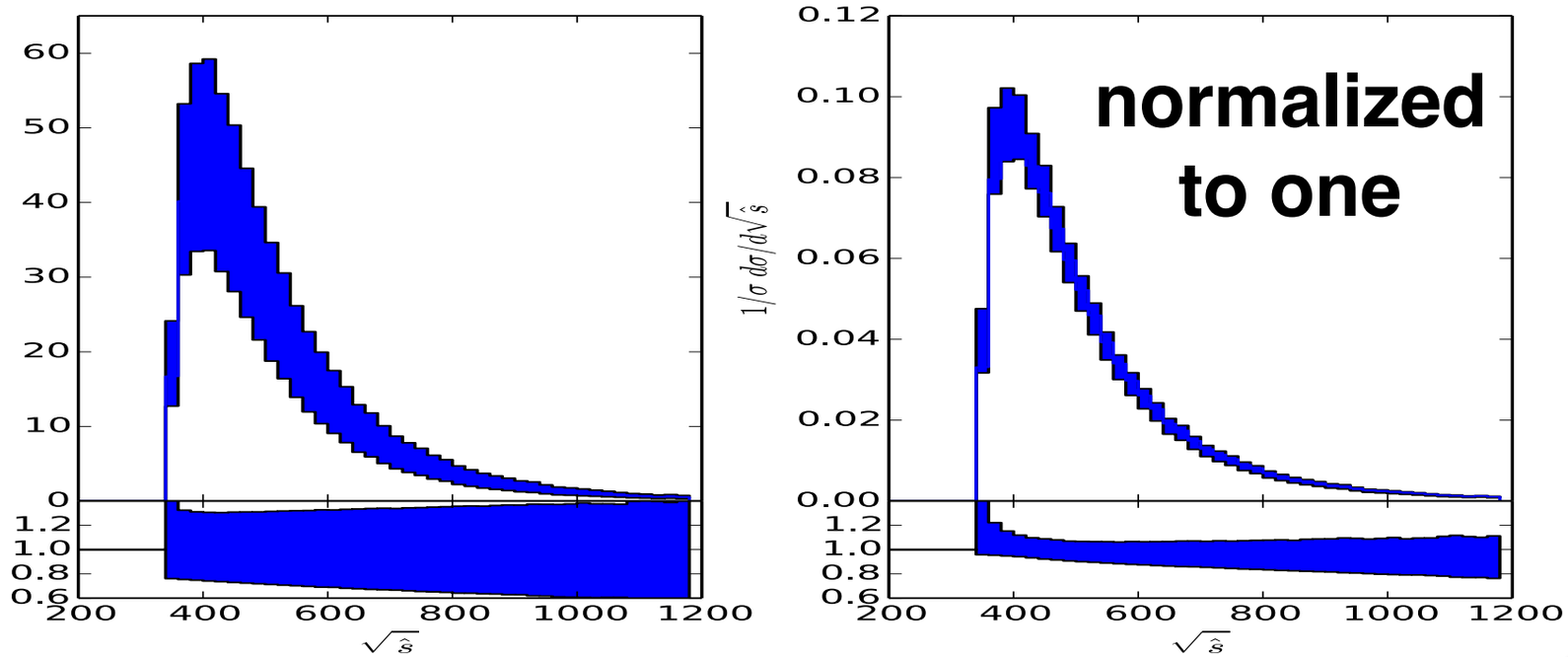
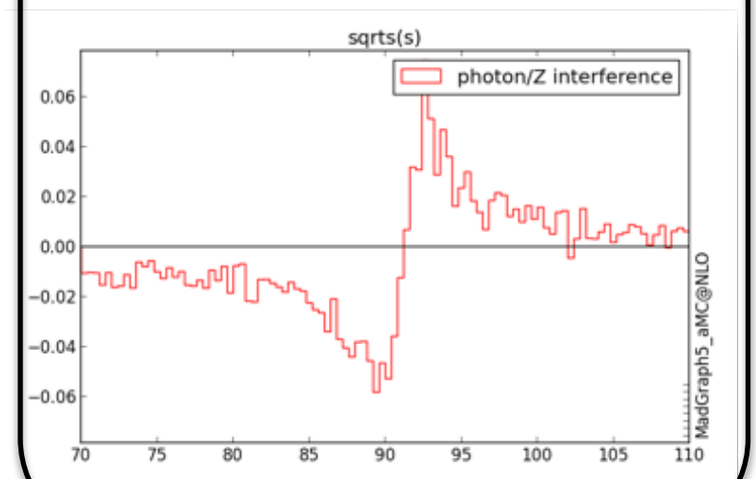
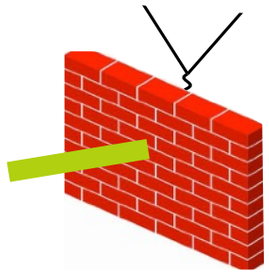


Interference



Plugin



Interface

MAD Analysis 5

BSM re-weighting

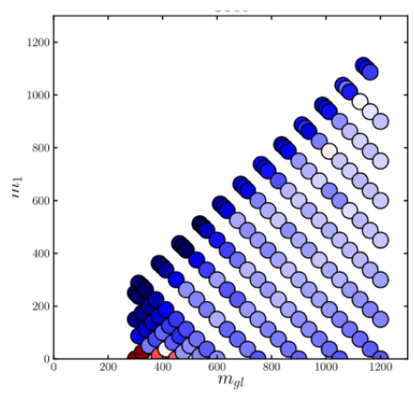
$$|M_{new}|^2 / |M_{old}|^2$$

LO Feature

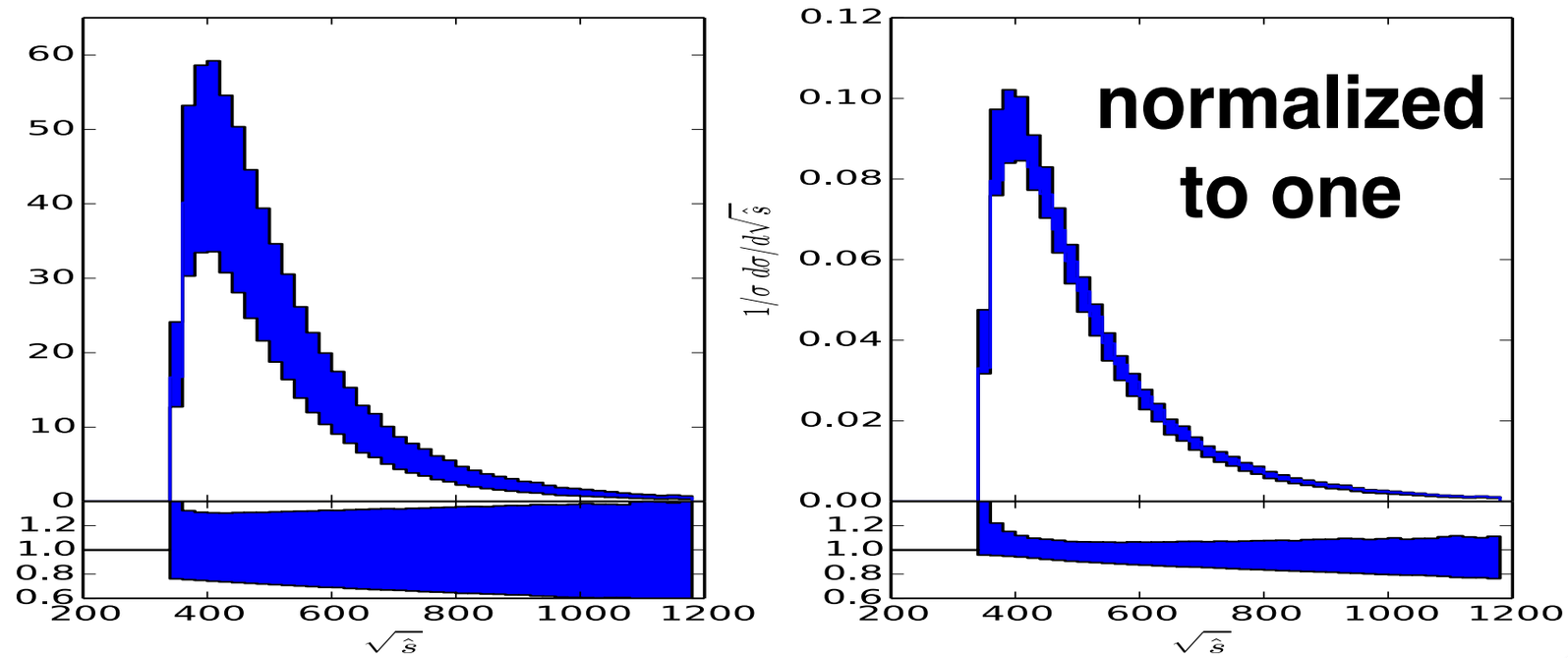
Auto-Width

$$\Gamma = ?$$

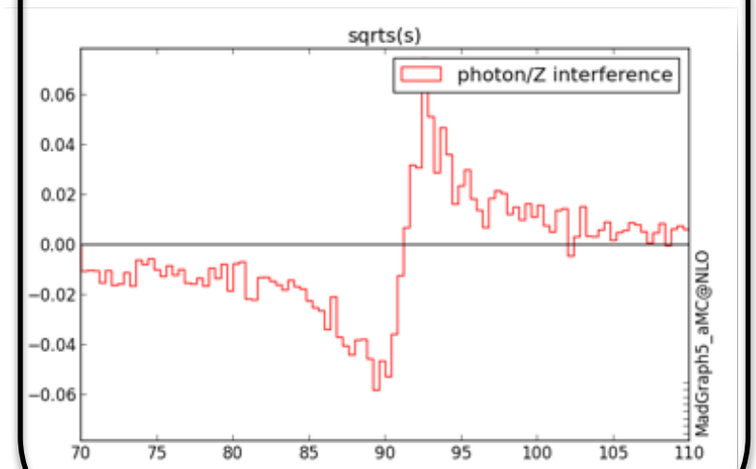
Parameter scan



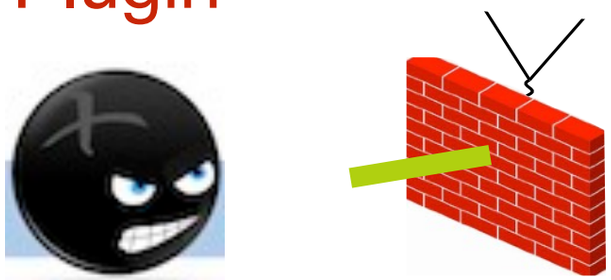
Systematics



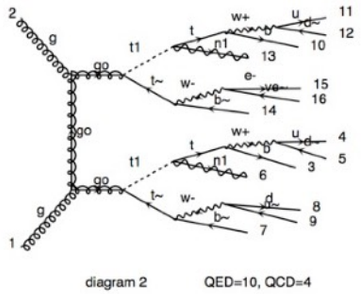
Interference



Plugin



Narrow-width



Interface

MAD Analysis 5

BSM re-weighting

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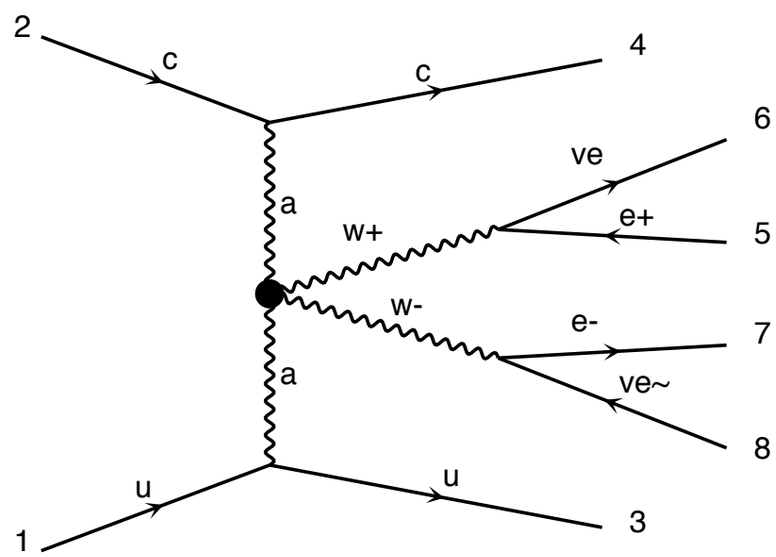
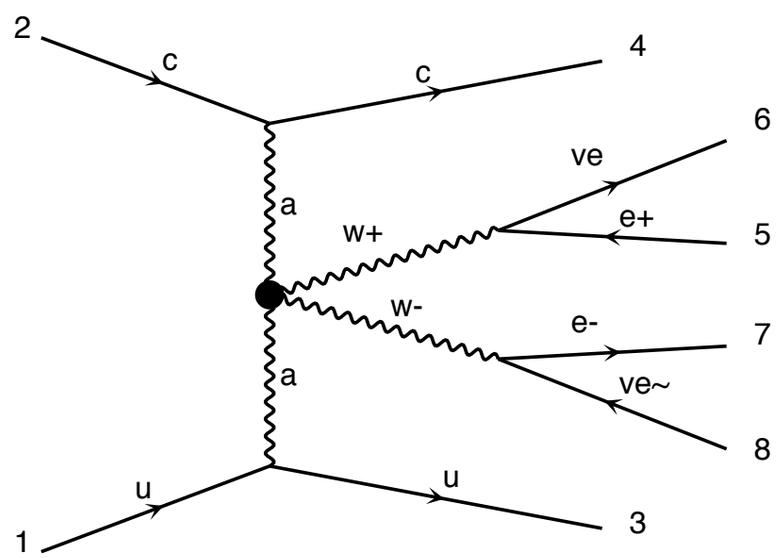
Decay

Resonant Diagram

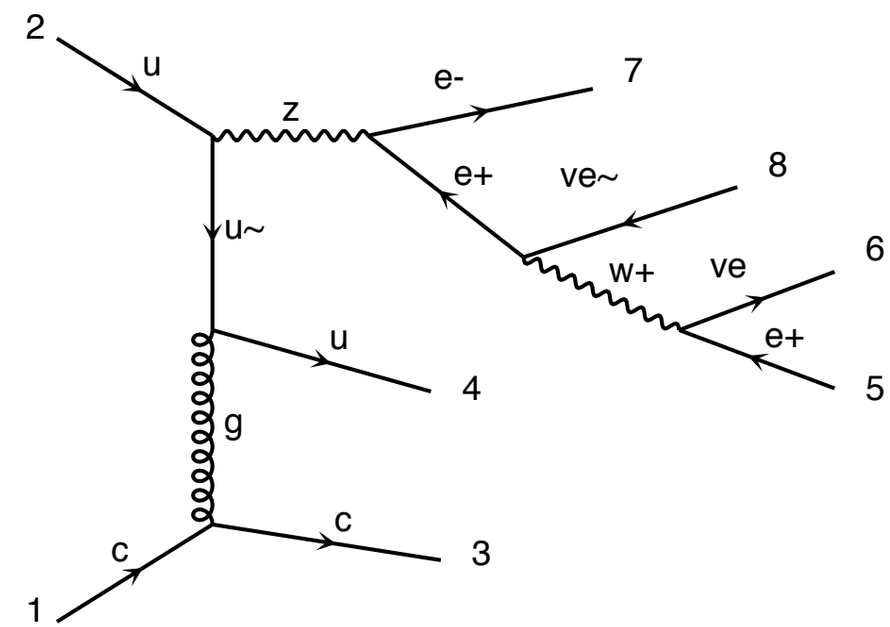


Decay

Resonant Diagram



Non Resonant Diagram



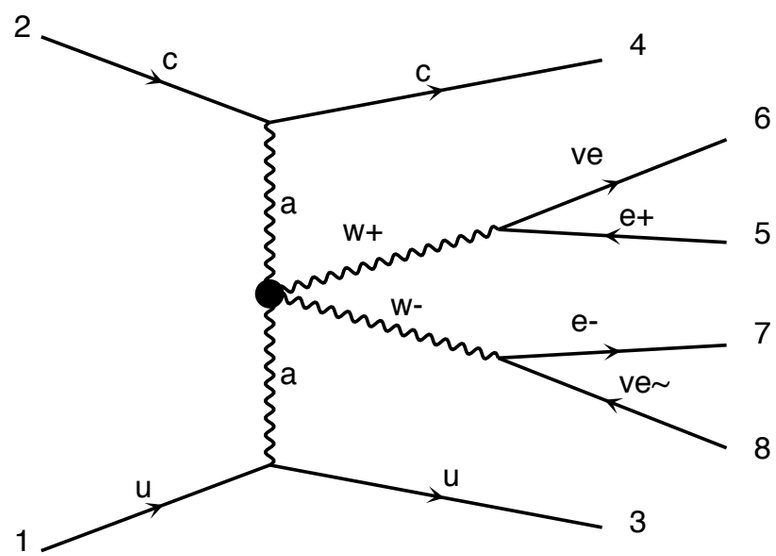
Problem

- Process complicated to have the full process

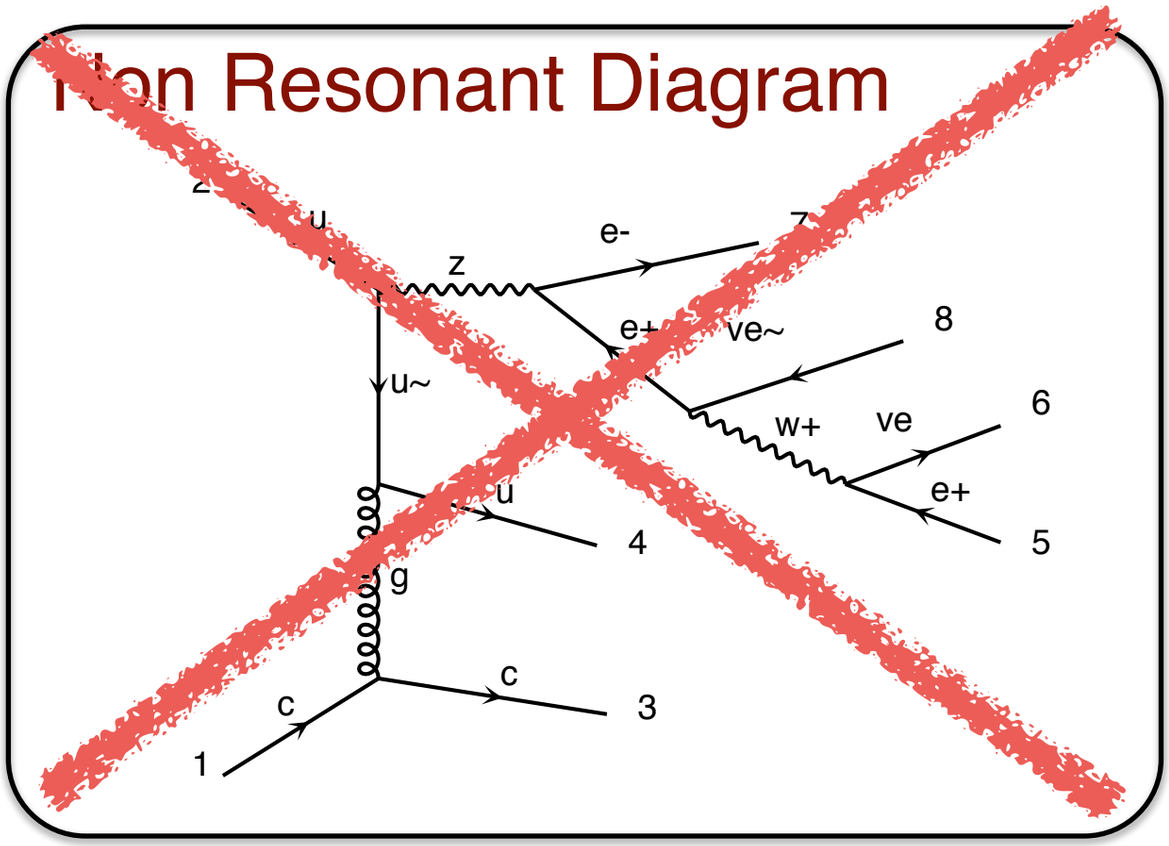
➡Including off-shell contribution

Decay

Resonant Diagram



Non Resonant Diagram



Problem

- Process complicated to have the full process

➡Including off-shell contribution

Solution

- Only keep on-shell contribution

Narrow-Width Approx.

Theory

$$\int dq^2 \left| \frac{1}{q^2 - M^2 - iM\Gamma} \right|^2 \approx \frac{\pi}{M\Gamma}\, \delta(q^2 - M^2)$$

$$\sigma_{full} = \sigma_{prod} * (BR + \mathcal{O}(\frac{\Gamma}{M}))$$

Comment

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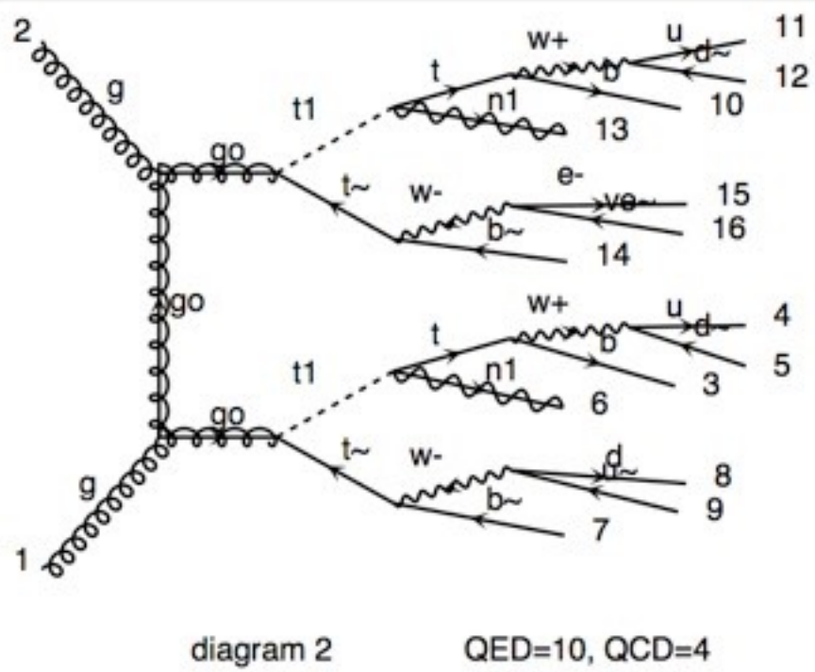
$$\sigma_{full} = \sigma_{prod} * (BR + \mathcal{O}(\frac{\Gamma}{M}))$$

Comment

- This is an Approximation!
- This force the particle to be on-shell!
  - Recover by re-introducing the Breit-wigner up-to a cut-off

Decay chain

- p p > t t~ w+, (t > w+ b, w+ > l+ vl), \
  (t~ > w- b~, w- > j j), \
  w+ > l+ vl



very long
decay chains possible to simulate
directly in MadGraph!

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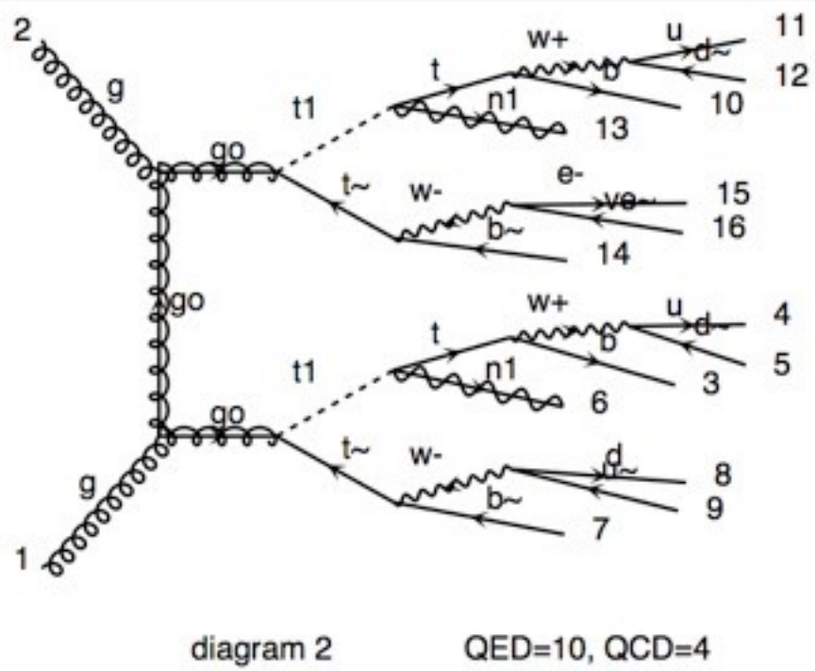
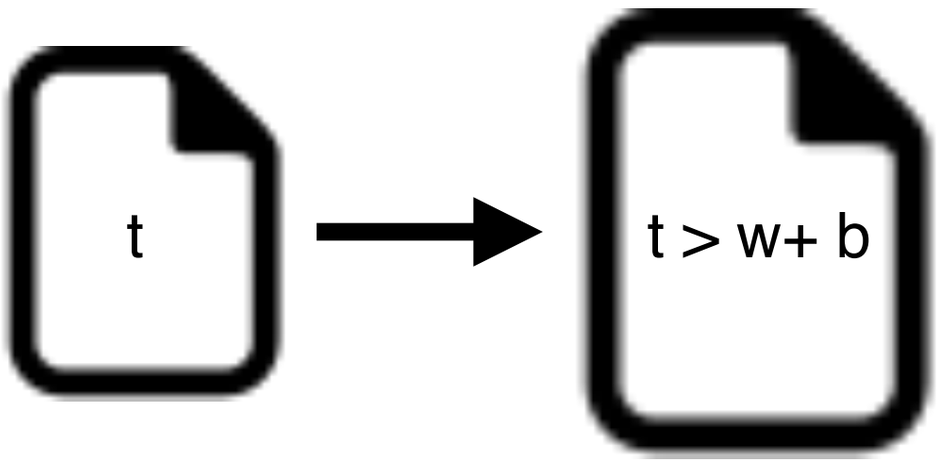


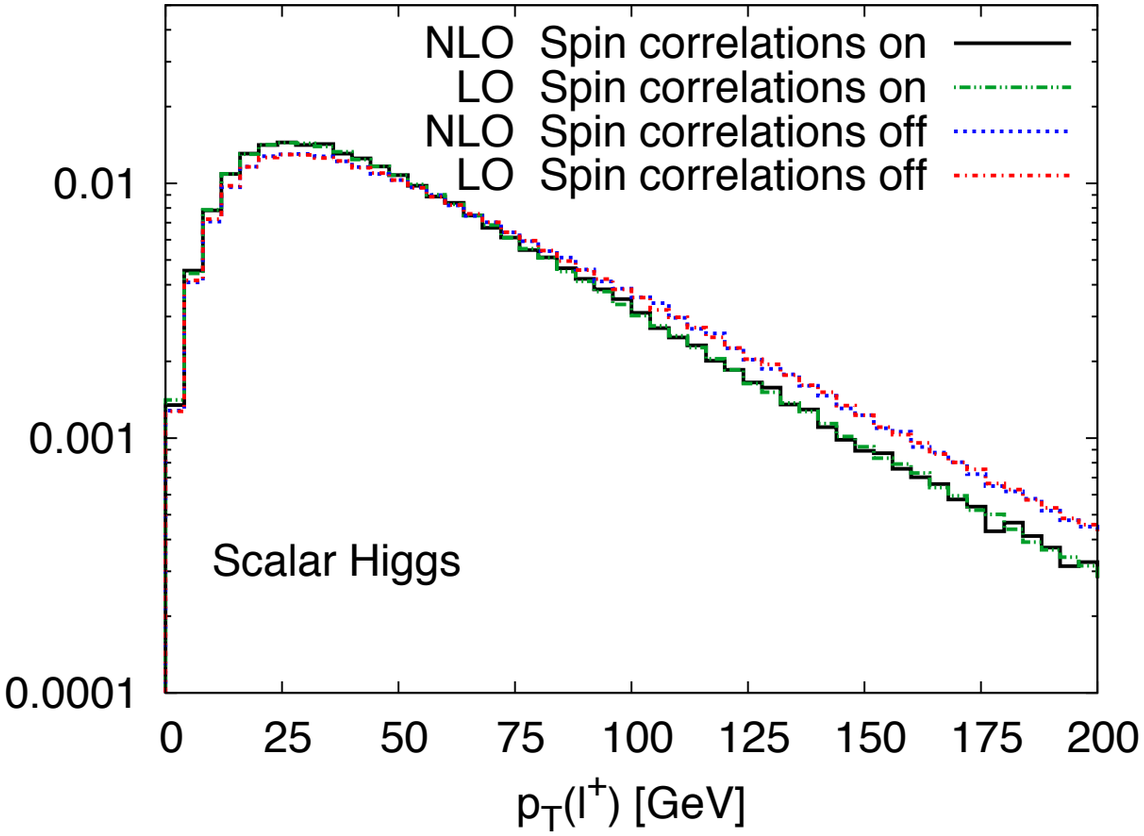
very long
decay chains possible to simulate
directly in MadGraph!

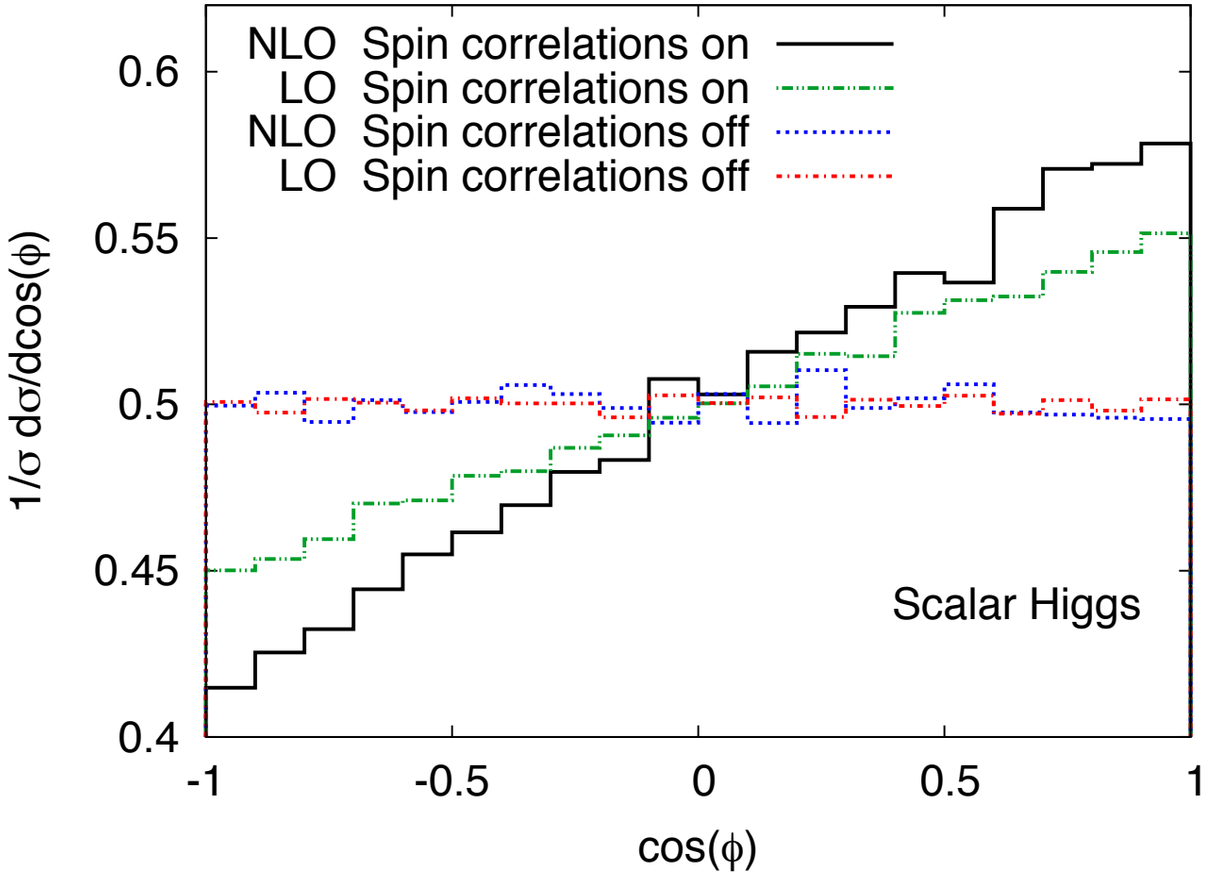
- Full spin-correlation
- Off-shell effects (up to cut-off)
- NWA not used for the cross-section

MadSpin

Decay as post-processing
- Independently of event generation
- But same accuracy (spin-correlation)
- Use NWA for cross-section



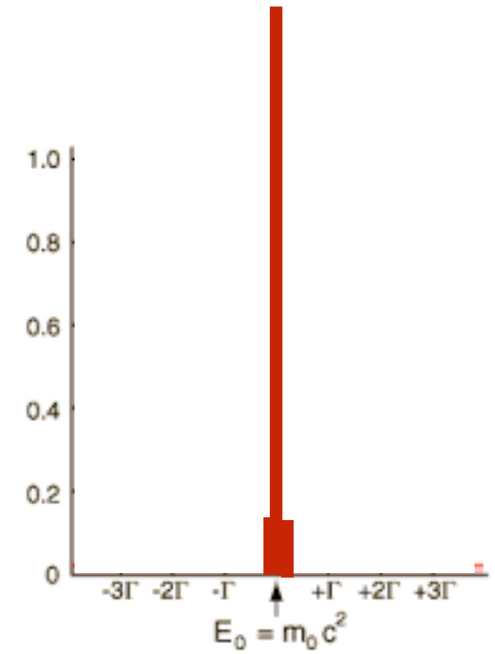




Very small width

$\Gamma < 10^{-8} M$

- Slows down the code
- Can lead to numerical instability



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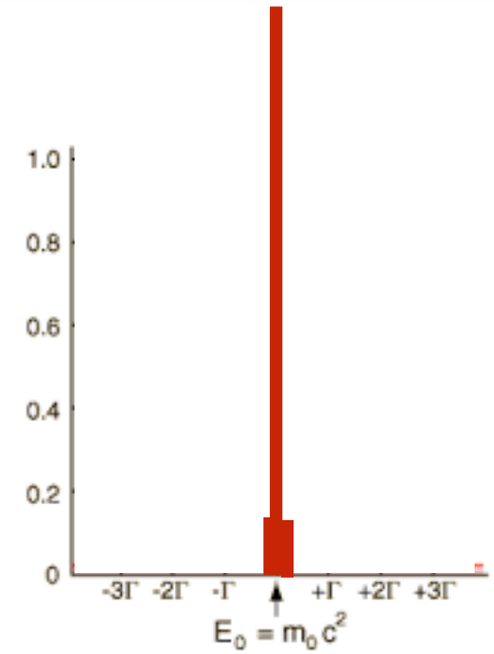
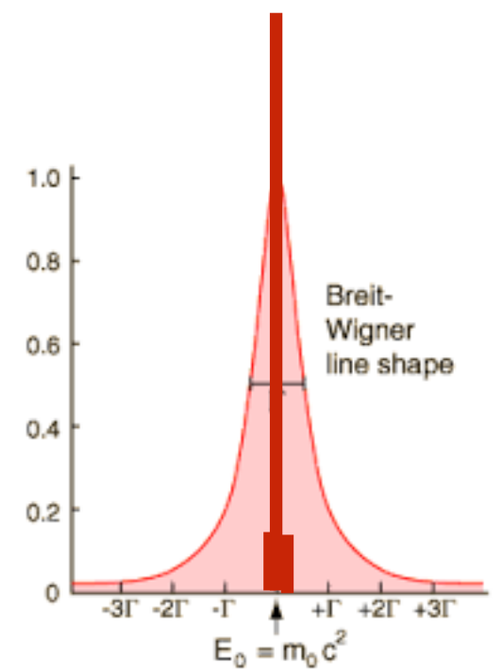


Solution

- Use a Fake-Width for the evaluation of the matrix-element
- Correct cross-section according to NWA formula $\frac{\Gamma_{fake}}{\Gamma_{true}}$



What to remember

- Analytical computation can be slower than numerical method
- Any BSM model are supported (at LO)
- Phase Space integration are slow
  - need knowledge of the function
  - cuts can be problematic
- Event generation are from free.
- All this are automated in MG5_aMC@NLO
- Important to know the physical hypothesis

Plan

- What is MG5_aMC?
- Details of the computation
  - Evaluation of matrix-element
  - Phase-Space integration
- Tools/functionality of MG5_aMC

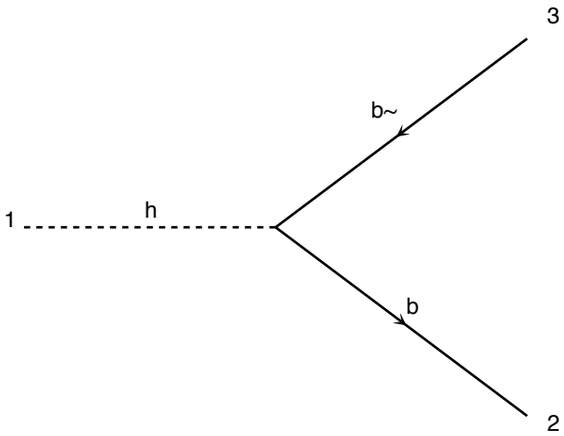
List of package

- SysCalc (computation of systematics)
- MadWidth (computation of width in NWA)
- MadSpin (decay with full spin-correlation)
- Re-Weighting (change of the weight of an event)
- Shower / Detector Interface
- MadWeight (Matrix-Element Method)
- Interference
- MadAnalysis5
- Tau Decay
- MadDM
- GPU

2-body decay

2 body decay

$$\Gamma = \frac{1}{2MS} \int d\Phi_2 |\mathcal{M}|^2$$



2-body decay

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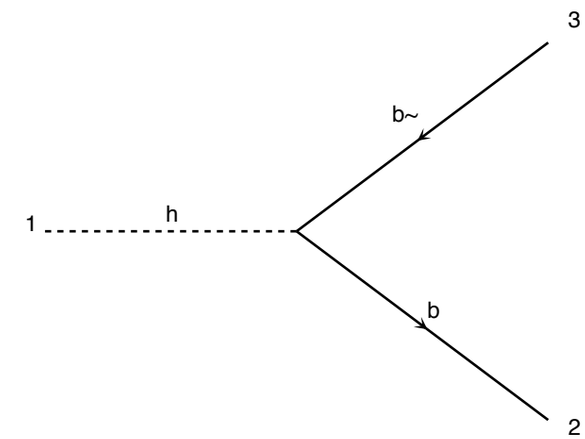

- By Lorentz Invariance the matrix element is constant over the phase-space.

$$\Gamma = \frac{\sqrt{\lambda(M^2, m_1^2, m_2^2)}|\mathcal{M}|^2}{16\pi S M^3}$$

$$\lambda(M^2, m_1^2, m_2^2) = \left(M^2 - m_1^2 - m_2^2\right)^2 - 4m_1^2 m_2^2$$

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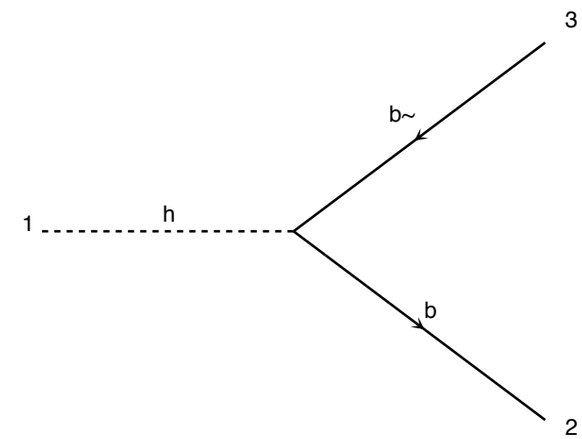

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- Calculable analytically by FeynRules

MadWidth

hep-ph/1402.1178

2-body

- Use FeynRules formula (instateneous)

MadWidth

hep-ph/1402.1178

2-body

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Fast-Estimation of 3-body

- Only use 2-body decay and PS factor

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Relevant?

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Relevant?

No

DONE

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Channel Generation

- Remove Sequence of 2-body/radiation diagram

Relevant?

Maybe

No

DONE

MadWidth

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Channel Generation

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DONE

Estimation of 3-body

- Based on the diagram. Approx. PS/Matrix-Element

Relevant?

MadWidth

hep-ph/1402.1178

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Maybe

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hep-ph/1402.1178

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Maybe

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DONE

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Estimation of 3-body

- Based on the diagram. Approx. PS/Matrix-Element

Relevant?

Yes?

Numerical Integration

MadWidth

hep-ph/1402.1178

2-body

- Use FeynRules formula (instateneous)

Fast-Estimation of 4 body

- Only use 2-body decay and PS factor

Relevant?

No

Maybe

Channel Generation

- Remove Sequence of 2-body/radiation diagram

DONE

No

Estimation of 4 body

- Based on the diagram. Approx. PS/Matrix-Element

Relevant?

Yes?

Numerical Integration

MadWidth

Limitation

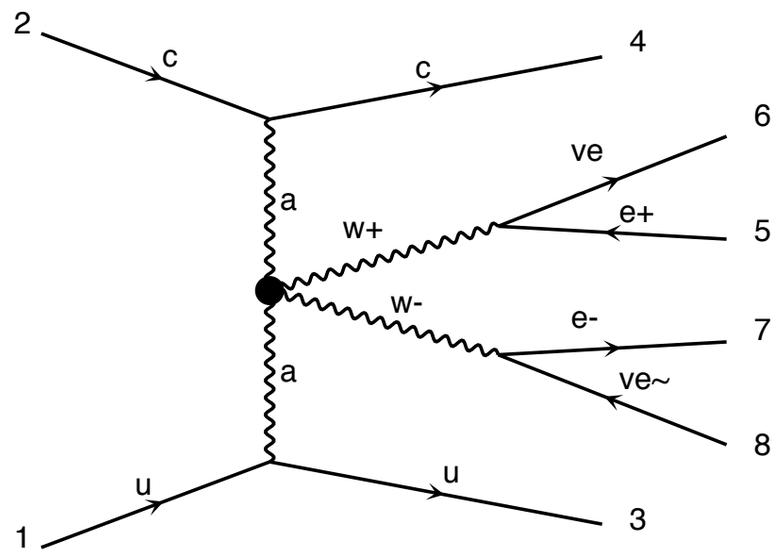
- Only LO
- No Loop Induced Decay
- Valid in Narrow-width approximation
- No hadronization effect

Lesson

- Be aware of code limitation
- Quite often those are not checked.

Decay

Resonant Diagram



Decay

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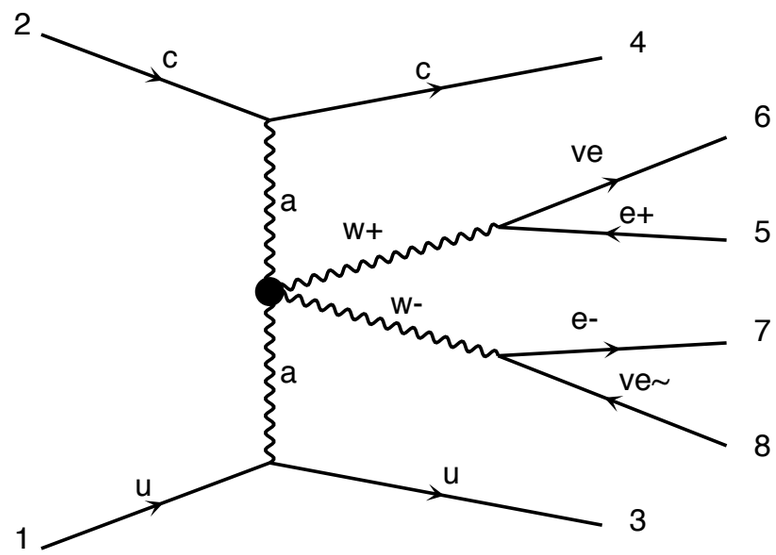
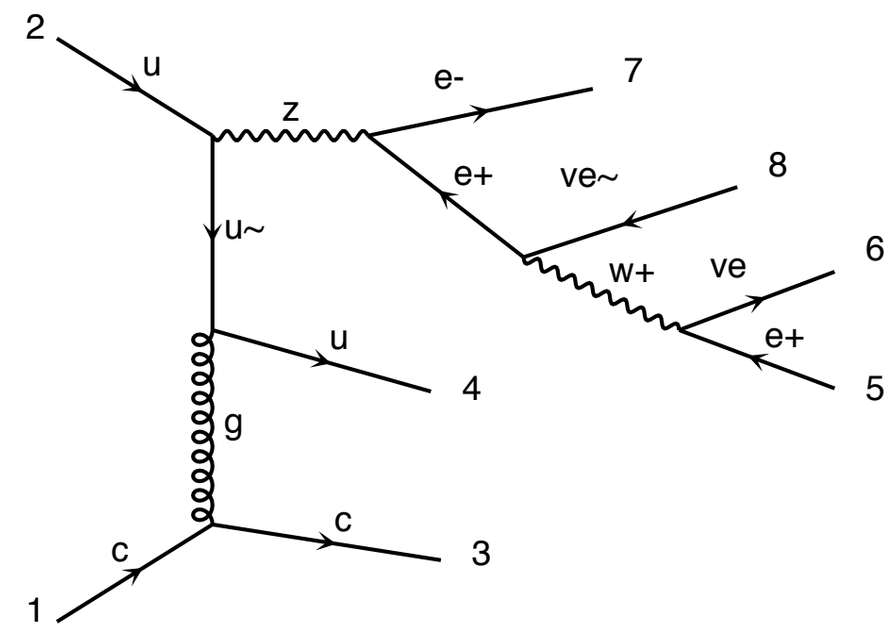


Non Resonant Diagram



Problem

- Process too complicated to compute all the Feynman Diagram

Decay

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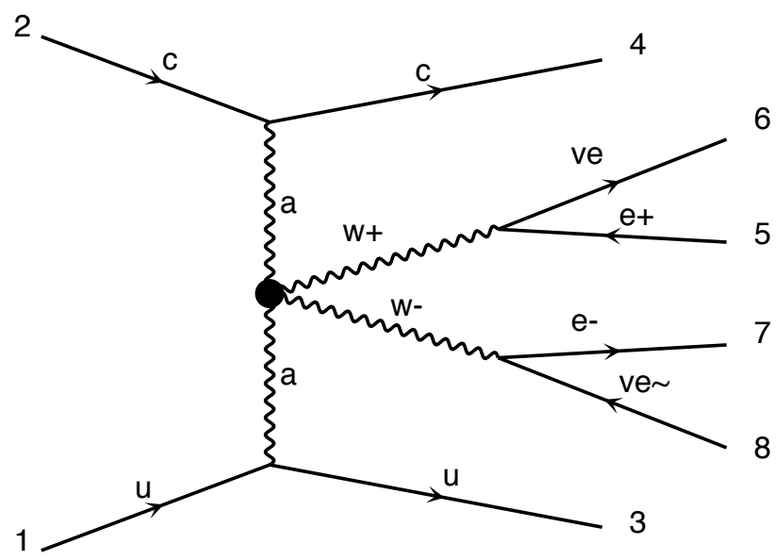
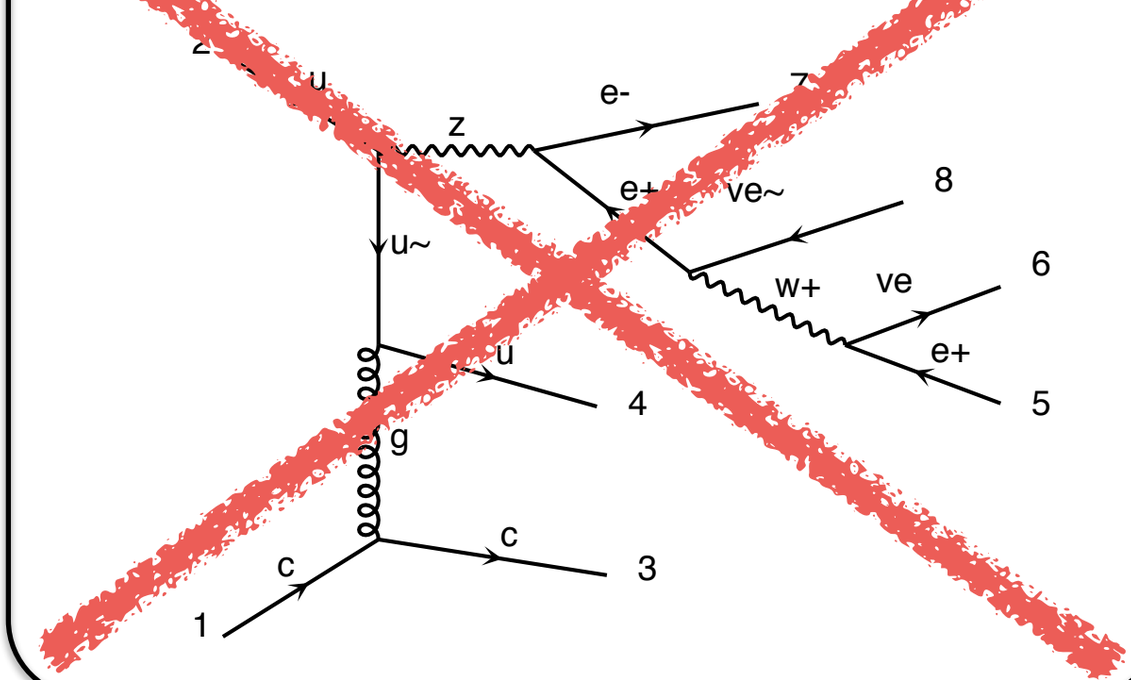


Non Resonant Diagram



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- This is an Approximation!
- This force the particle to be on-shell!
  - Recover by re-introducing the Breit-wigner up-to a cut-off

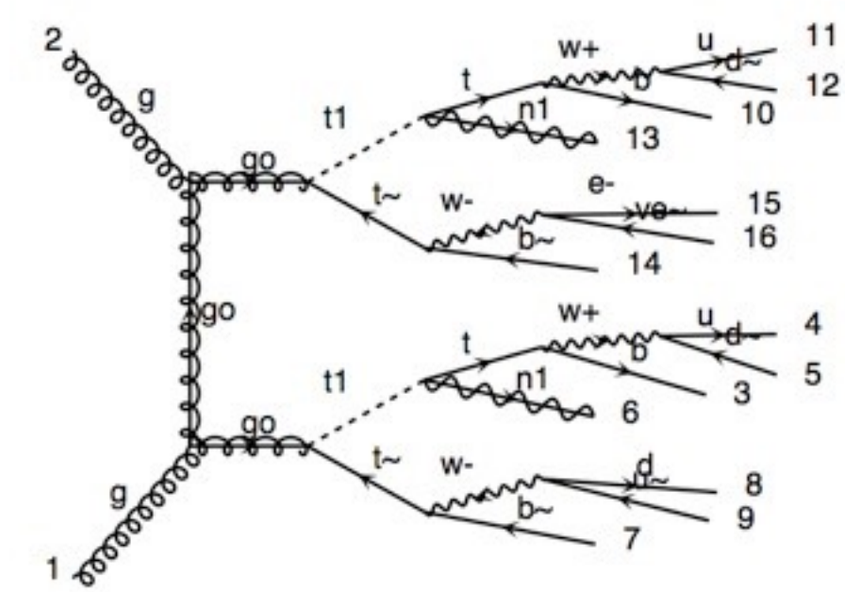
Decay chains

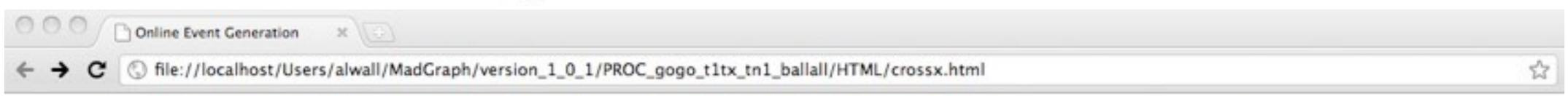
- p p > t t~ w+, (t > w+ b, w+ > l+ vl), \
  (t~ > w- b~, w- > j j), \
  w+ > l+ vl
- Separately generate core process and each decay
  - Decays generated with the decaying particle as resulting wavefunction
- Iteratively combine decays and core processes
- Difficulty: Multiple diagrams in decays

Decay chains

- Decay chains retain full matrix element for the diagrams compatible with the decay
- Full spin correlations (within and between decays)
- Full width effects
- However, no interference with non-resonant diagrams
  - ➡ Description only valid close to pole mass
  - ➡ Cutoff at $|m \pm n\Gamma|$ where n is set in run_card.

Decay chains





Results for g g > go go , (go > t1 t~ , t~ > b~ all all / h+ , (t1 > t n1 , t > b all all / h+)) in the mssm

Available Results

Links	Events	Tag	Run	Collider	Cross section (pb)	Events
results banner	Parton-level LHE	fermi	test	p p 7000 x 7000 GeV	.33857E-03	10000

Main Page

Thanks to developments in MadEvent, also (very) long decay chains possible to simulate directly in MadGraph!

MadSpin

[Artoisenet, OM et al. 1212.3460]

[Frixione, Leanen, Motylinski,Webber (2007)]

One Event

offshell	spin	unweighted
No	No	YES

MadSpin

[Artoisenet, OM et al. 1212.3460]

[Frixione, Leanen, Motylinski,Webber (2007)]

One Event

- smear the mass
- flat decay

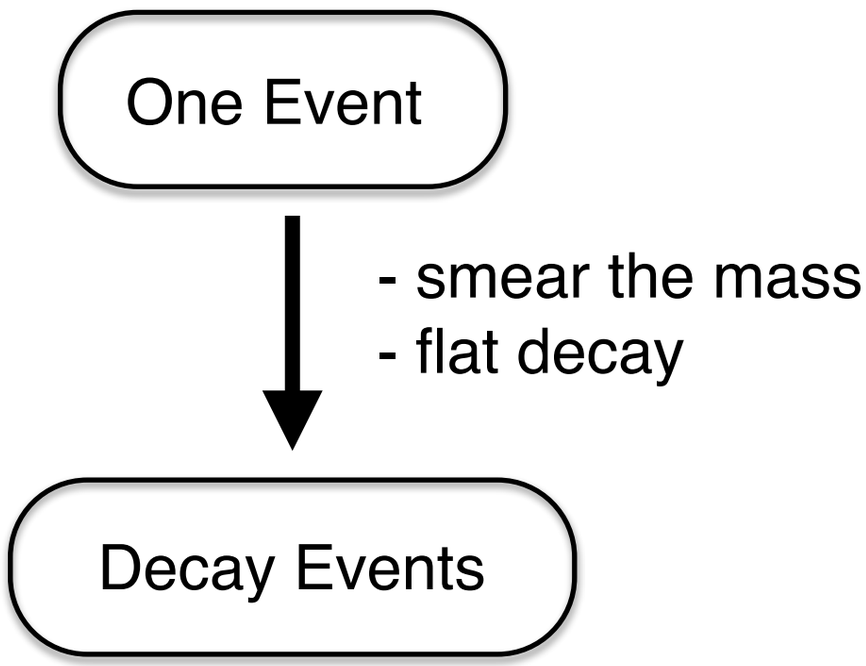
Decay Events

offshell	spin	unweighted
No	No	YES

MadSpin

[Artoisenet, OM et al. 1212.3460]

[Frixione, Leanen, Motylinski,Webber (2007)]

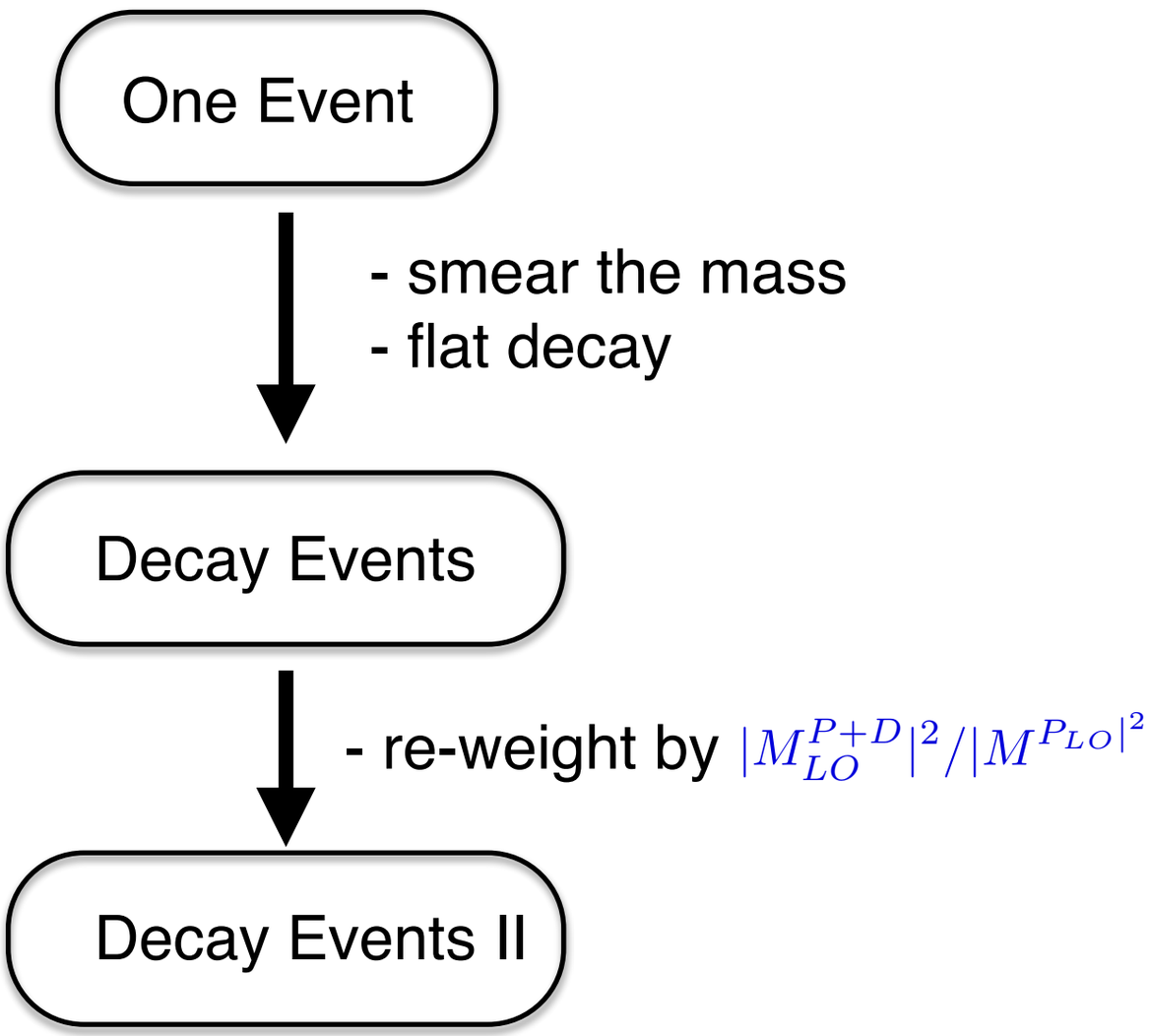


offshell	spin	unweighted
No	No	YES
YES	No	No

MadSpin

[Artoisenet, OM et al. 1212.3460]

[Frixione, Leanen, Motylinski,Webber (2007)]

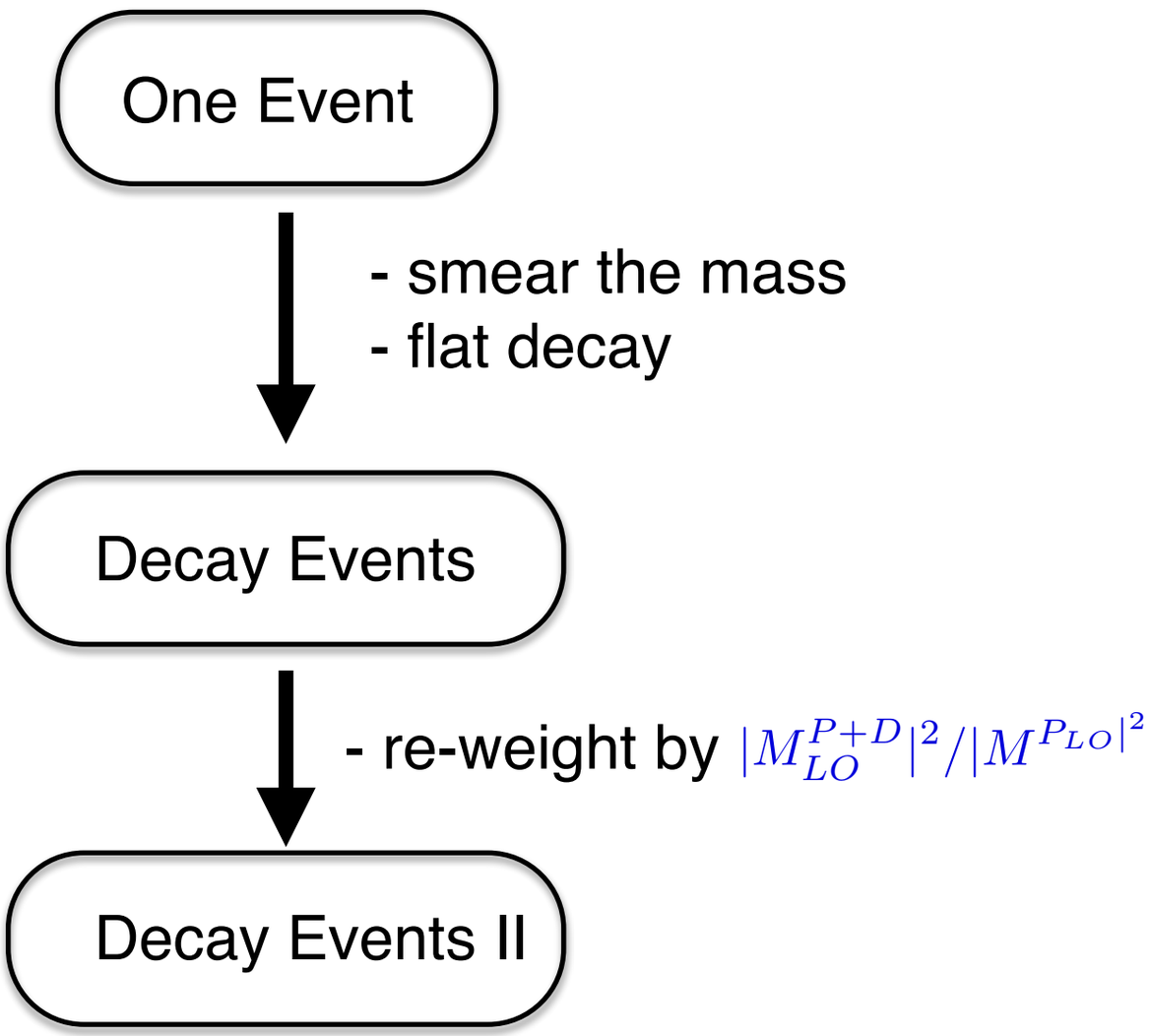


offshell	spin	unweighted
No	No	YES
YES	No	No

MadSpin

[Artoisenet, OM et al. 1212.3460]

[Frixione, Leanen, Motylinski,Webber (2007)]

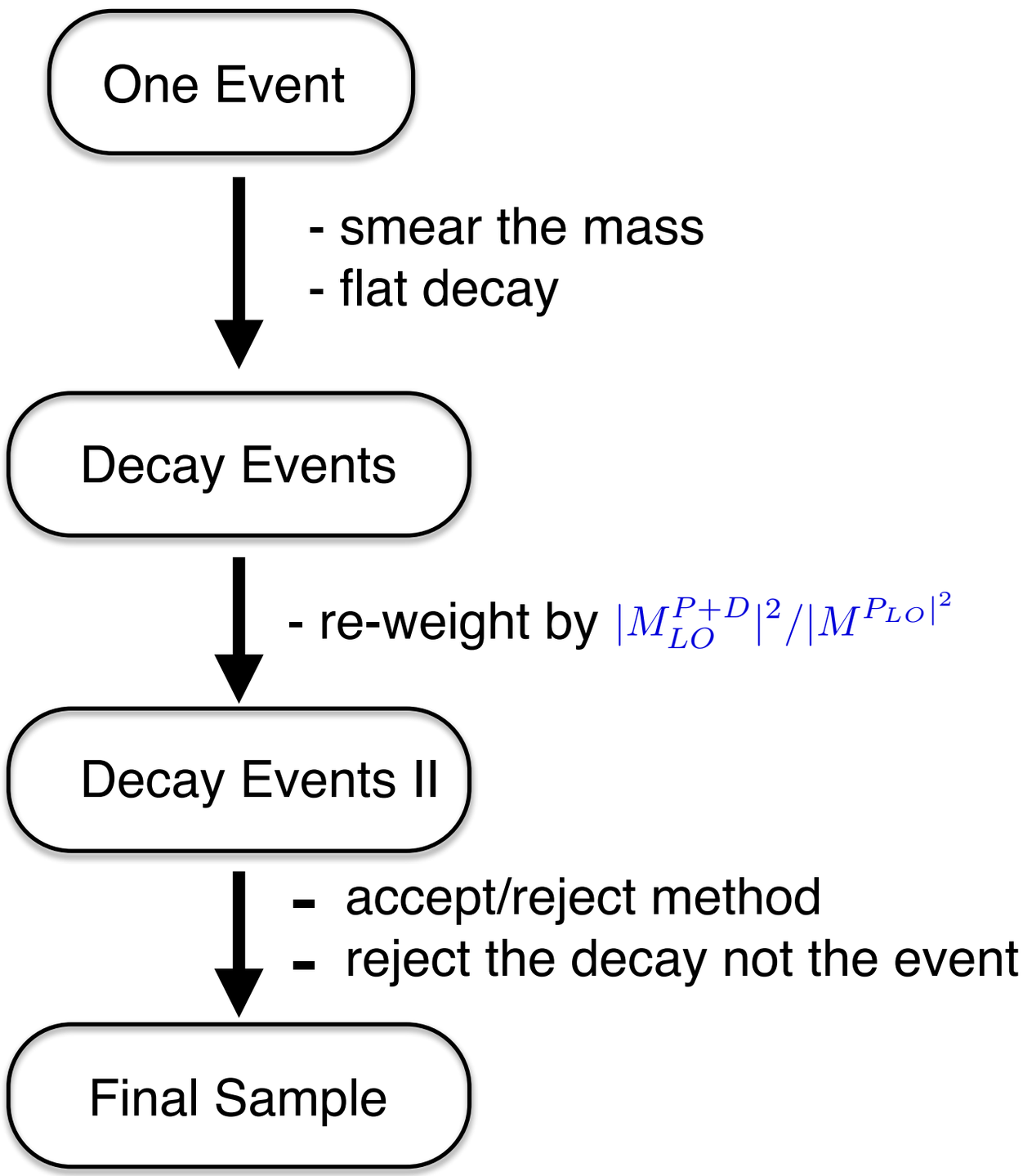


offshell	spin	unweighted
No	No	YES
YES	No	No
YES	YES	No

MadSpin

[Artoisenet, OM et al. 1212.3460]

[Frixione, Leanen, Motylinski,Webber (2007)]

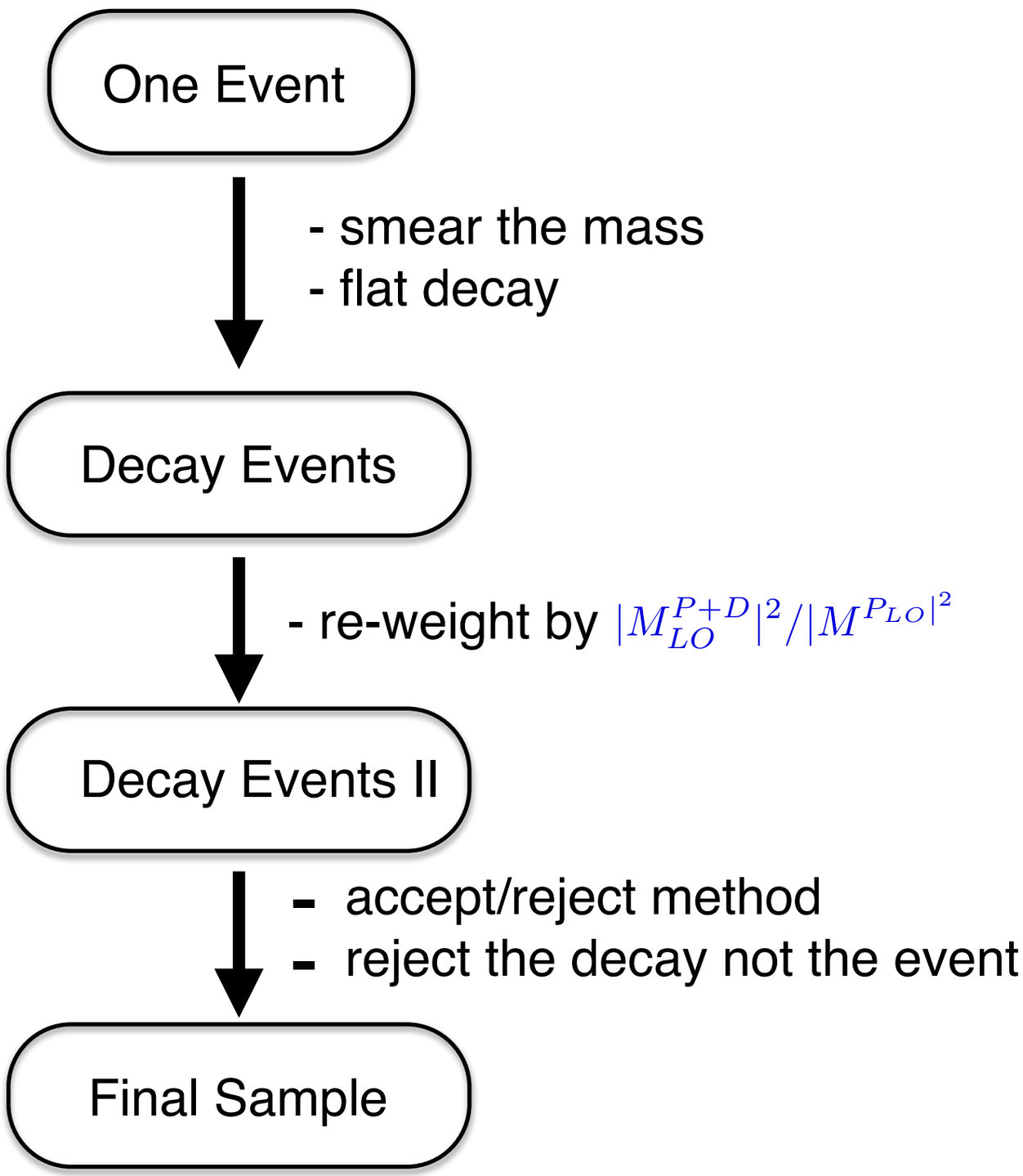


offshell	spin	unweighted
No	No	YES
YES	No	No
YES	YES	No

MadSpin

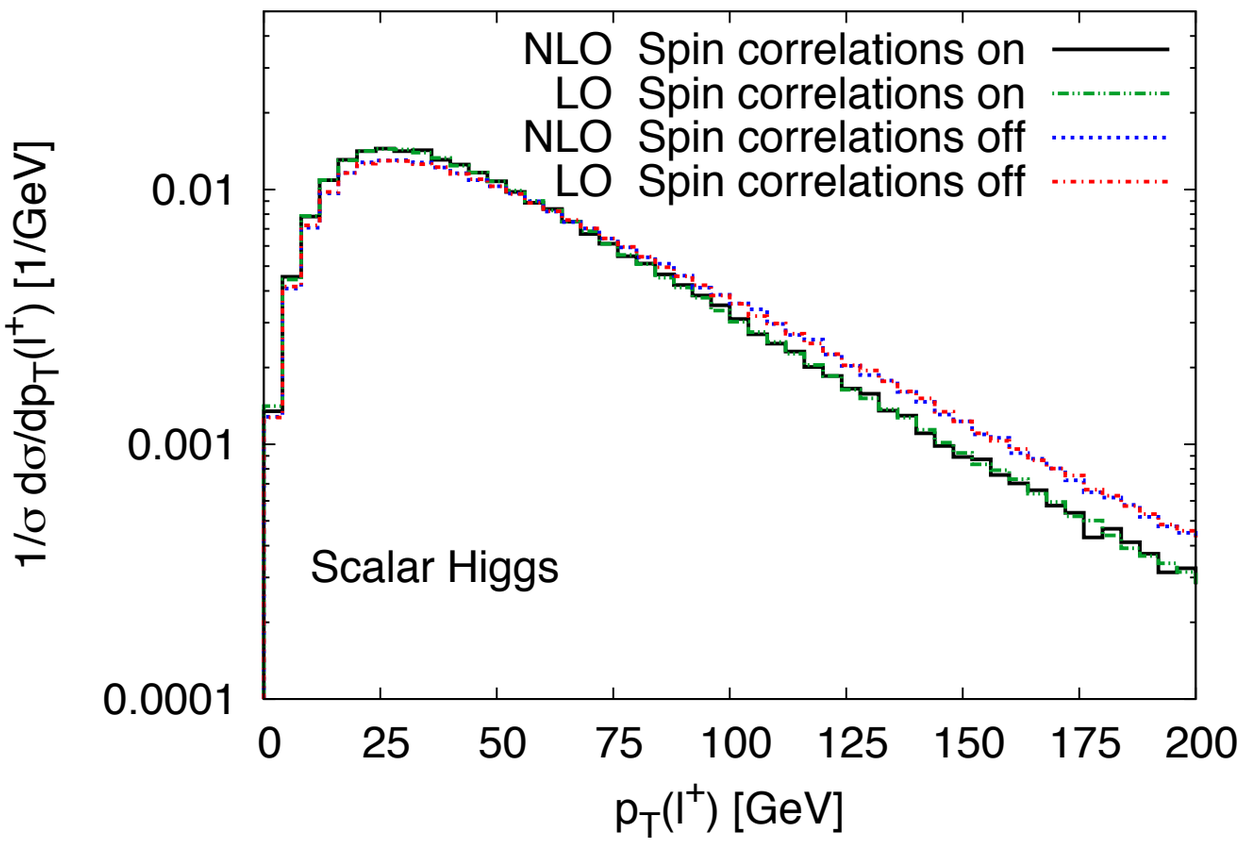
[Artoisenet, OM et al. 1212.3460]

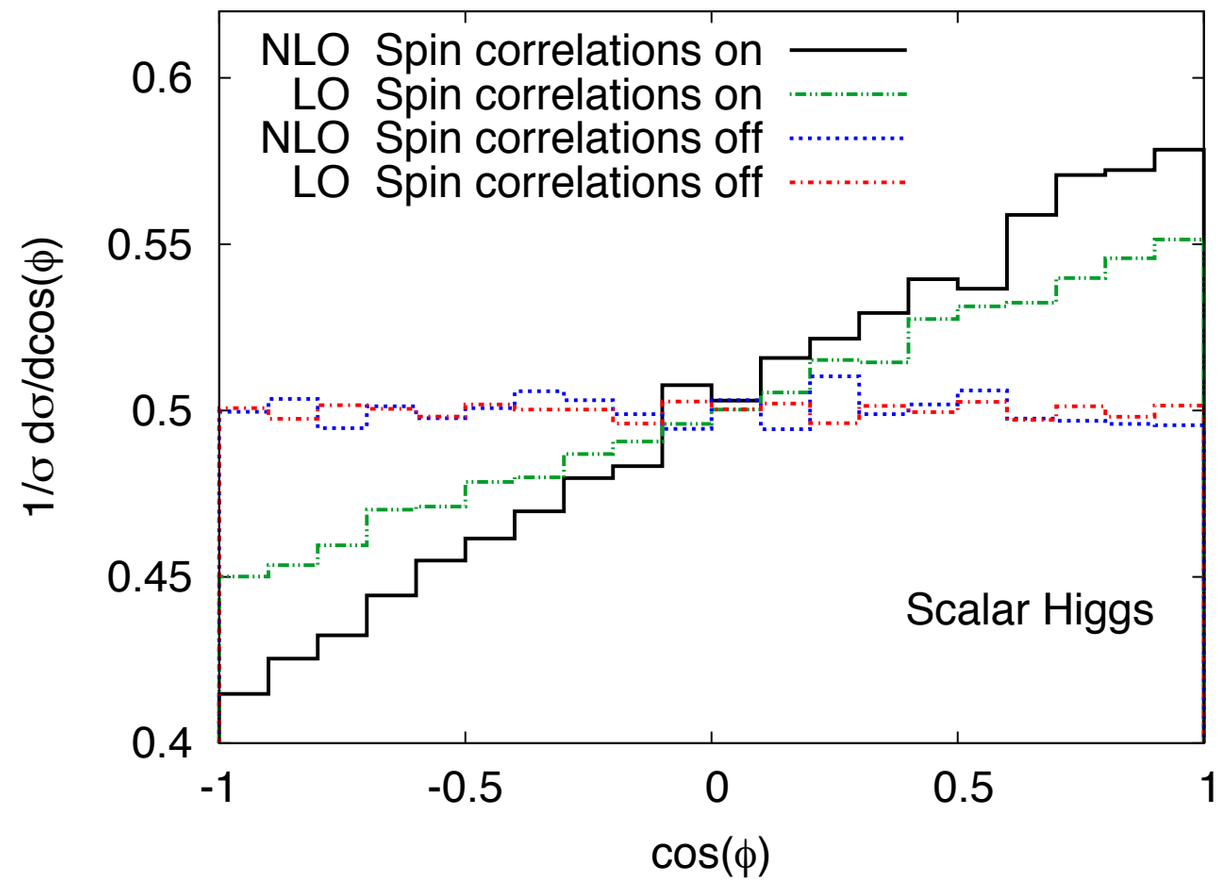
[Frixione, Leanen, Motylinski,Webber (2007)]



offshell	spin	unweighted
No	No	YES
YES	No	No
YES	YES	No
YES	YES	YES

TTH Example


NLO Spin correlations on
LO Spin correlations on
NLO Spin correlations off
LO Spin correlations off
Scalar Higgs
0.01
0.001
0.0001
0
25
50
75
100
125
150
175
200
$p_T(l^+)$ [GeV]
$1/\sigma\ d\sigma/dp_T(l^+)$ [1/GeV]


NLO Spin correlations on
LO Spin correlations on
NLO Spin correlations off
LO Spin correlations off
Scalar Higgs
0.6
0.55
0.5
0.45
0.4
-1
-0.5
0
0.5
1
$\cos(\phi)$
$1/\sigma\ d\sigma/d\cos(\phi)$

Tutorial

Olivier Mattelaer
IPPP/Durham

Tutorial map

Learning MG5

- follow the built-in tutorial
- cards meaning
- meaning of QCD/QED
- details of syntax ($/)
- script
- width computation
- decay chain

BSM CASE

- check the model
- width computation
- signal generation
  - decay chain
- merging sample generation
- background/NLO generation

Learning MG5_aMC

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?

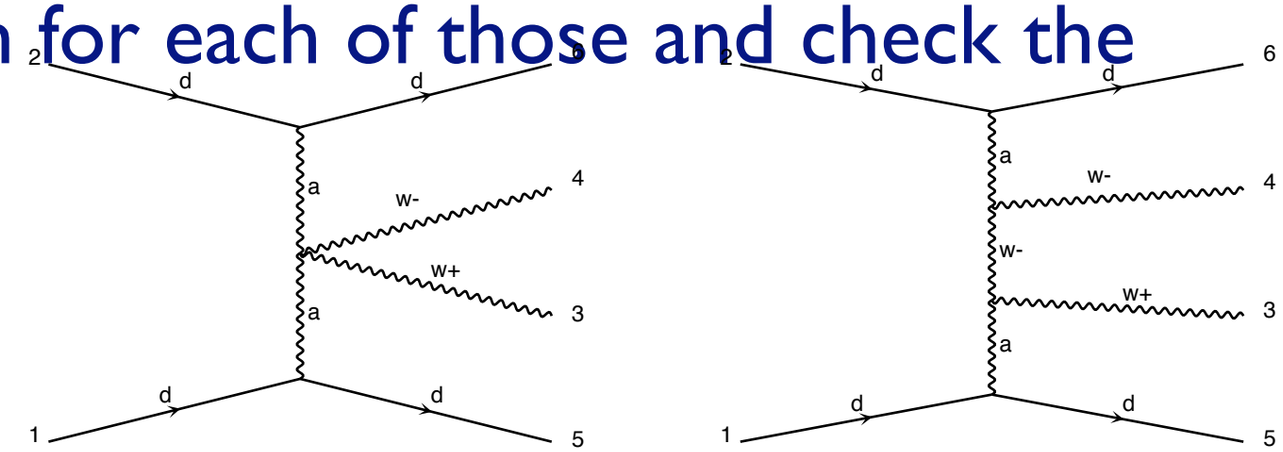
- Read the Cards and identify what they do
  - ➡ param_card: model parameters
  - ➡ run_card: beam/run parameters and cuts
- https://answers.launchpad.net/madgraph5/+faq/2014

Exercise II: Cards Meaning

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

Exercise II : Syntax

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



- Generate VBF process

Exercise III: Syntax

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

Hint :To plot automatically distributions:
mg5> install MadAnalysis

- Use the invariant mass distribution to determine the

Exercise IV: Automation/Width

- Compute the cross-section for the top pair production for 3 different mass points.
  - ➡ Do NOT use the interactive interface
    - 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. (run ./bin/mg5 PATH_TO_FILE)

Examples

File:

```
import model EWDim6
generate p p > z z
ouput TUTO_DIM6
launch
  set nevents 5000
  set MZ 100
```

How to Run:

```
./bin/mg5_amc PATH
```

Exercise V: Decay Chain

- Generate p p > t t~ h, fully decayed (fully leptonic decay for the top)
  - ➡ Using the decay-chain formalism
  - ➡ Using MadSpin
- Compare cross-section
  - ➡ which one is the correct one?
  - ➡ Why are they different?
- Compare the shape.

BSM Tutorial

Exercise I: Check the model validity

- Check the model validity:
  - ➡ check p p > uv uv~
  - ➡ check p p > ev ev~
  - ➡ check p p > t t~ p1 p2

- This checks
  - ➡ gauge invariance
  - ➡ lorentz invariance
  - ➡ that various way to compute the matrix element provides the same answer

Exercise II: Width computation

- Check with MG the width computed with FR:
  - ➡ generate uv > all all; output; launch
  - ➡ generate ev > all all; output; launch
  - ➡ generate p1 > all all; output; launch
  - ➡ generate p2 > all all; output; launch
- Check with MadWidth
  - ➡ compute_widths uv ev p1 p2
  - ➡ (or Auto in the param_card)

FR Number
0.0706 GeV
0.00497 GeV
0 GeV
0.0224 GeV

- Muv = 400 GeV Mev = 50 GeV λ=0.1
- m1 = 1GeV m2 = 100GeV m12 = 0.5 GeV

Exercise III:

- Compute cross-section and distribution
  - ➡ uv pair production with decay in top and Φ_1/Φ_2 (semi leptonic decay for the top
- Hint: The width of the new physics particles has to be set correctly in the param_card.
  - ➡ You can either use "Auto" arXiv:1402.1178
  - ➡ or use the value computed in exercise 1
- Hint: For sub-decay, you have to put parenthesis:
  - ➡ example:

    p p > t t~ w+, (t > w+ b, w+ >e+ ve), (t~ > b~ w-, w- > j j), w+ > l+ vl

Too Slow?

- Use MadSpin! arXiv:1212.3460
  - ➡ Use Narrow Width Approximation to factorize production and decay
- instead of
  - ➡ p p > t t~ w+, (t > w+ b, w+ >e+ ve), (t~ > b~ w-, w- > j j), w+ > l+ vl
- Do
  - ➡ p p > t t~ w+
- At the question:

```
The following switches determine which programs are run:
 1 Run the pythia shower/hadronization:                    pythia=OFF
 2 Run PGS as detector simulator:                             pgs=OFF
 3 Run Delphes as detector simulator:                     delphes=NOT INSTA
 4 Decay particles with the MadSpin module:               madspin=OFF
 5 Add weight to events based on coupling parameters:    reweight=OFF
  Either type the switch number (1 to 5) to change its default setting,
  or set any switch explicitly (e.g. type 'madspin=ON' at the prompt)
  Type '0', 'auto', 'done' or just press enter when you are done.
 [0, 1, 2, 4, 5, auto, done, pythia=ON, pythia=OFF, ... ][60s to answer]
```

- At the next question edit the madspin_card and define the decay

Exercise IV: generate multiple multiplicity sample for pythia8

- We will do MLM matching
  - ➡ in the run_card.dat ickkw=1
  - ➡ the matching scale (Qcut) will be define in pythia
    - in madgraph we use xqcut which should be smaller than Qcut (but at least 10-20 GeV)

Exercise V: Have Fun

- Simulate Background
- Go to NLO (ask me the model)
- …

Solution Learning MG5_aMC

Exercise II: Cards Meaning

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

Param_card

Run_card

- top mass

```
###################################
## INFORMATION FOR MASS
###################################
Block mass
    6 1.730000e+02 # MT
   23 9.118800e+01 # MZ
   25 1.200000e+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 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
## 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 # [illegible]
  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)))
```

W Mass is an internal parameter!

MG5 didn't use this value!

So you need to change MZ or Gf or alpha_EW

Exercise III: Syntax

- What's the meaning of the order QED/QCD
- What's the difference between
  - ➡ p p > t t~
  - ➡ p p > t t~ QED=2
  - ➡ p p > t t~ QED=0
  - ➡ p p > t t~ QCD^2==2

Solution 1 : Syntax

- What's the meaning of the order QED/QCD
  - ➡ By default MG5 takes the lowest order in QED!
  - ➡ p p > t t~ => p p > t t~ QED=0
  - ➡ p p > t t~ QED=2
    - 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

- QED<=2 is the SAME as QED=2
  - ➡ quite often source of confusion since most of the people use the = syntax
- QCD^2==2
  - ➡ returns the interference between the QCD and the QED diagram

Cross section (pb)
5.455e-17 ± 4.7e-19 ± systematics

Solution I Syntax

- generate p p > w+ w- j j
  - ➡ 76 processes
  - ➡ 1432 diagrams

- 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

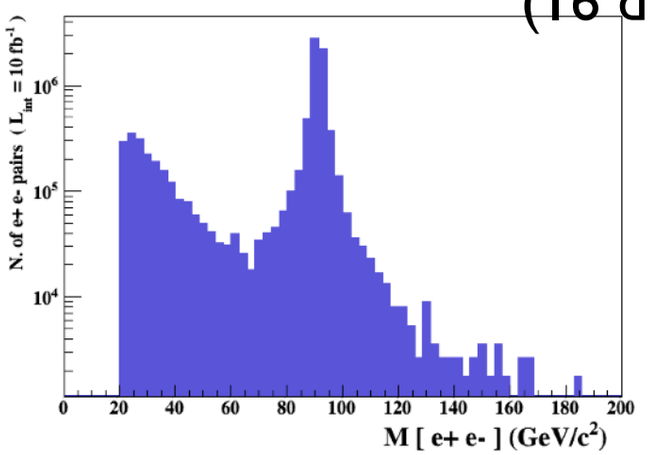
Exercise IV: Syntax

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

Hint :To have automatic distributions:
mg5> install MadAnalysis

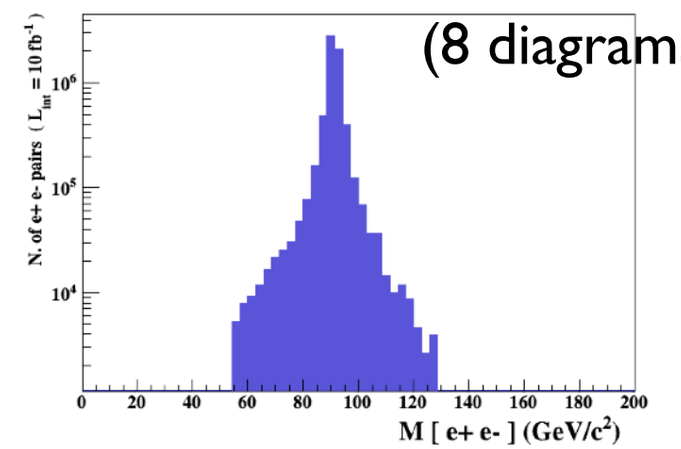
p p > e+ e-

(16 diagrams)



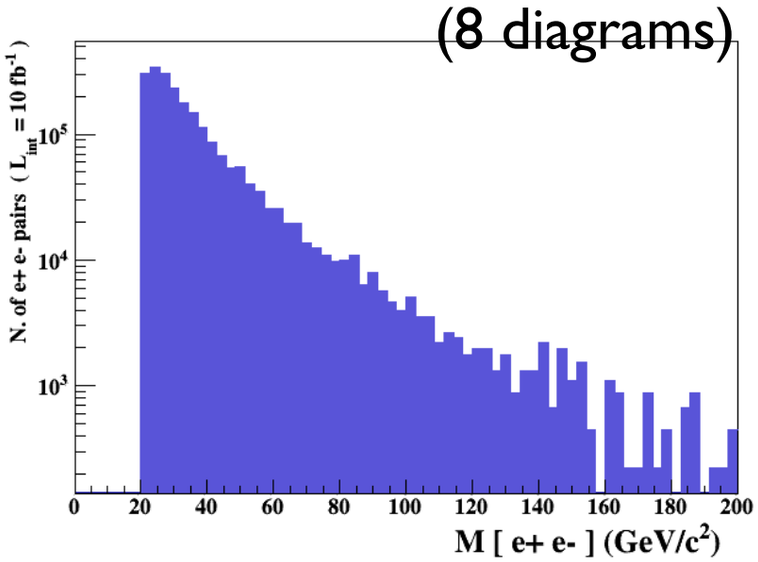
p p >z , z > e+ e-

(8 diagrams)



p p > e+ e- /z

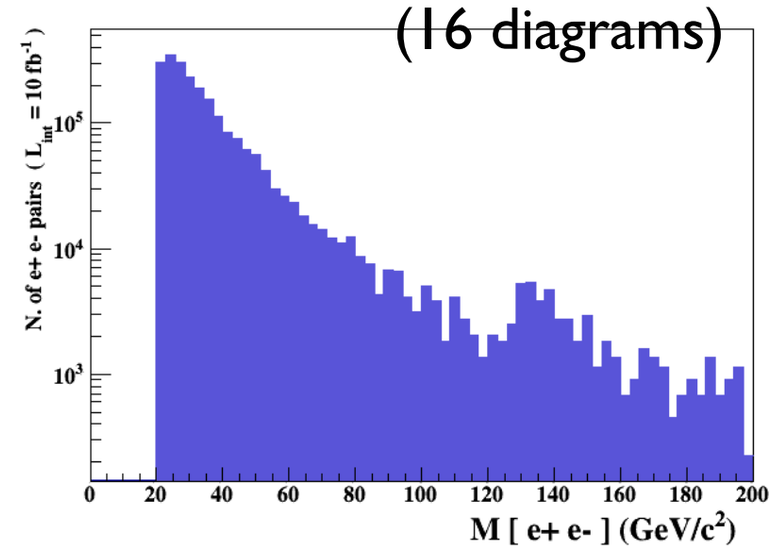
(8 diagrams)



No Z

p p > e+ e- $ z

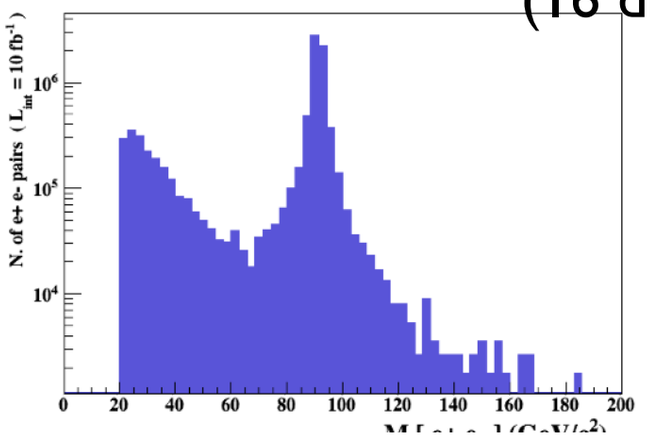
(16 diagrams)



Z- onshell veto

p p > e+ e-

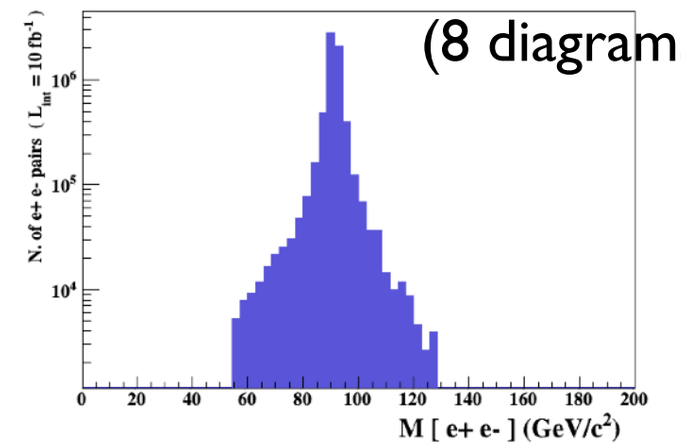
(16 diagrams)



Correct Distribution

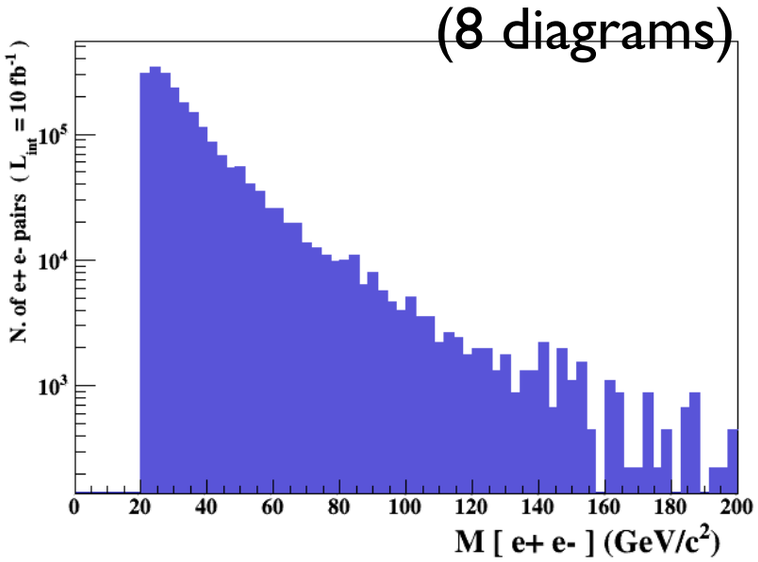
p p >z , z > e+ e-

(8 diagrams)



p p > e+ e- /z

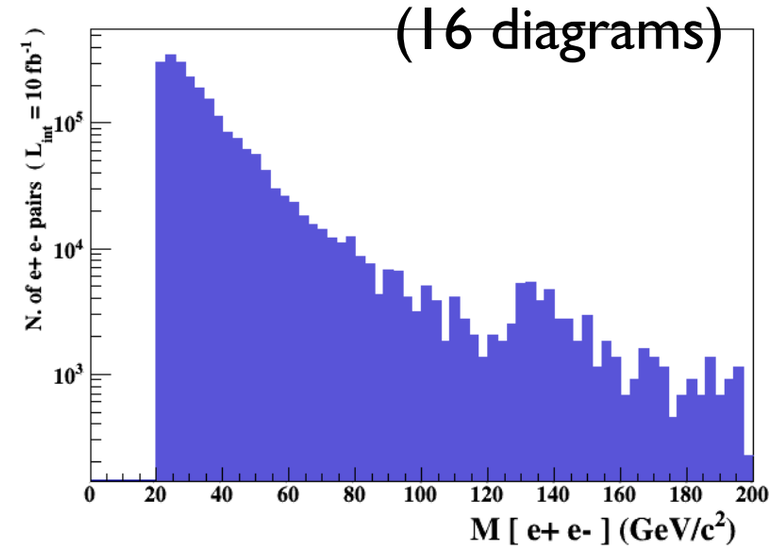
(8 diagrams)



No Z

p p > e+ e- $ z

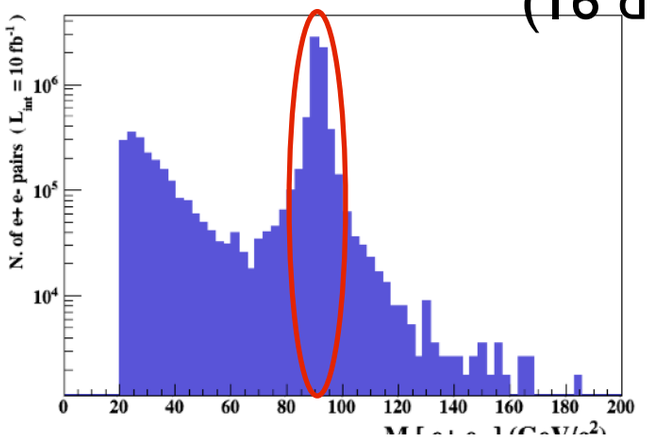
(16 diagrams)



Z- onshell veto

p p > e+ e-

(16 diagrams)

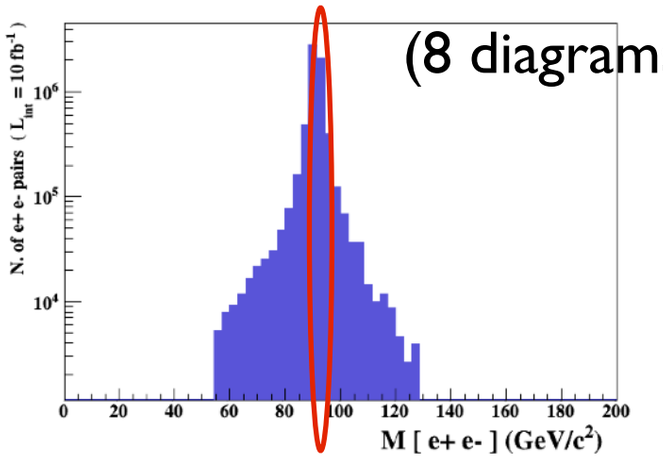


Correct Distribution

Z Peak

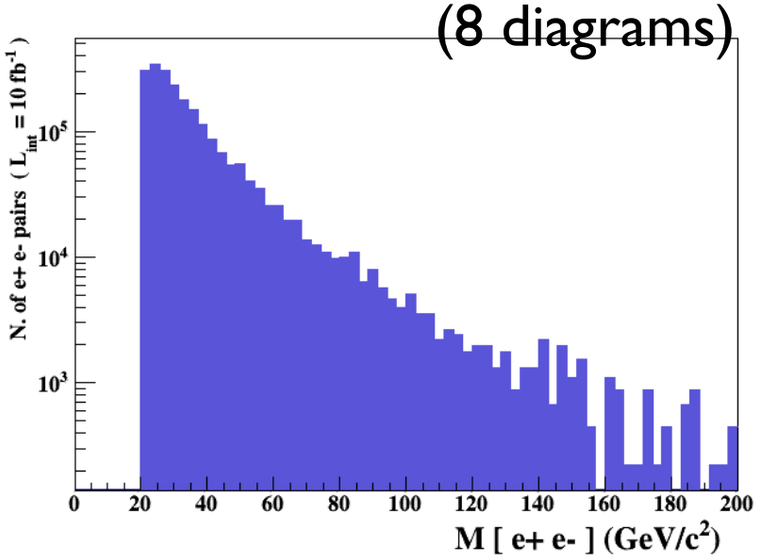
p p >z , z > e+ e-

(8 diagrams)



p p > e+ e- /z

(8 diagrams)

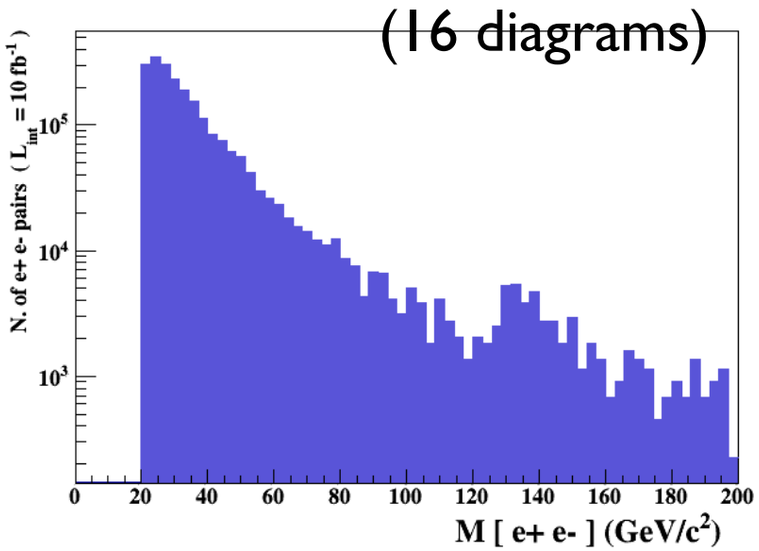


No Z

NO Z Peak

p p > e+ e- $ z

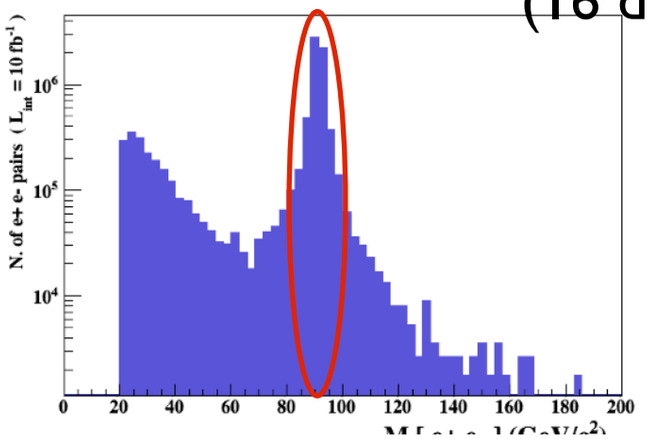
(16 diagrams)



Z- onshell veto

p p > e+ e-

(16 diagrams)

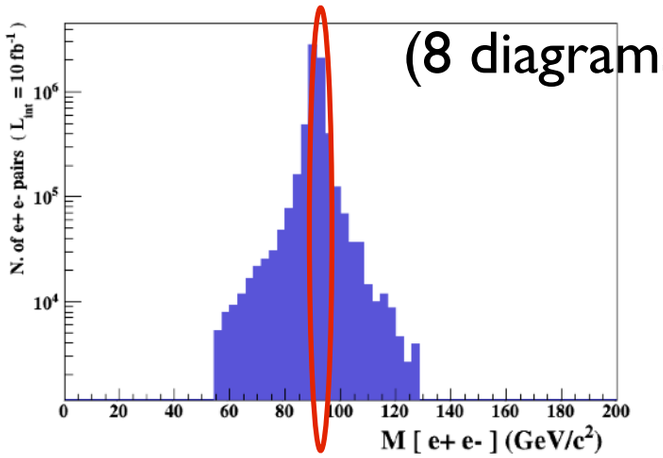


Correct Distribution

Z Peak

p p >z , z > e+ e-

(8 diagrams)

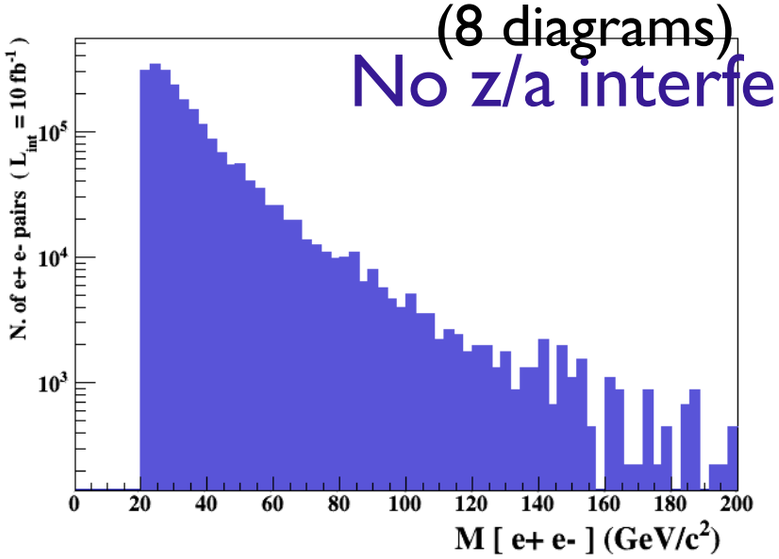


p p > e+ e- /z

(8 diagrams)

No z/a interference

NO Z Peak

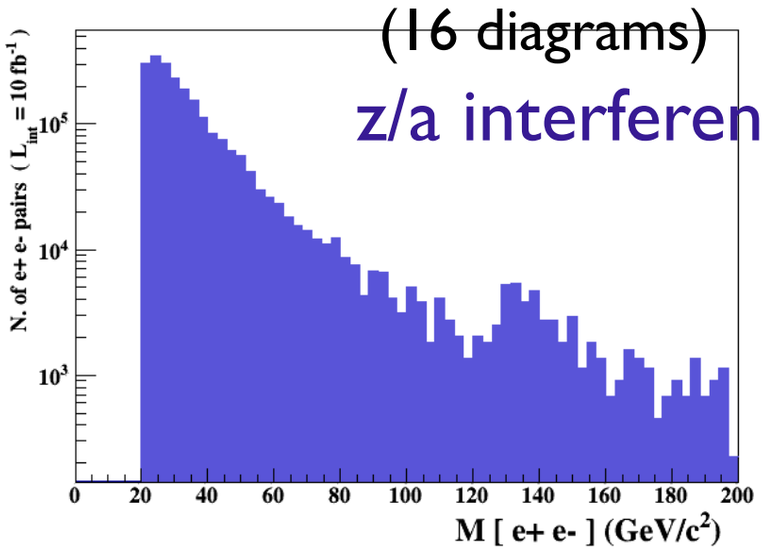


No Z

p p > e+ e- $ z

(16 diagrams)

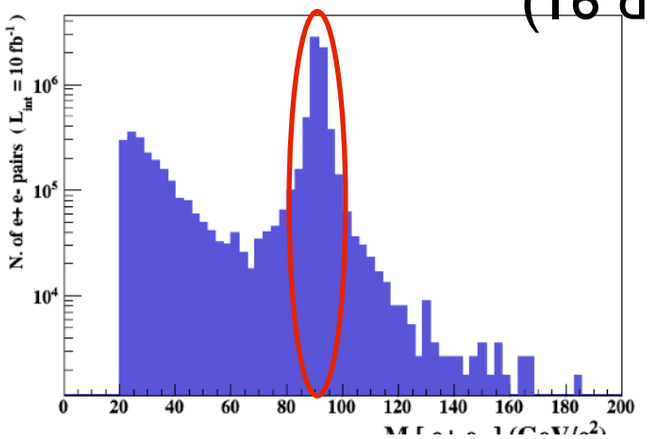
z/a interference



Z- onshell veto

p p > e+ e-

(16 diagrams)

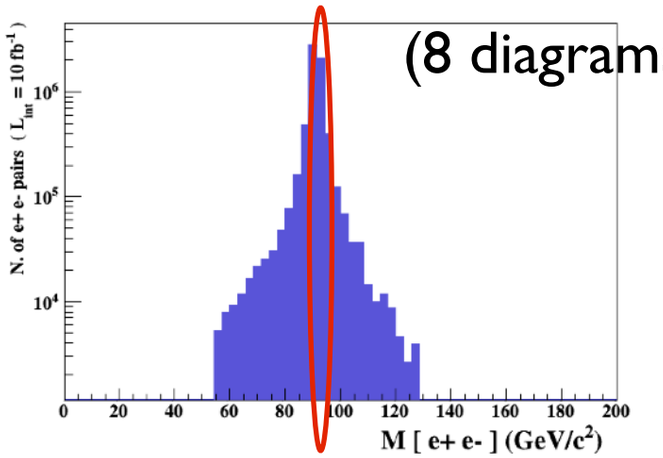


Correct Distribution

Z Peak

p p >z , z > e+ e-

(8 diagrams)



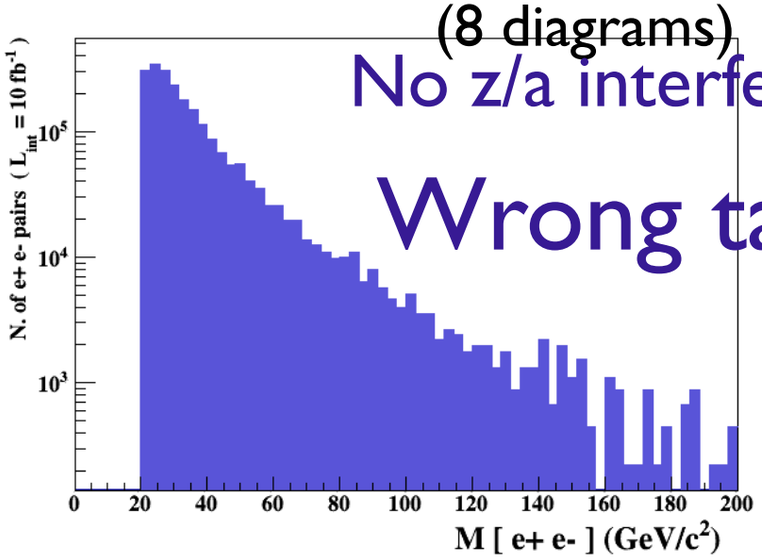
p p > e+ e- /z

(8 diagrams)

NO Z Peak

No z/a interference

Wrong tail



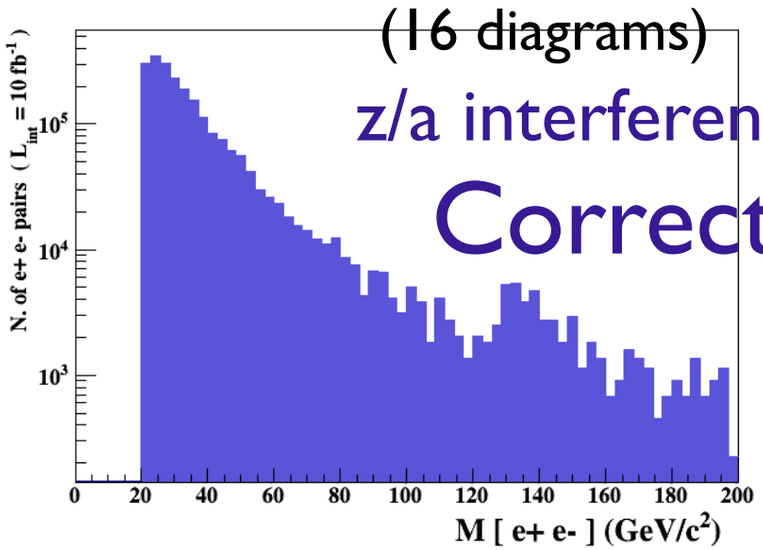
No Z

p p > e+ e- $ z

(16 diagrams)

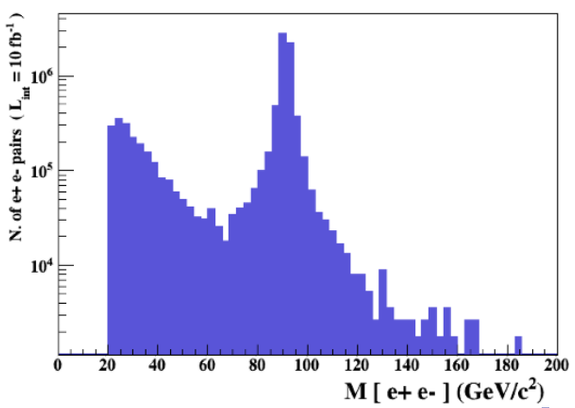
z/a interference

Correct tail



Z- onshell veto

p p > e+ e- p p >z , z > e+ e- p p > e+ e- $ z



(16 diagrams)

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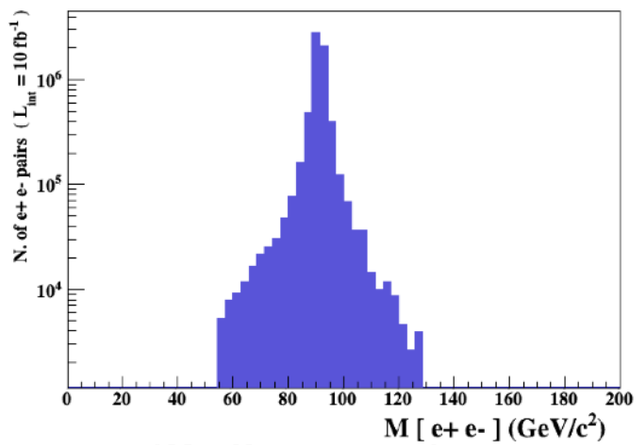
two other one.



(8 diagrams)

+

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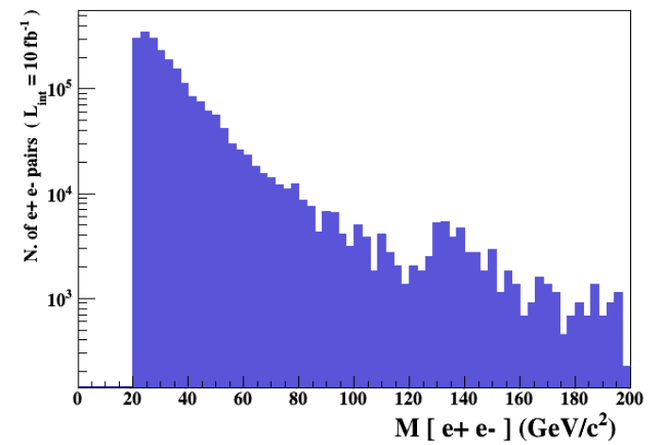


(16 diagrams)

Onshell cut: BW_cut

- The "$" forbids the Z to be onshell but the photon invariant mass can be at MZ (i.e. on shell substraction).

$$|M^* - M| < BW_{cut} * 1$$

- 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.

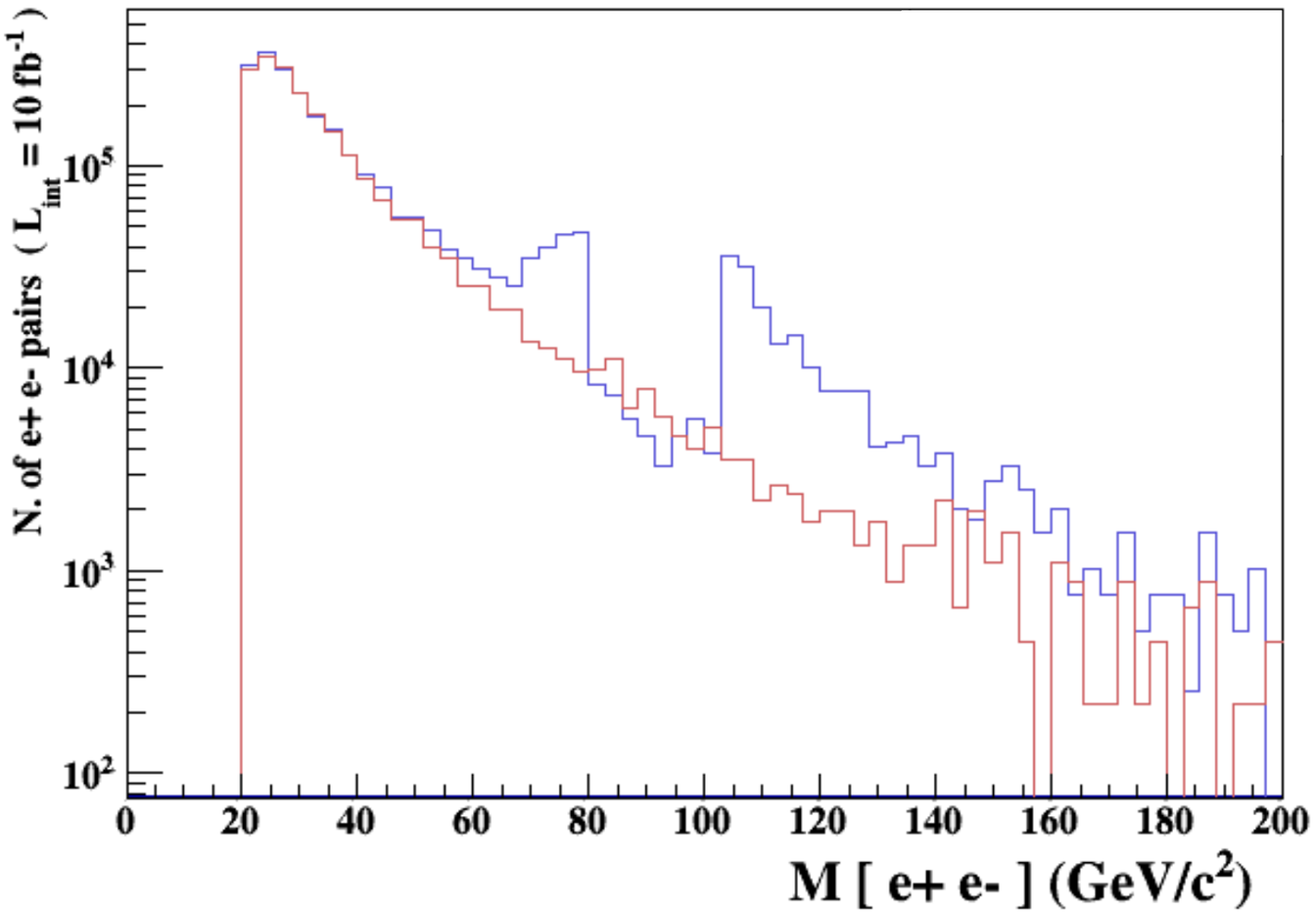
See previous slide warning

$ explanation

p p > e+ e- / Z

(red curve)

(blue curve)



See previous slide warning

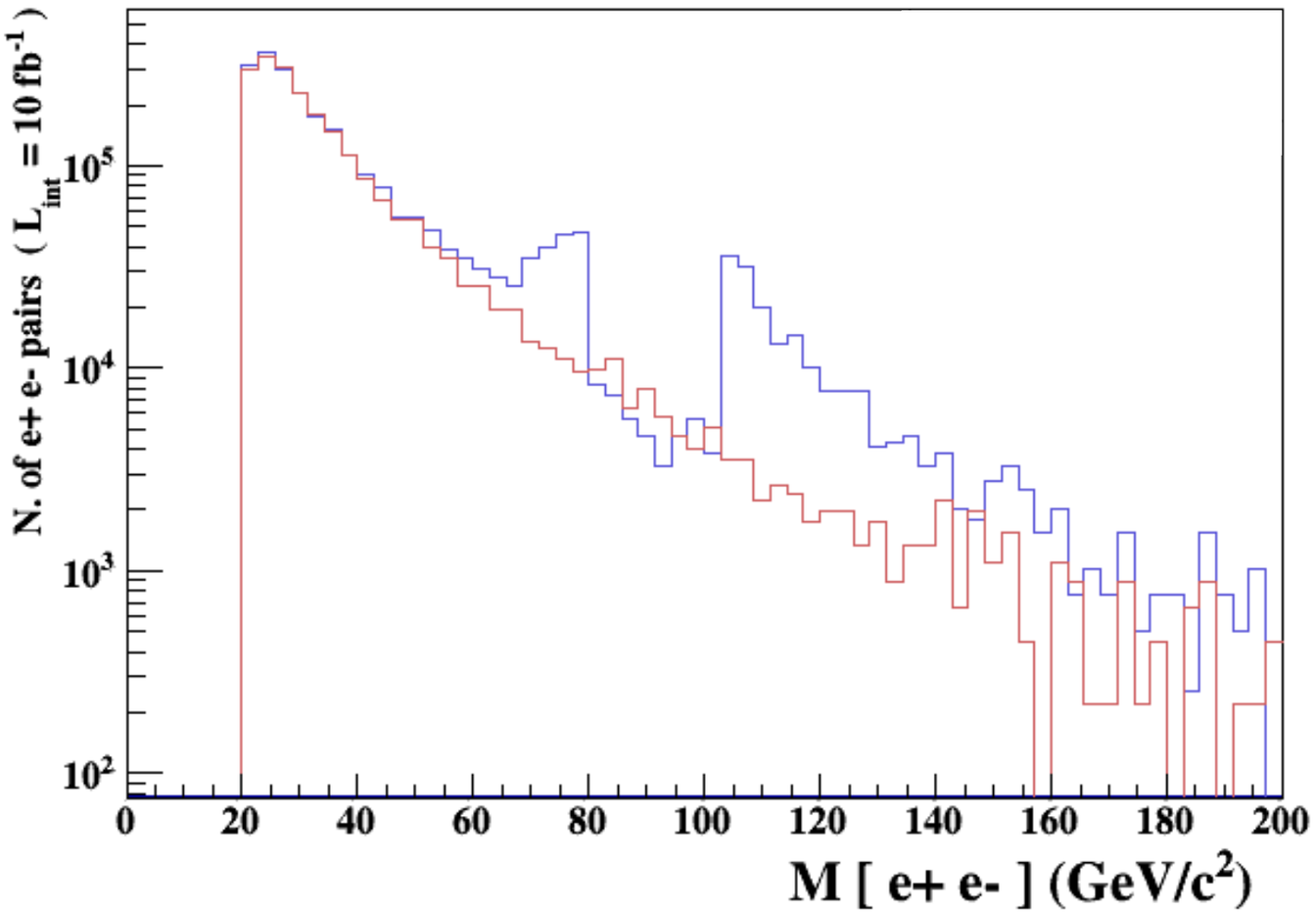
$ explanation

p p > e+ e- / Z

(red curve)

adding p p > e+ e- $ Z

(blue curve)



See previous slide warning

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p p > e+ e- / Z

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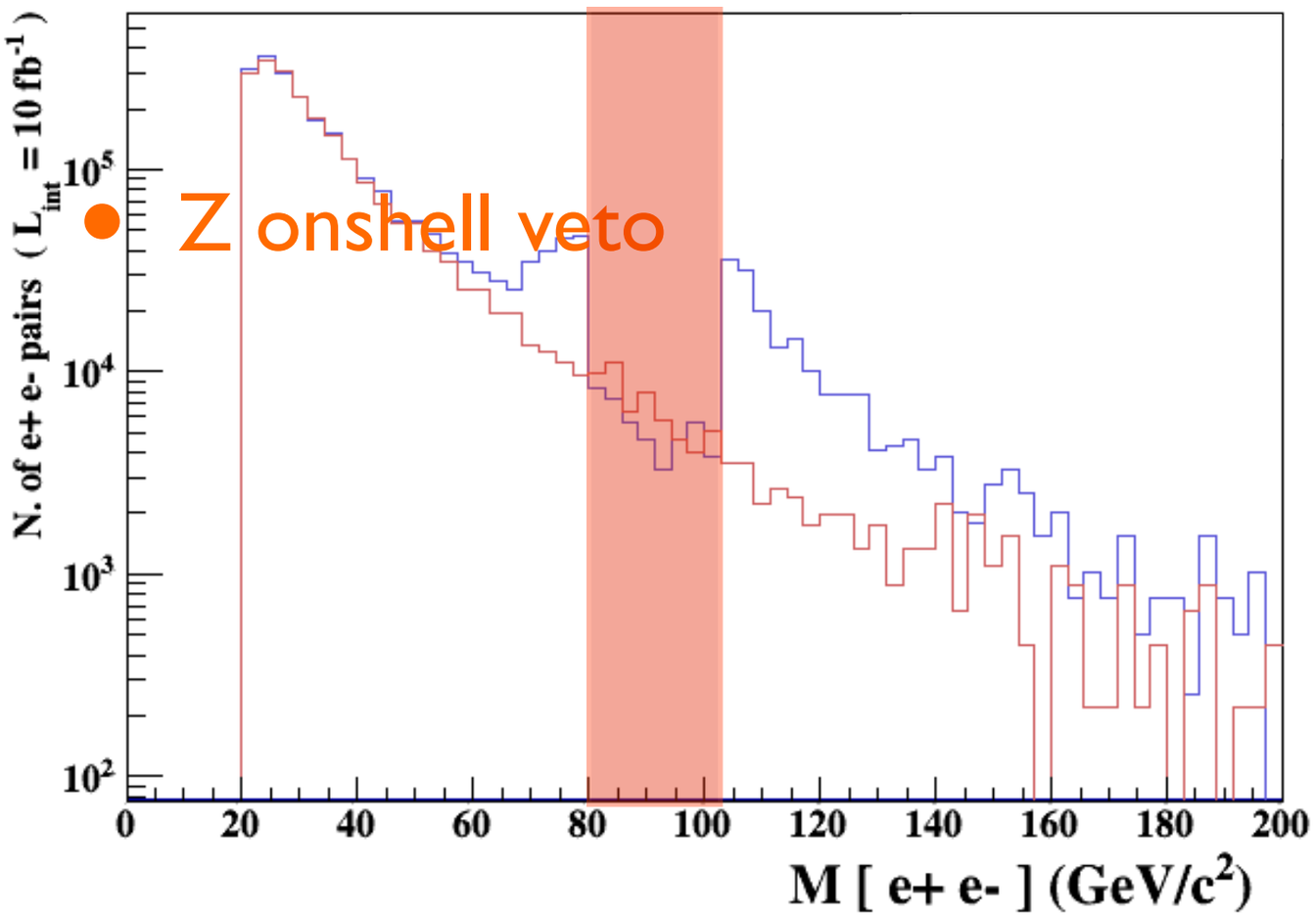


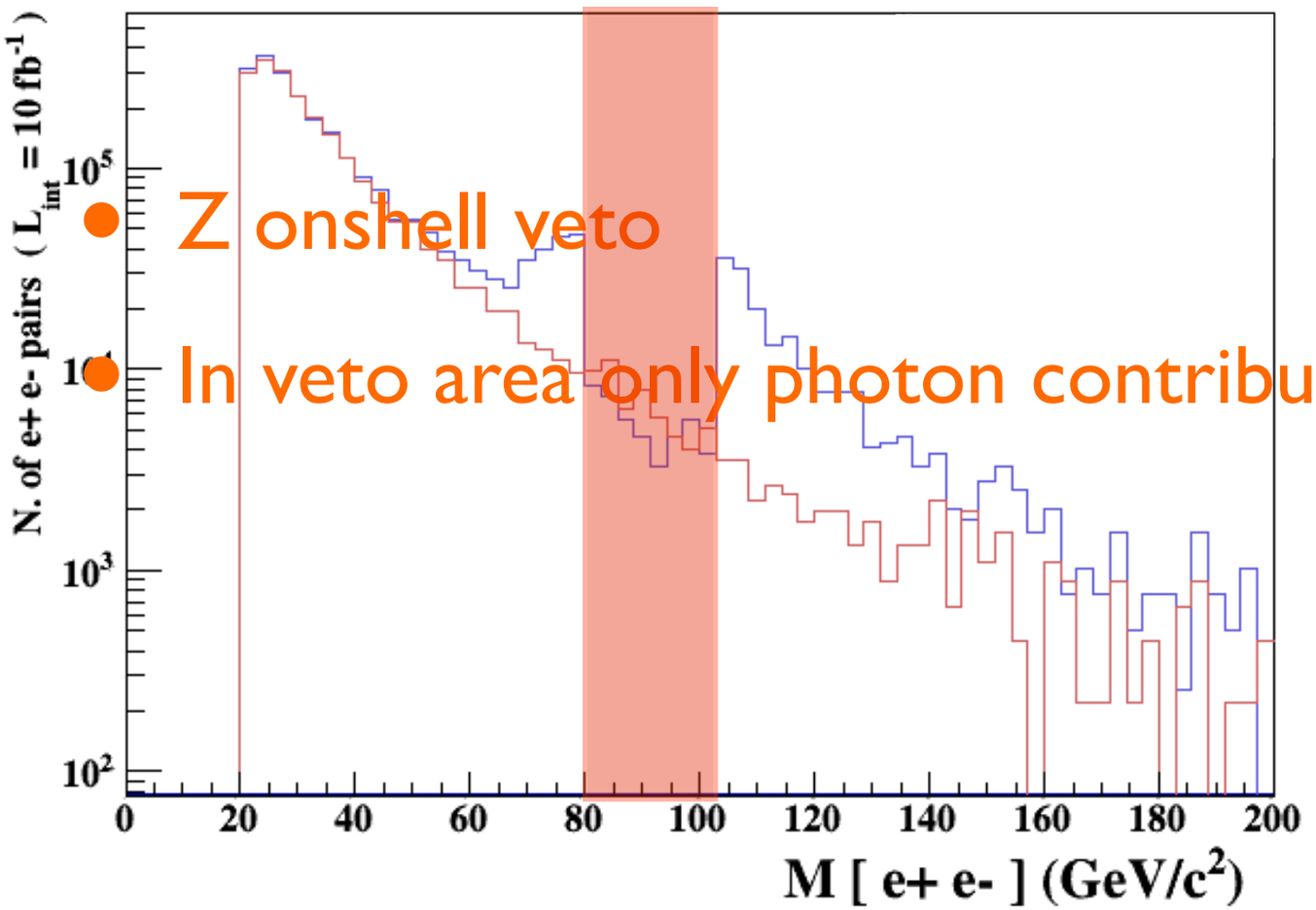
5 times width area

See previous slide warning

$ explanation

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

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



Z onshell veto

In veto area only photon contribution

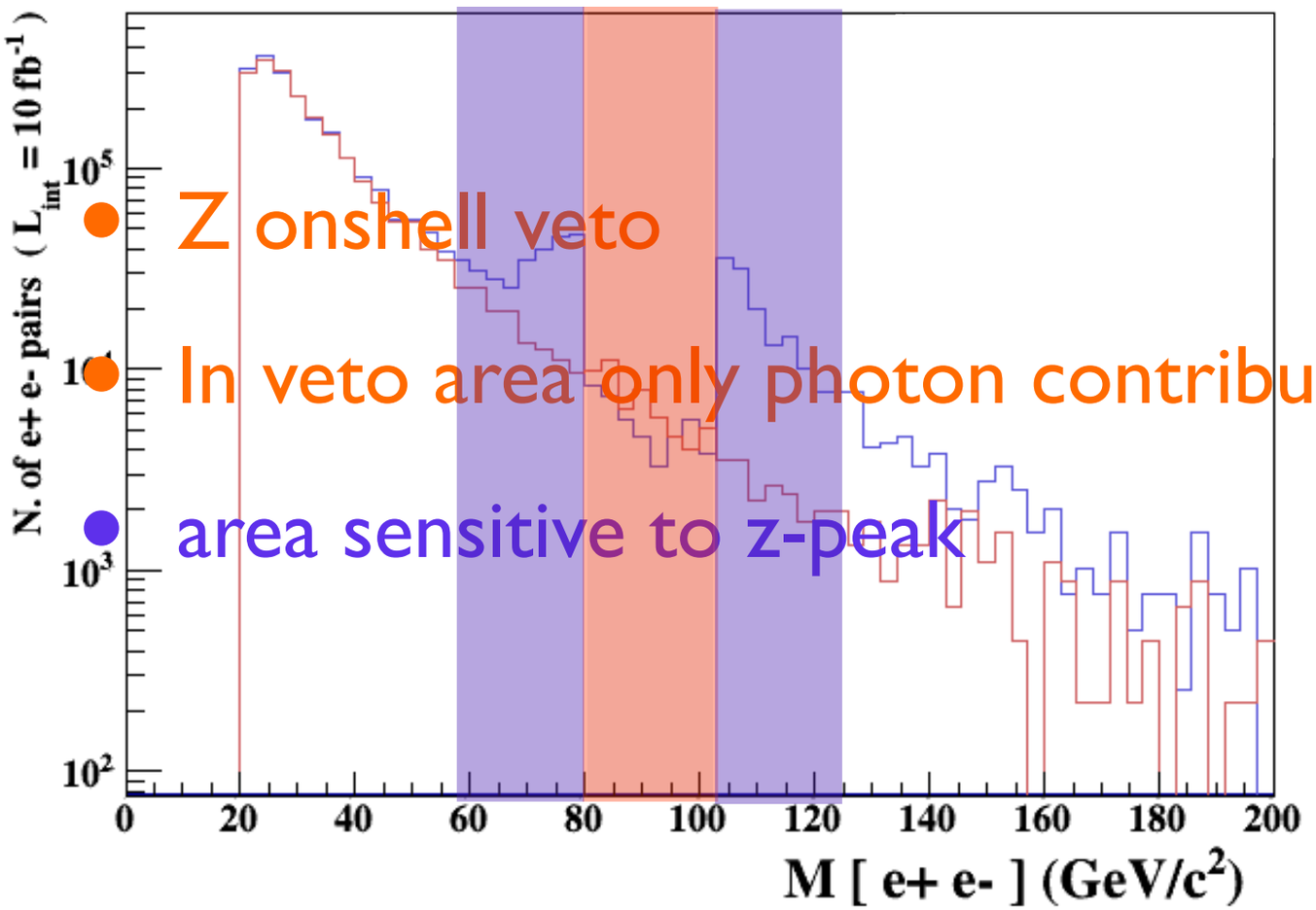
5 times width area

See previous slide warning

$ explanation

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

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



5 times width area

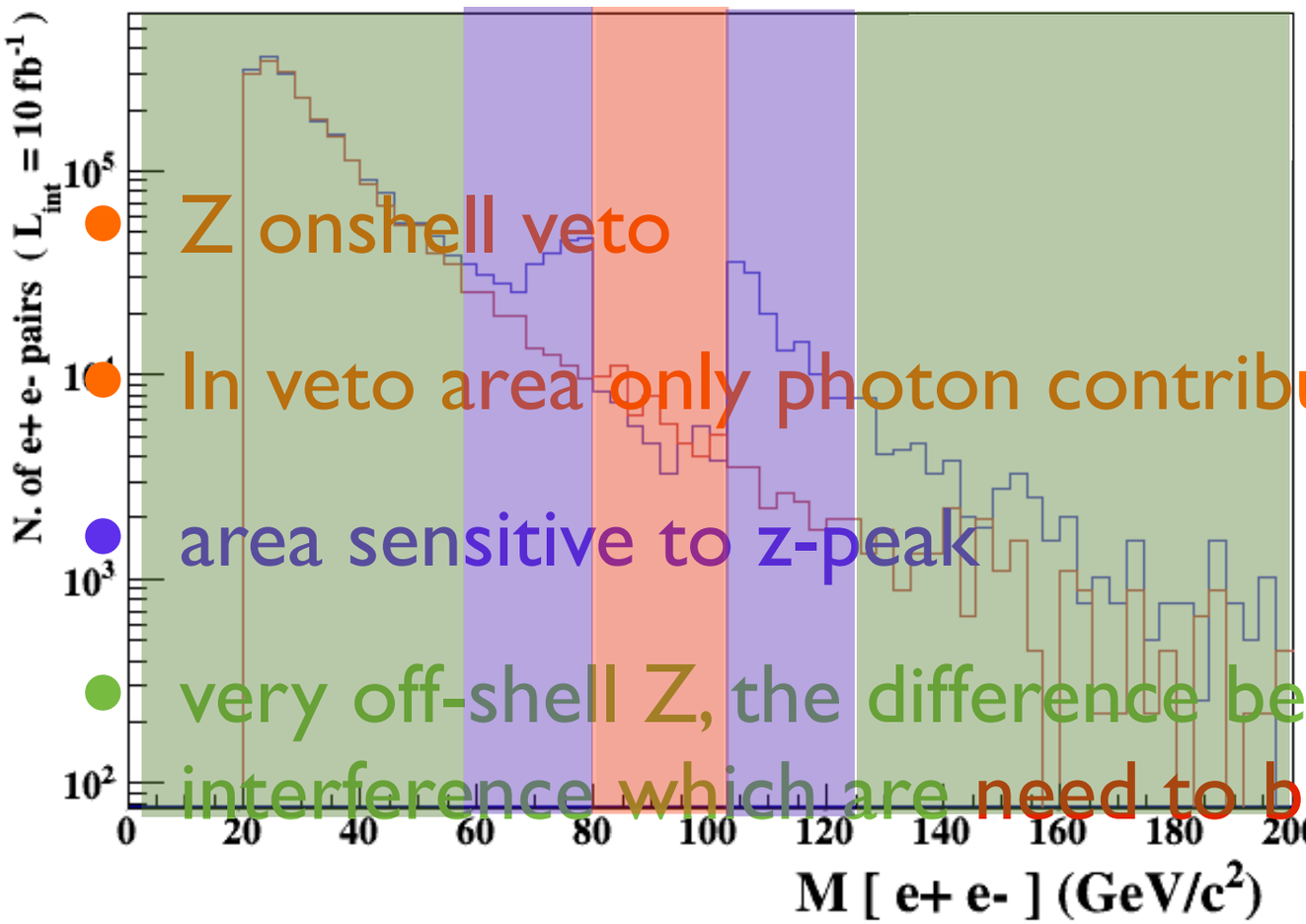
15 times width area

See previous slide warning

$ explanation

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

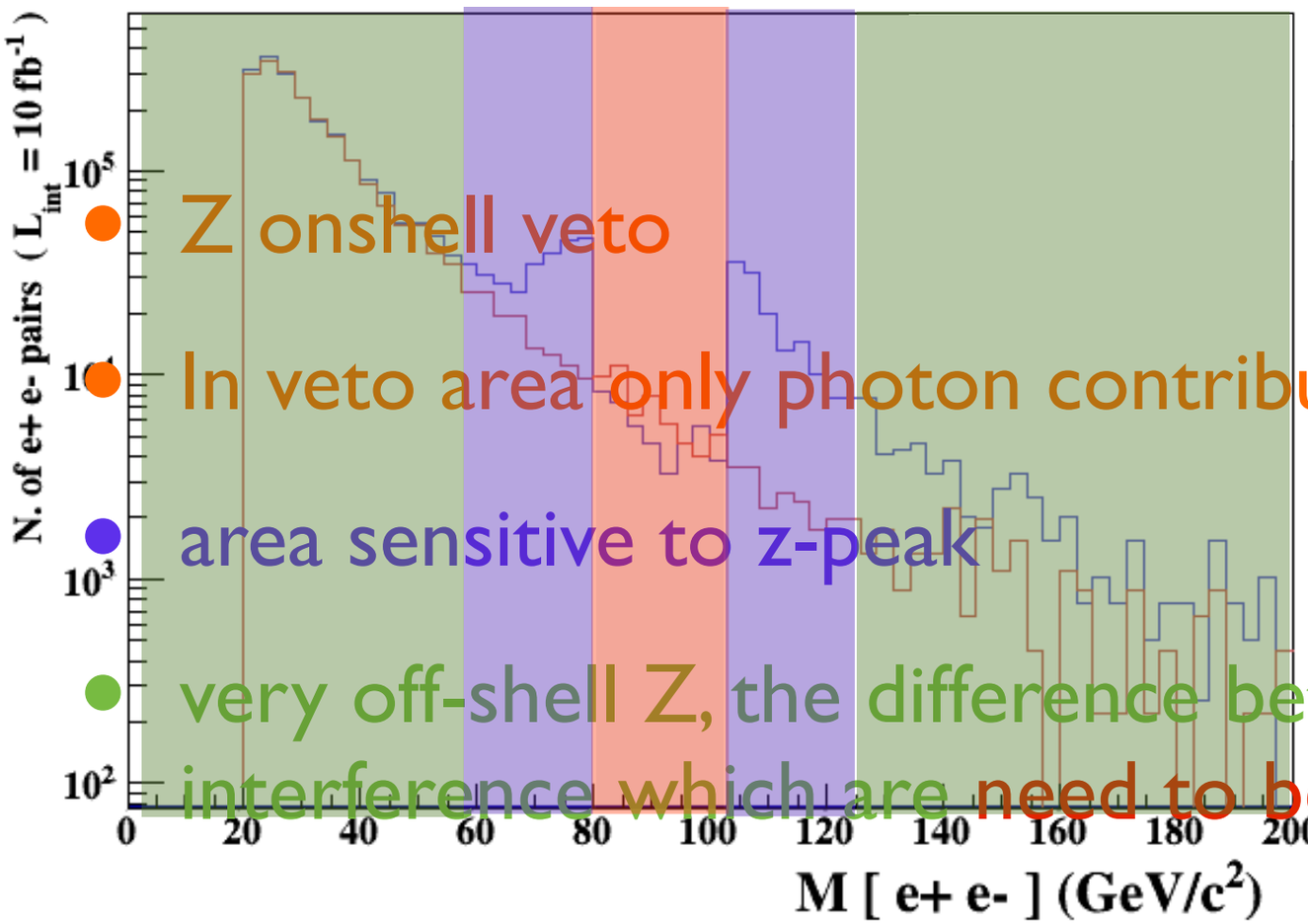
>15 times width area

See previous slide warning

$ explanation

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.

- Syntax Like
  - ➡ p p > z > e+ e- (ask one S-channel z)
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Avoid Those as much as possible!

- 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: Automation

- 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: Automation

```
import model sm
generate p p > t t~
output
launch
set mt 160
set wt Auto
done
launch
set mt 165
set wt Auto
launch
set mt 170
set wt Auto
launch
set mt 175
set wt Auto
launch
set mt 180
set wt Auto
launch
set mt 185
set wt Auto
```

- Run it by:
  - ./bin/mg5 PATH
    - (smarter than ./bin/mg5 < PATH)
- If an answer to a question is not present: Default is taken automatically

Exercise VI: Decay

MadSpin

MadSpin Card

- generate p p > t t~ h

➡ decay t > w+ b, w+ > e+ ve

➡ decay t~ >w- b~, w- > e- ve~

➡ decay h > b b~

2m18.214s

0.004707

MadGraph

- generate p p > t t~ h, (t > w+ b, w+ > e+ ve), (t~ >w- b~, w- > e- ve~), h > b b~

9m30.806s

0.003014

Different here because of cut (not cut should be applied since 2.3.0)