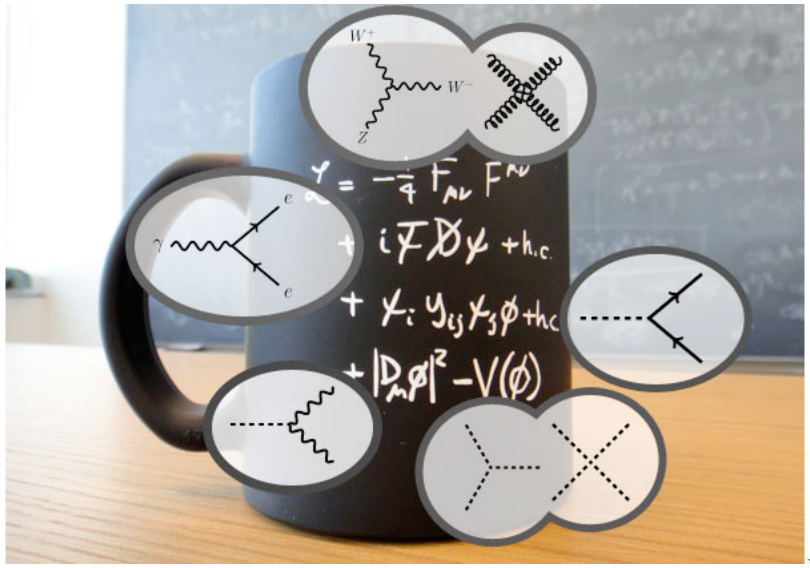
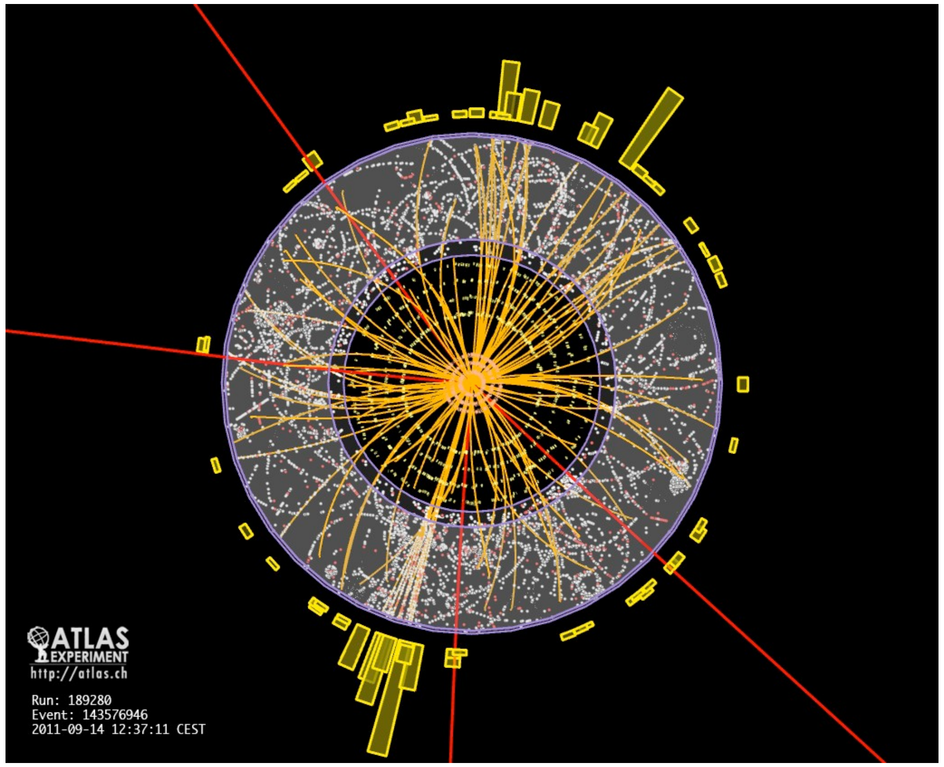
UCLouvain
Institut de recherche en mathématique et physique
Centre de Cosmologie, Physique des Particules et Phénoménologie

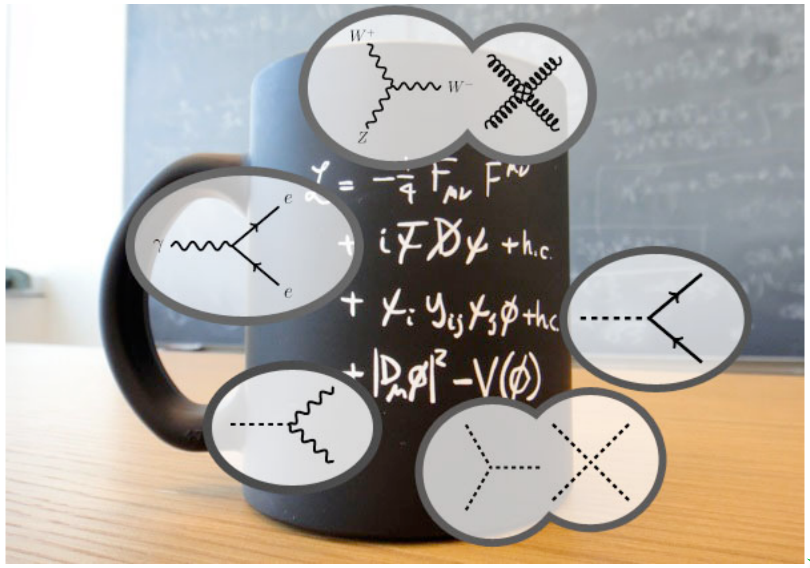
MonteCarlo Simulation

Olivier Mattelaer



Monte-Carlo Physics





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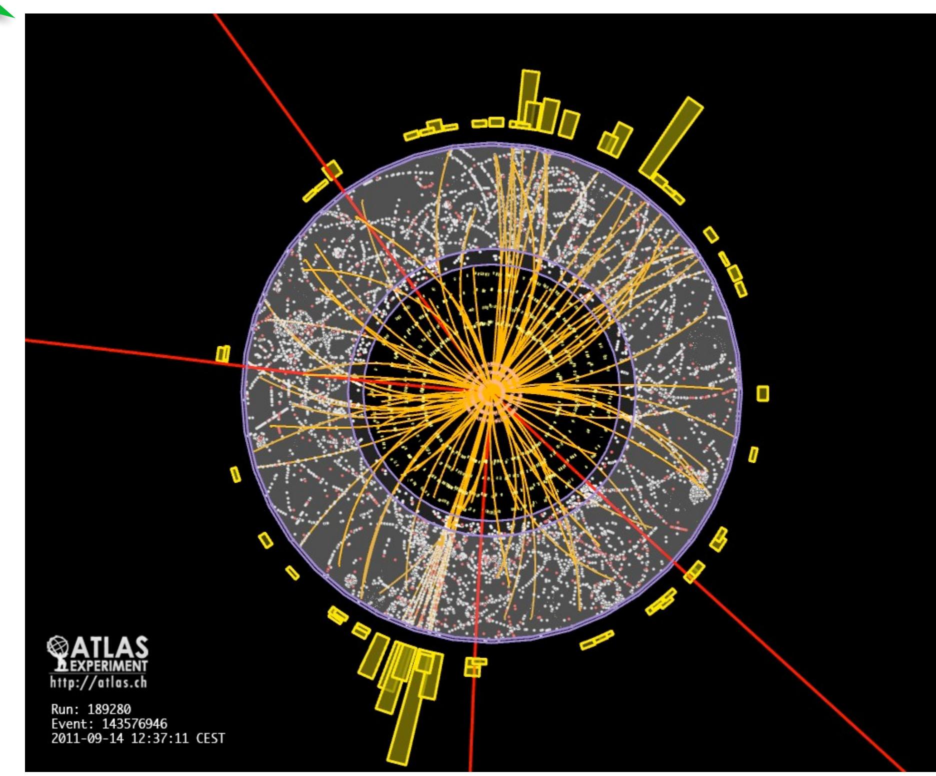
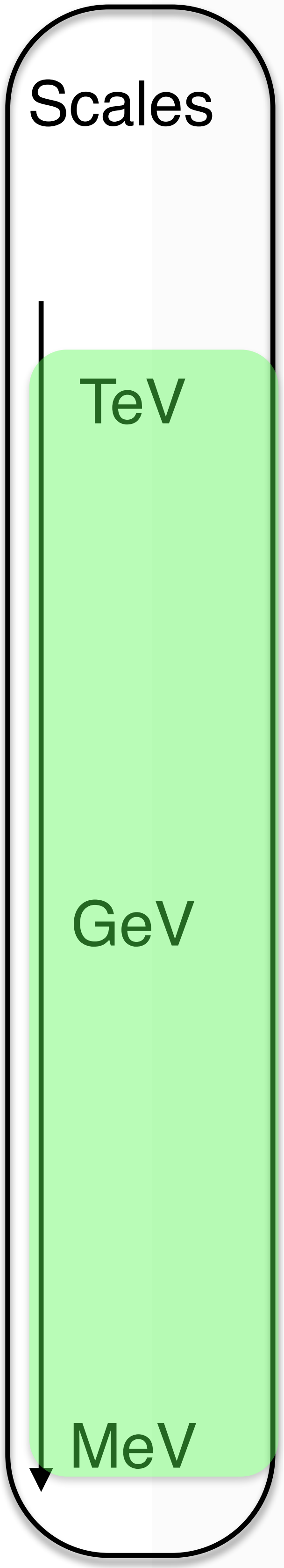


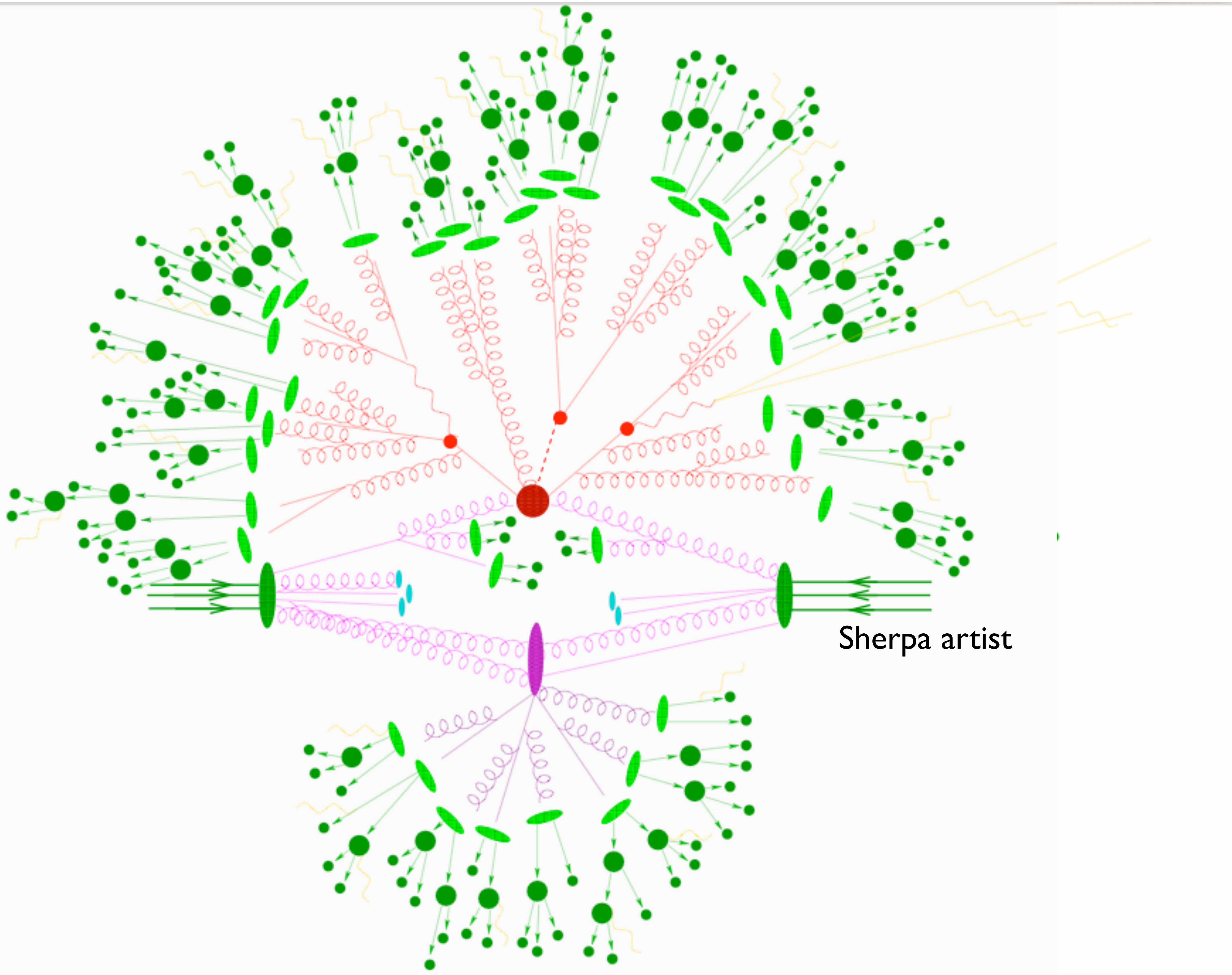
Our goal

- Cross-section
- Differential cross-section
- Un-weighted events

Simulation of collider events

What are the MC for?





Sherpa artist

What are the MC for?

Scales

TeV

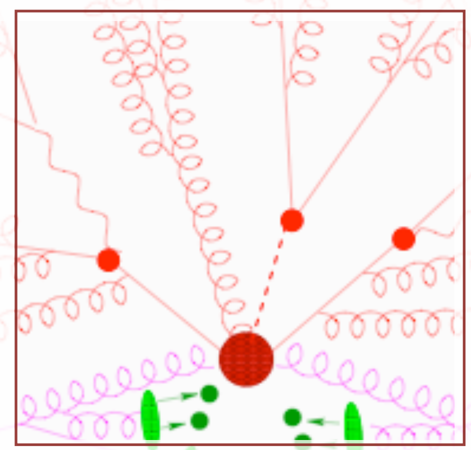
GeV

MeV

1. High-Q^2 Scattering

2. Parton Shower

☞ where BSM physics lies



☞ process dependent

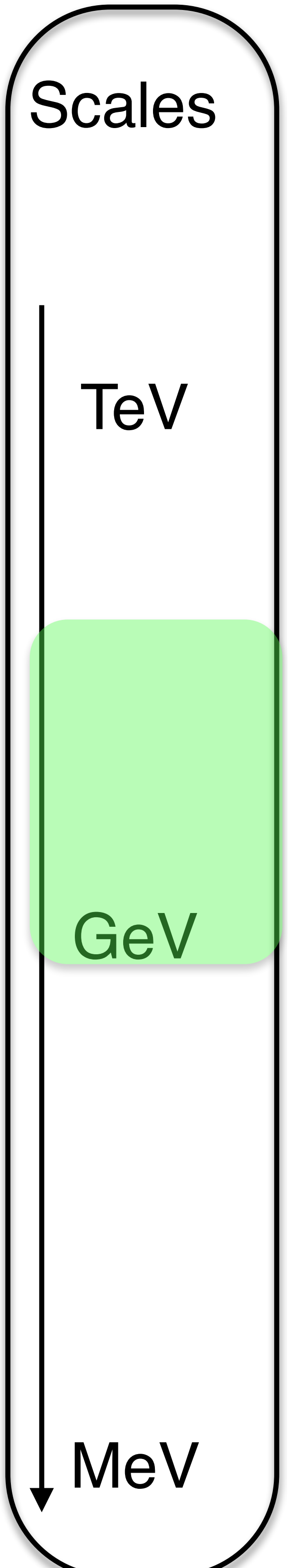
☞ first principles description

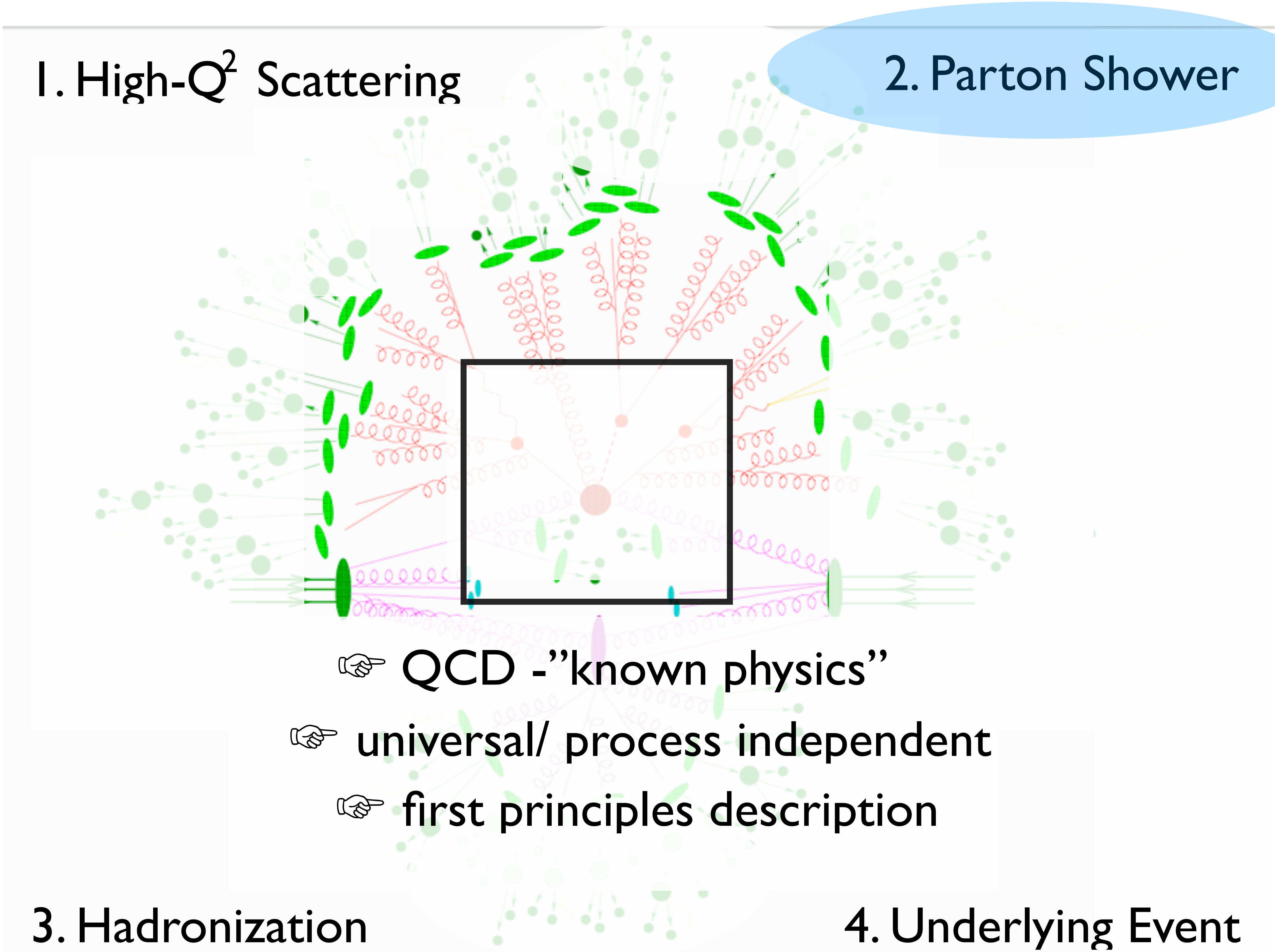
☞ it can be systematically improved

3. Hadronization

4. Underlying Event

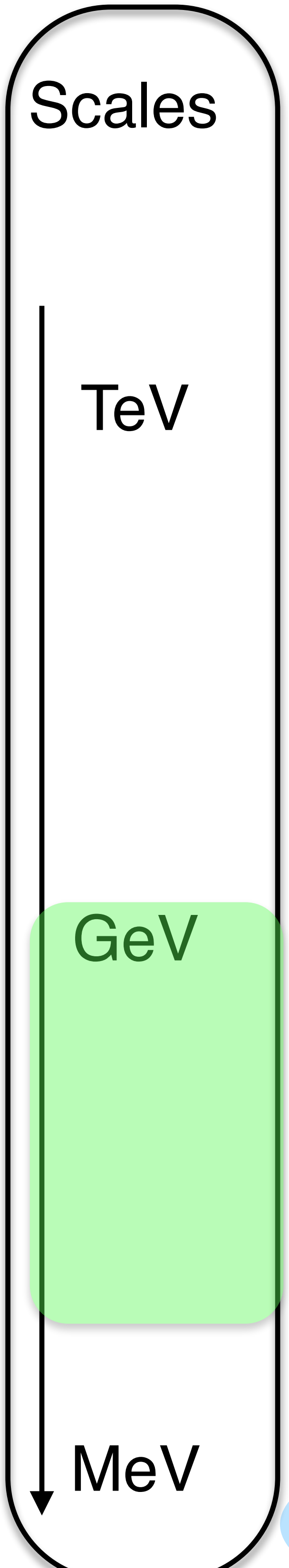
What are the MC for?





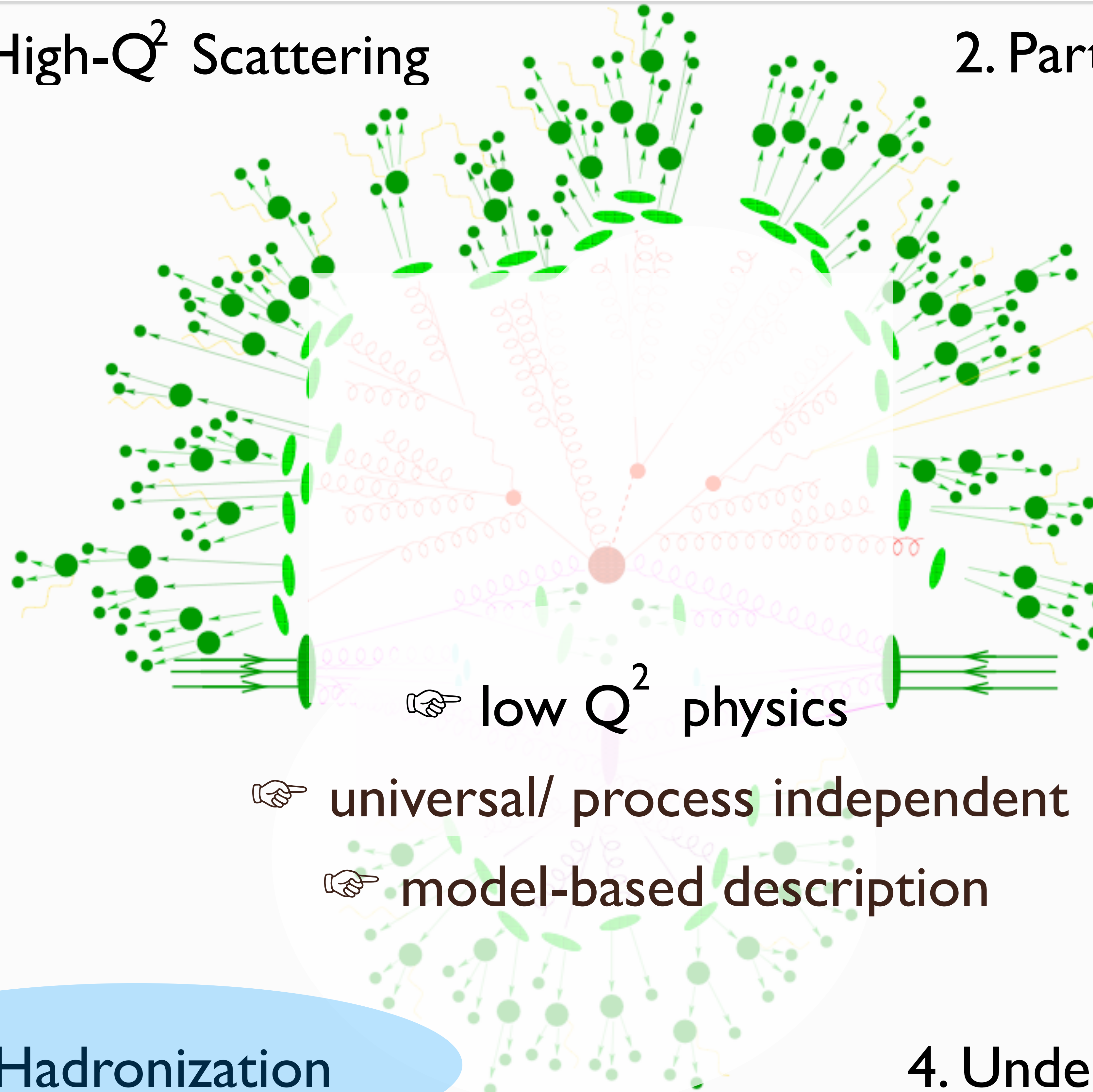
- ☞ QCD -"known physics"
- ☞ universal/ process independent
- ☞ first principles description

What are the MC for?



1. High-Q^2 Scattering

2. Parton Shower

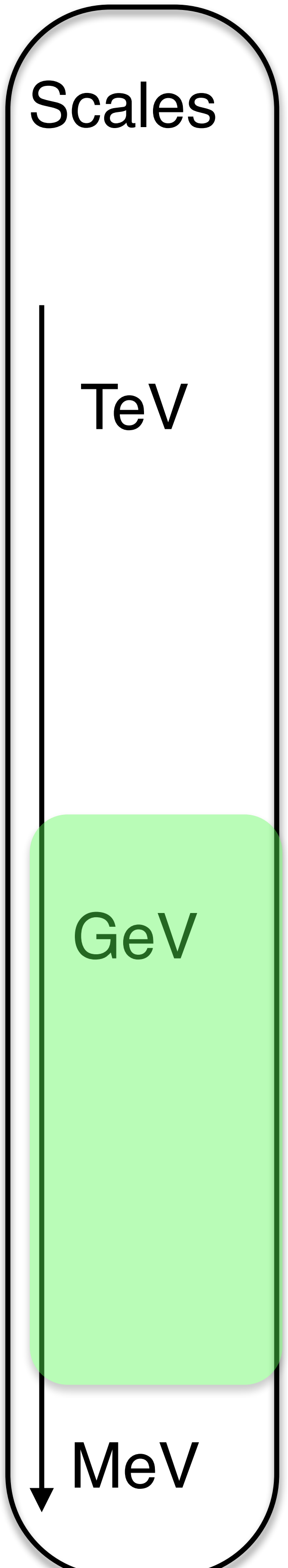


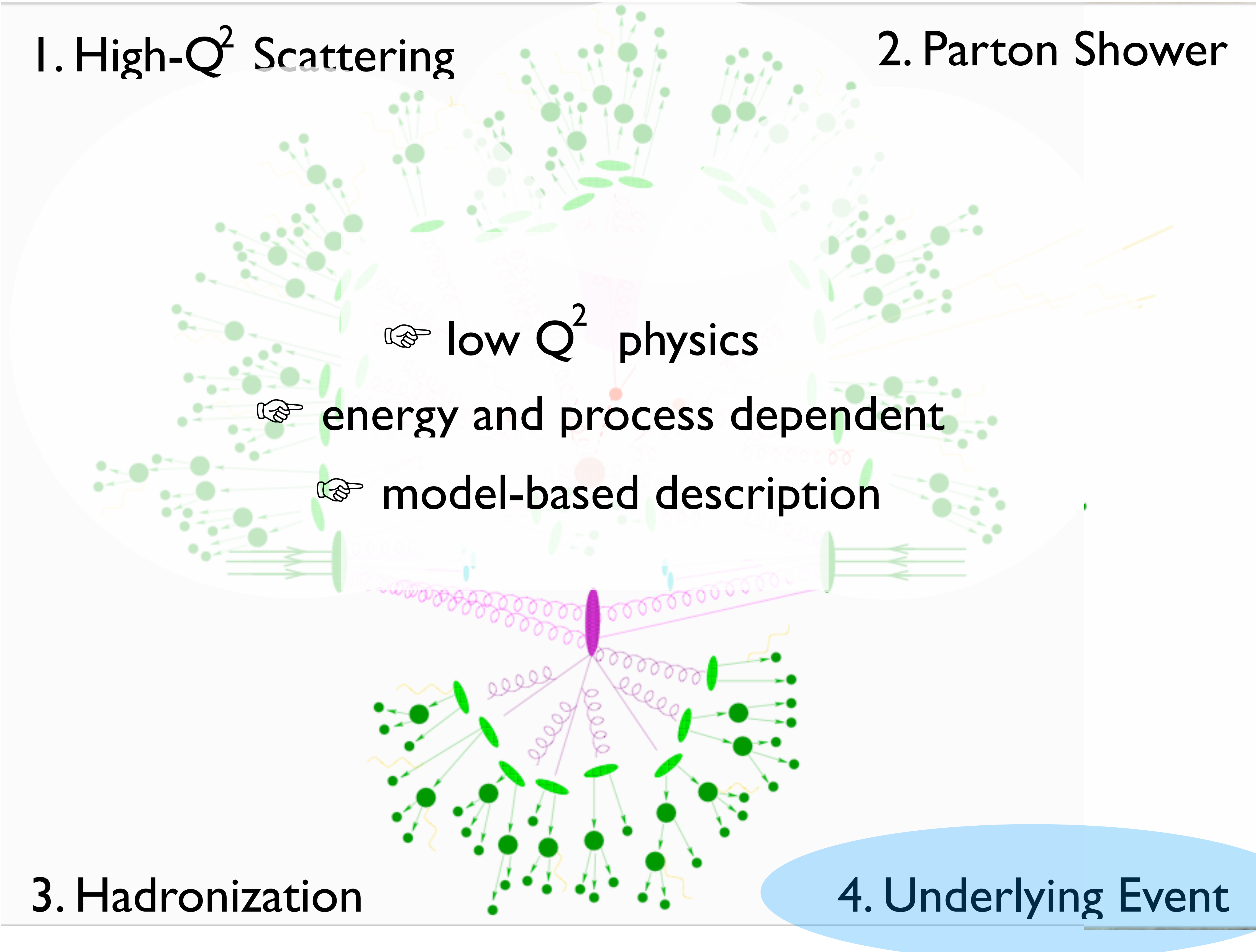
- ☞ low Q^2 physics
- ☞ universal/ process independent
- ☞ model-based description

3. Hadronization

4. Underlying Event

What are the MC for?





- ☞ low Q^2 physics
- ☞ energy and process dependent
- ☞ model-based description

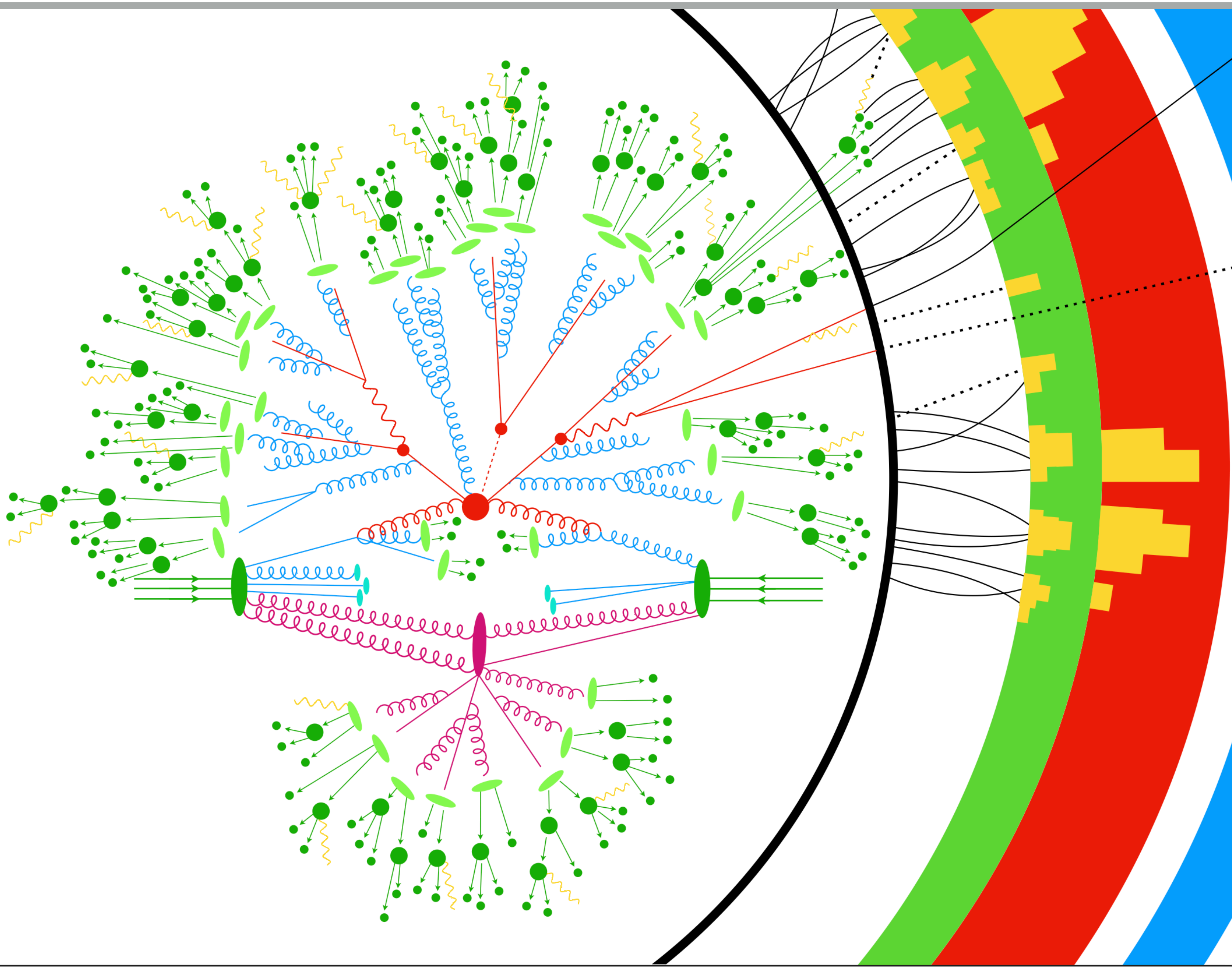
What are the MC for?

Scales

TeV

GeV

MeV



Question time

1 Allez sur wooclap.com

2 Entrez le code d'événement dans le bandeau supérieur

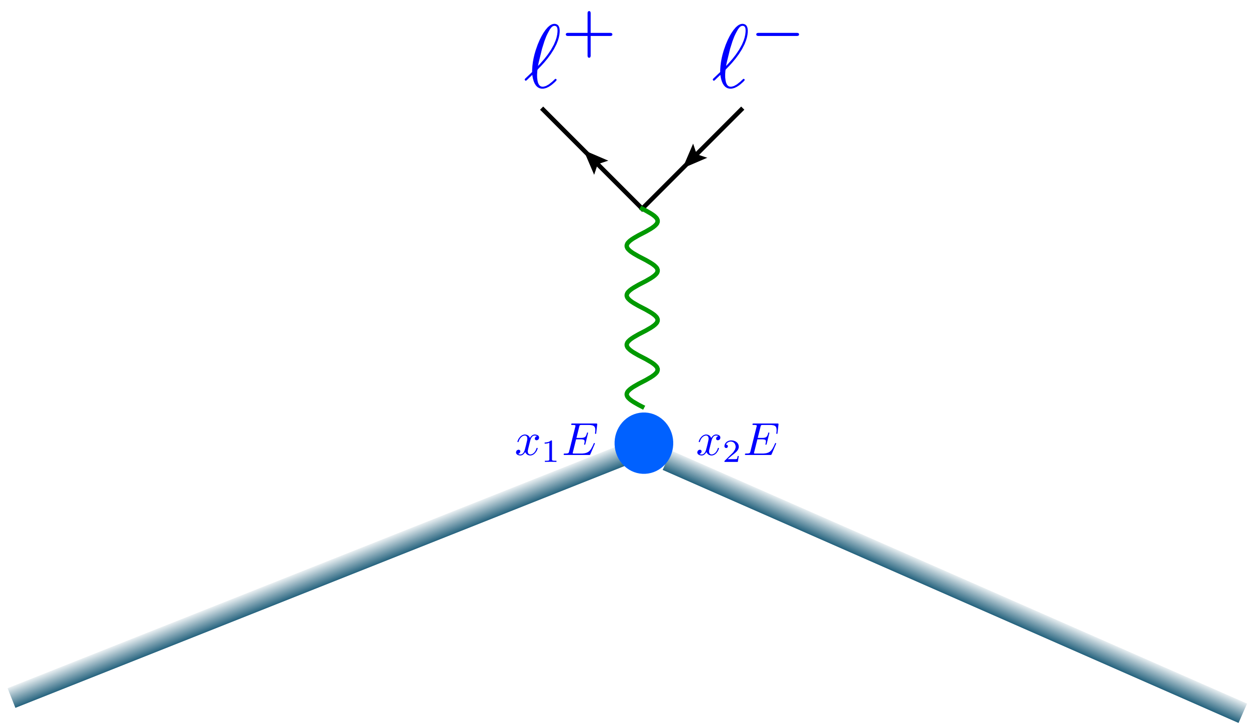
Code d'événement
MADGRAPH

Activer les réponses par SMS

To Remember

- Multi-scale problem
  - ➡ New physics visible only at High scale
  - ➡ Problem split in different scale
    - ❑ Factorisation theorem

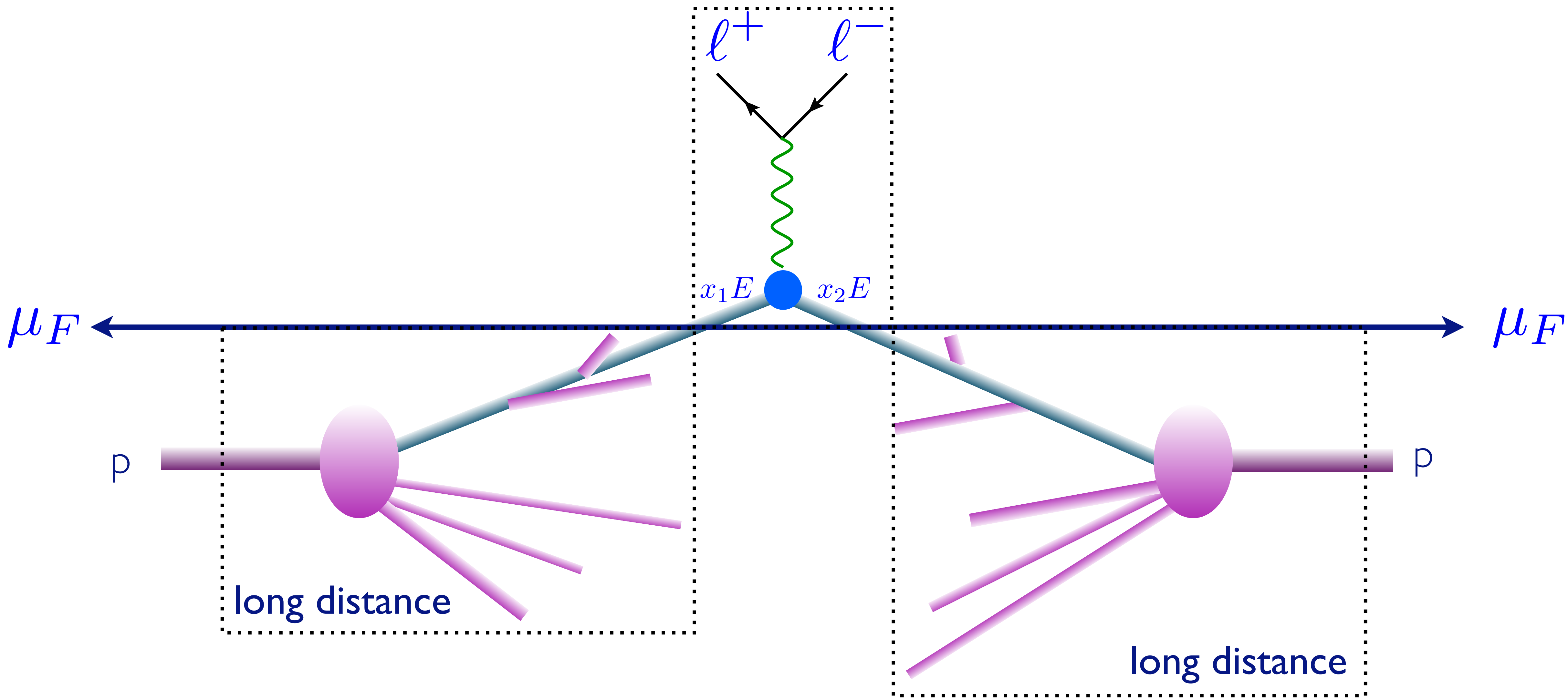
Master formula for the LHC



$$\hat{\sigma}_{ab \to X}(\hat{s}, \mu_F, \mu_R)$$

Parton-level cross section

Master formula for the LHC

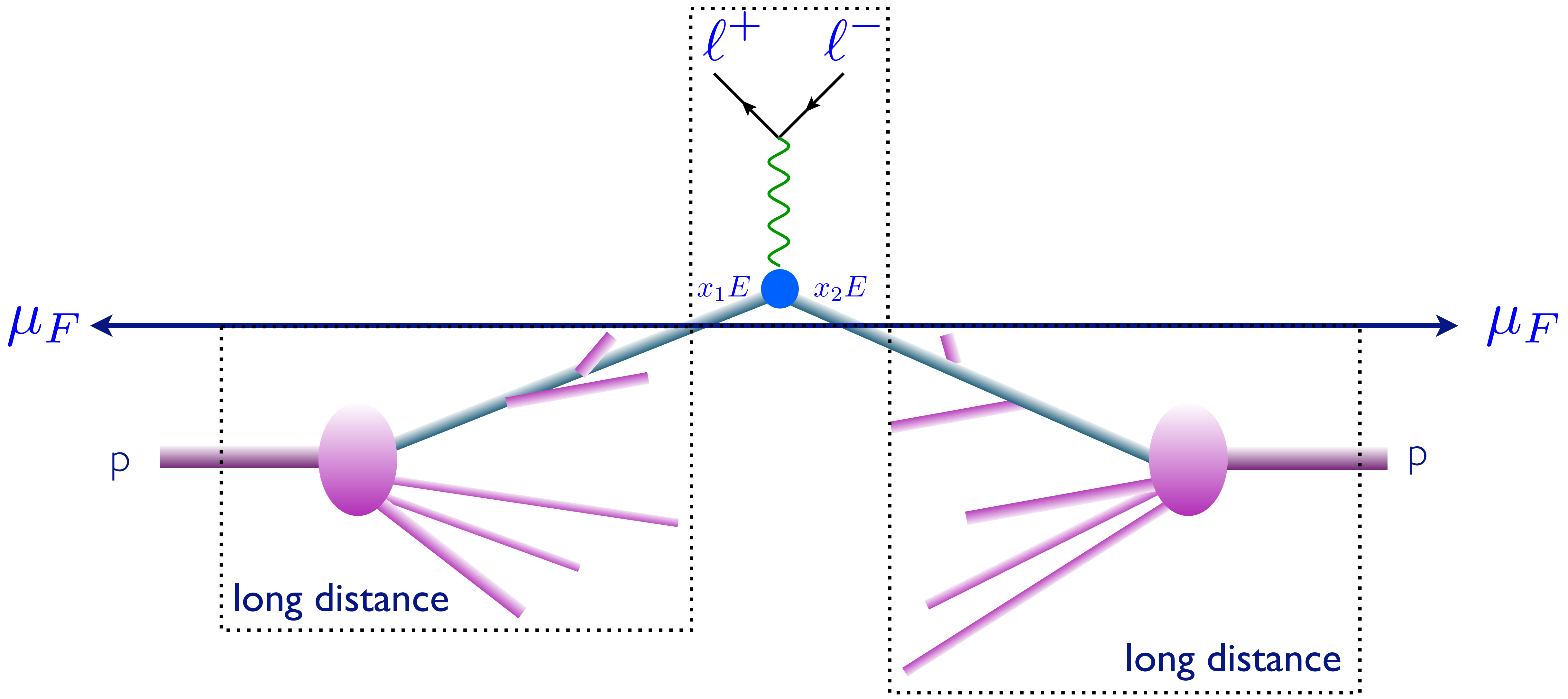


$$f_a(x_1, \mu_F) f_b(x_2, \mu_F) \, \hat{\sigma}_{ab \to X}(\hat{s}, \mu_F, \mu_R)$$

Parton density functions

Parton-level cross section

Master formula for the LHC



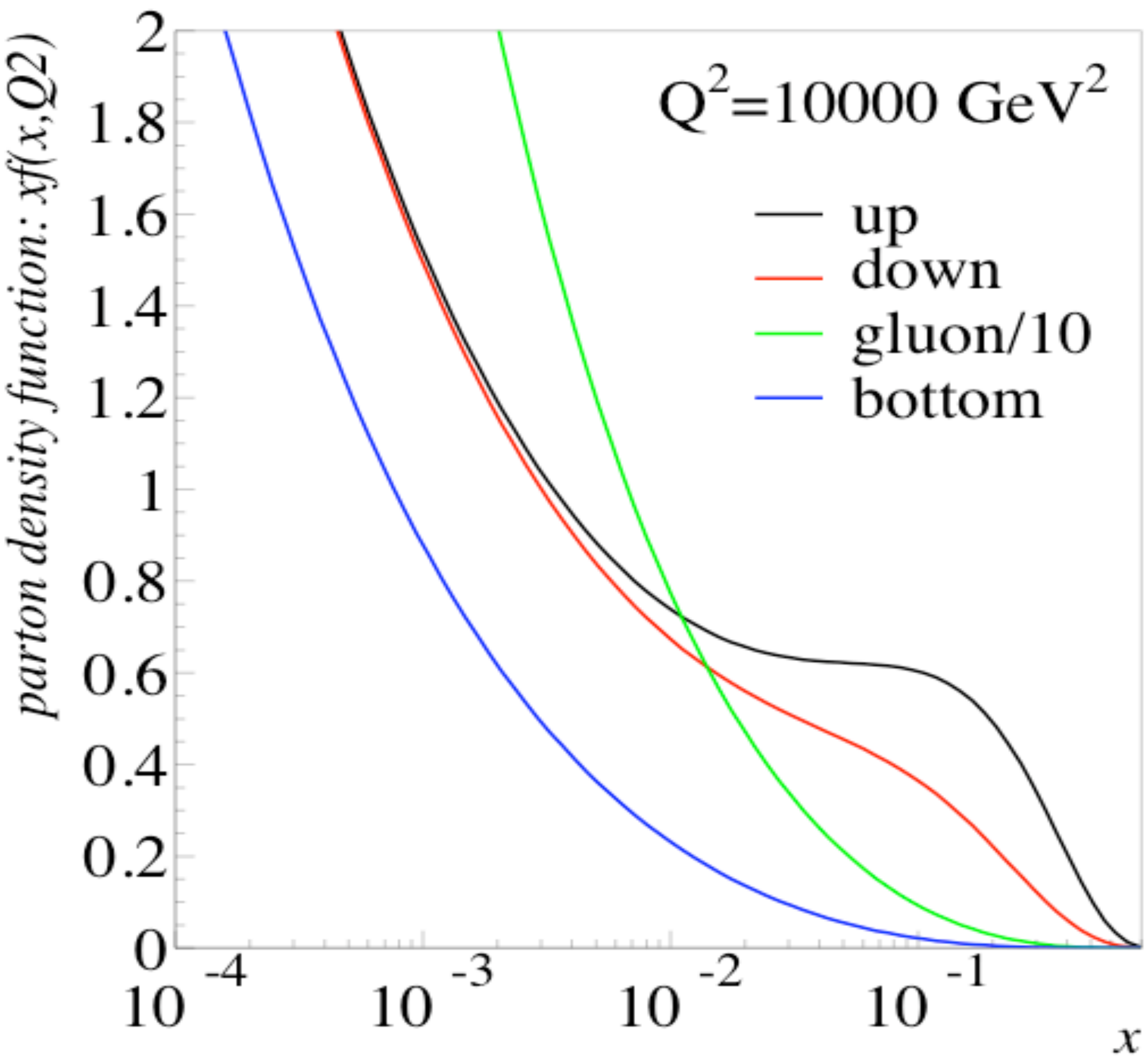
$$\sum_{a,b} \int dx_1 dx_2 d\Phi_{\rm FS}\, f_a(x_1, \mu_F) f_b(x_2, \mu_F)\, \hat{\sigma}_{ab\to X}(\hat{s}, \mu_F, \mu_R)$$

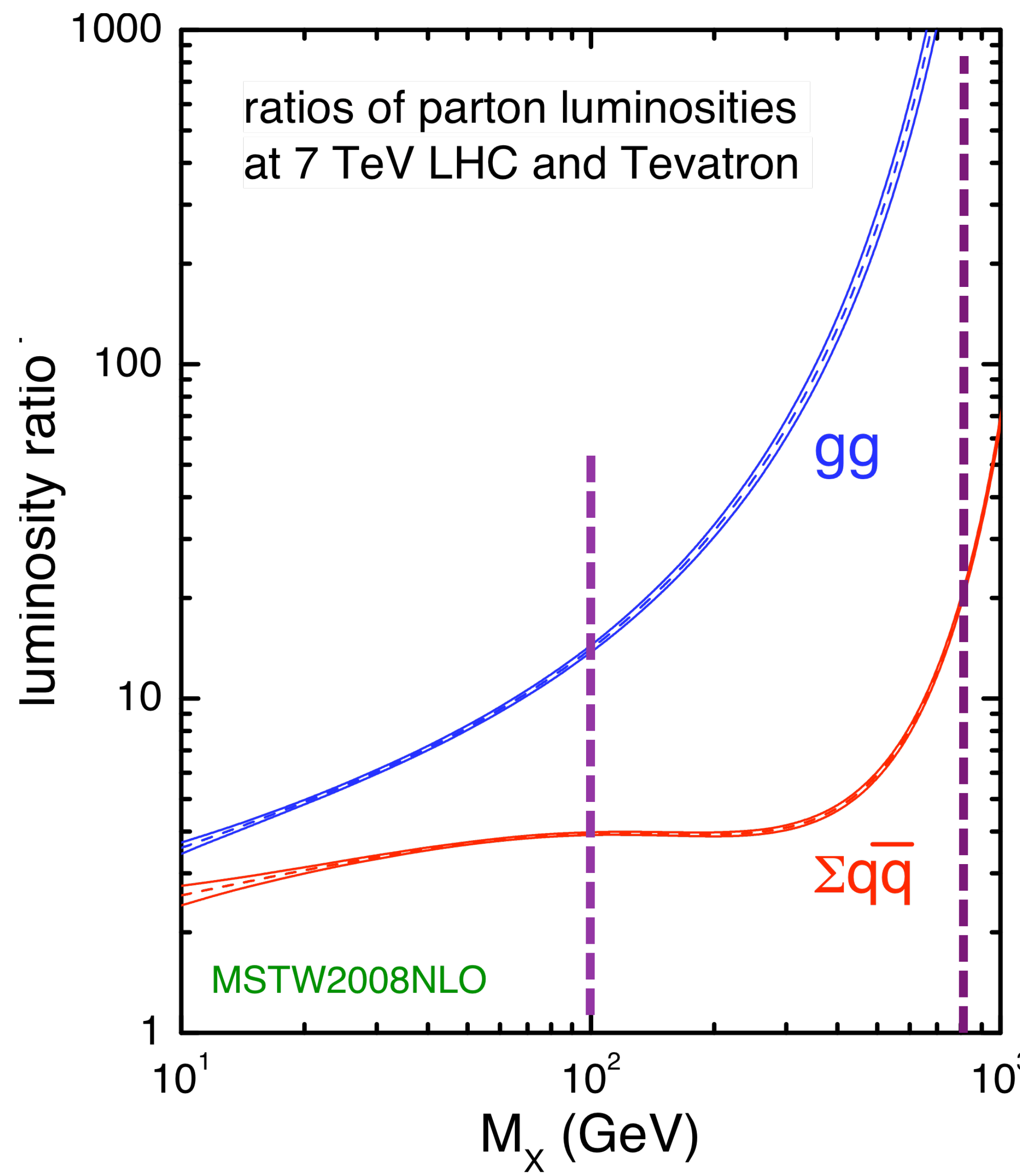
Phase-space integral

Parton density functions

Parton-level cross section

Parton densities



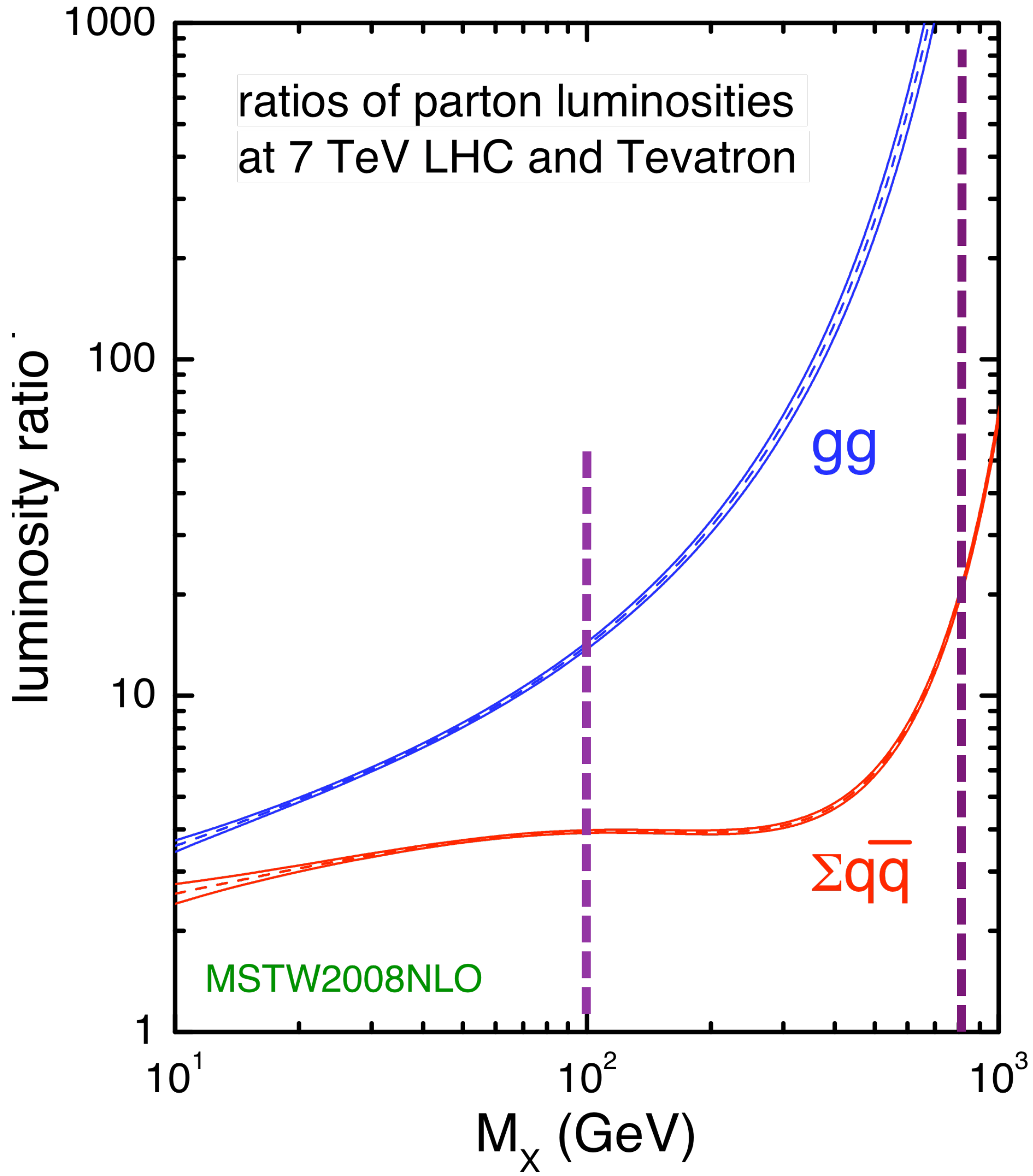


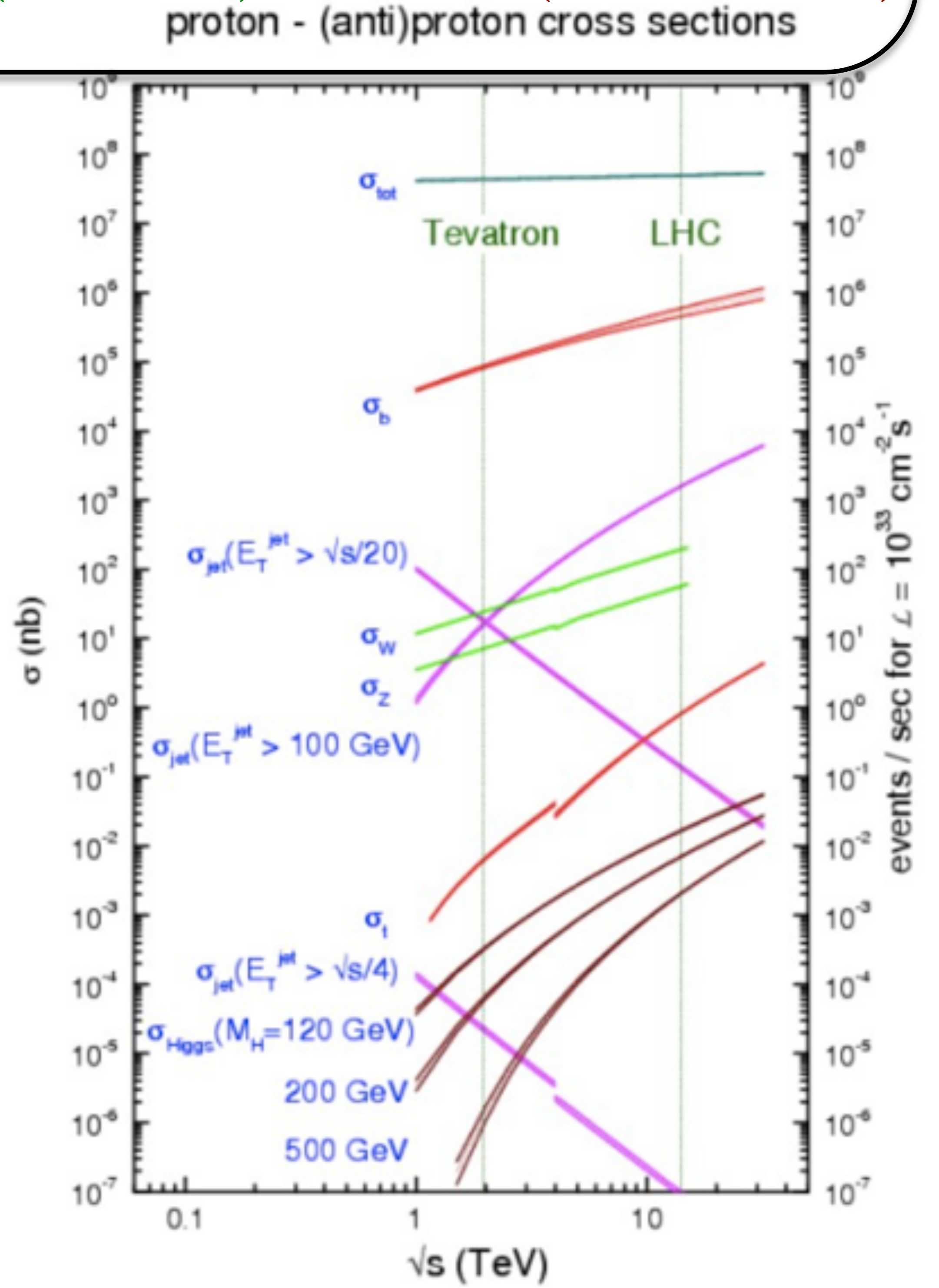
At small x (small ŝ), gluon domination.
At large x valence quarks

LHC formidable at large mass –
For low mass, Tevatron backgrounds smaller

Hadron colliders

$$\sum_{a,b} \int dx_1 dx_2 d\Phi_{\rm FS}\, f_a(x_1,\mu_F) f_b(x_2,\mu_F)\, \hat\sigma_{ab\to X}(\hat s,\mu_F,\mu_R)$$





Hadron colliders

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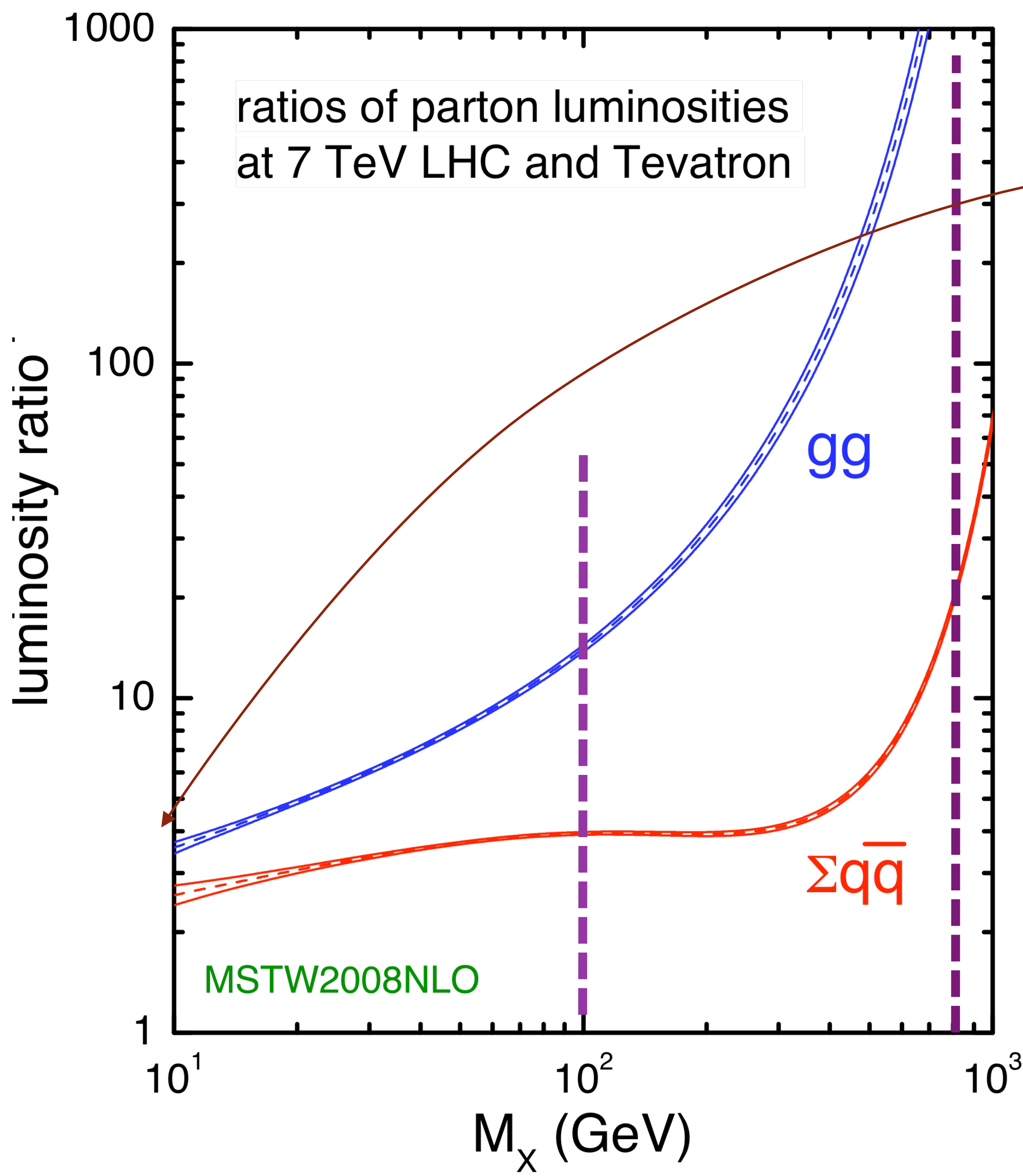

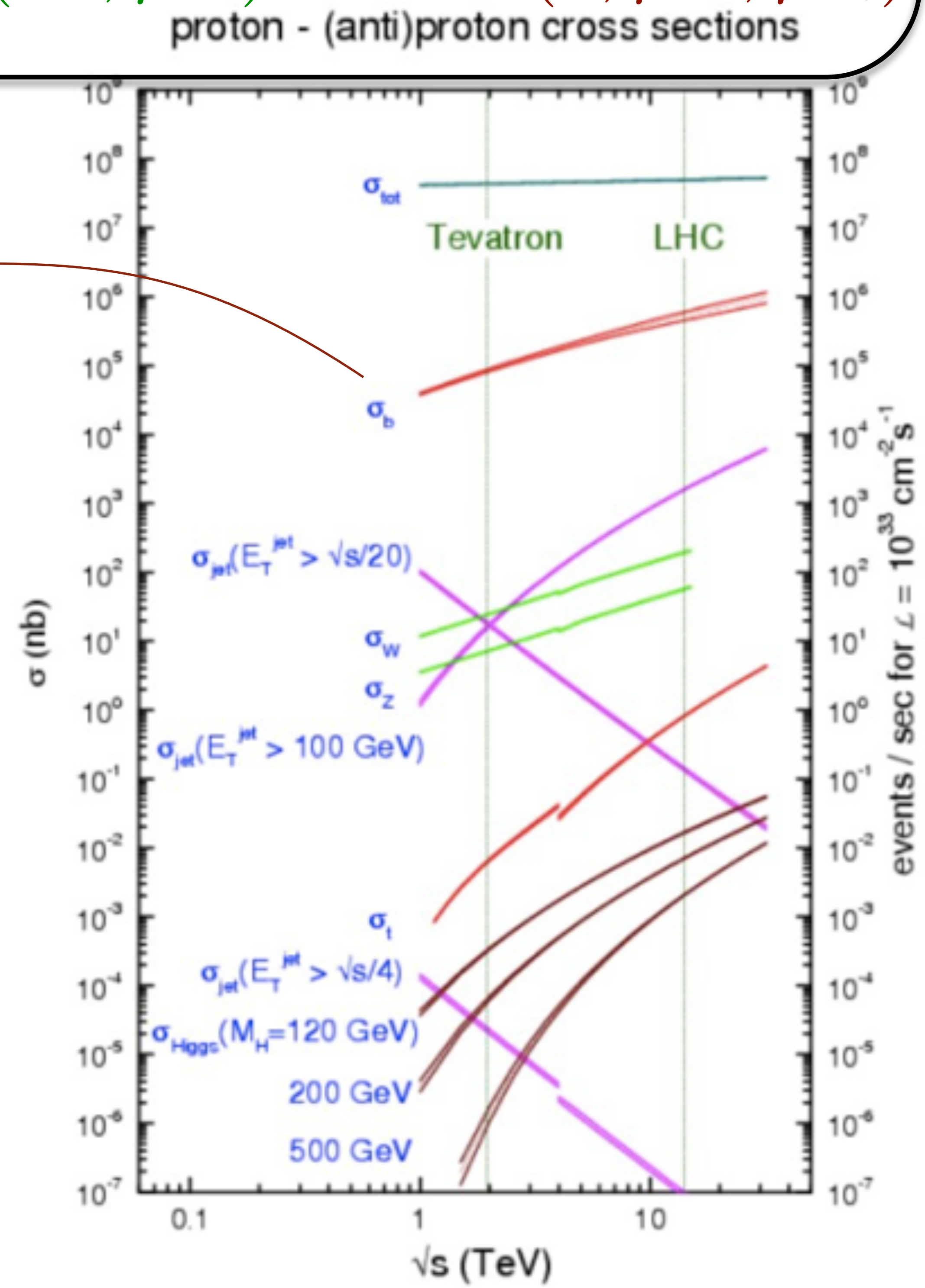

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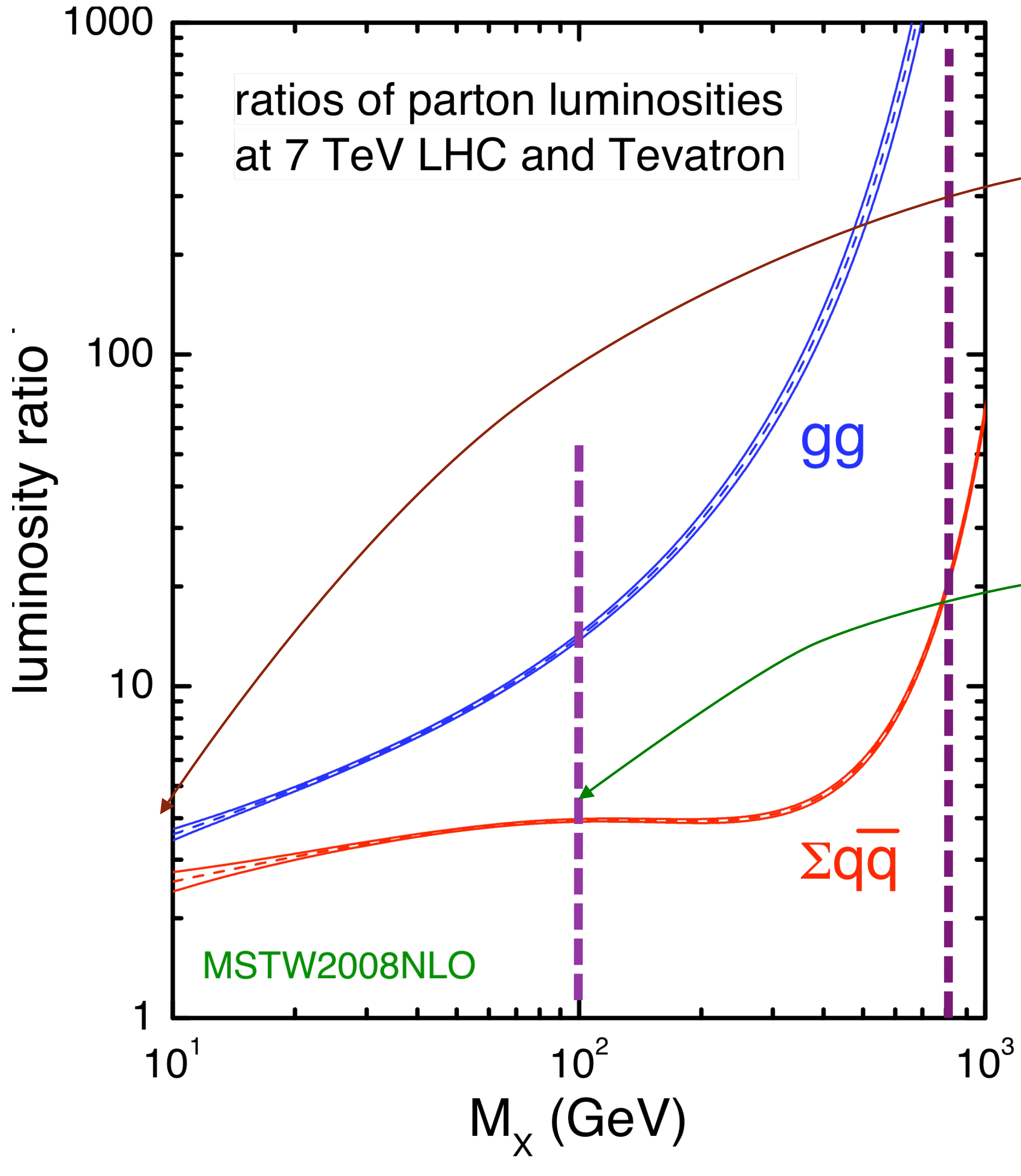

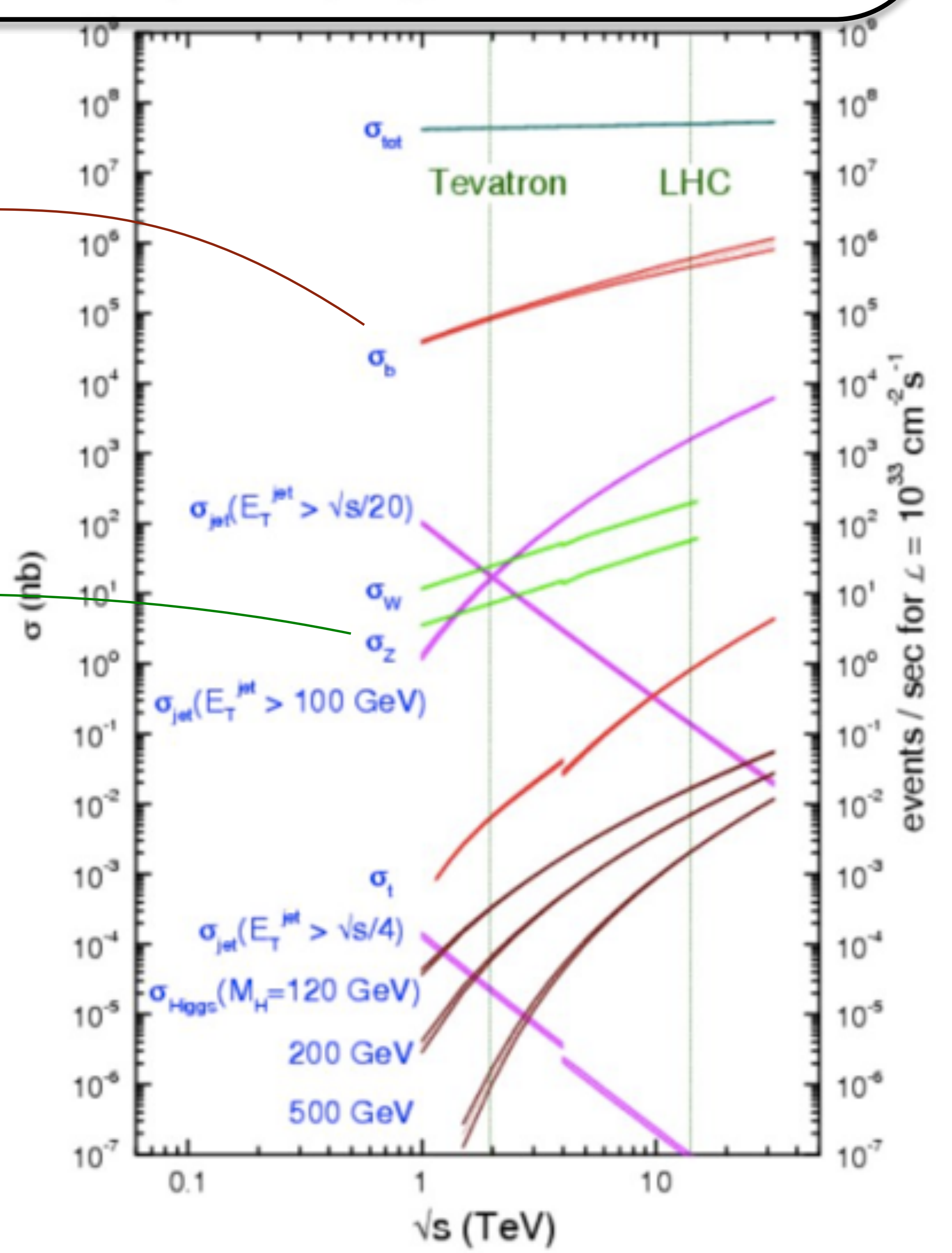

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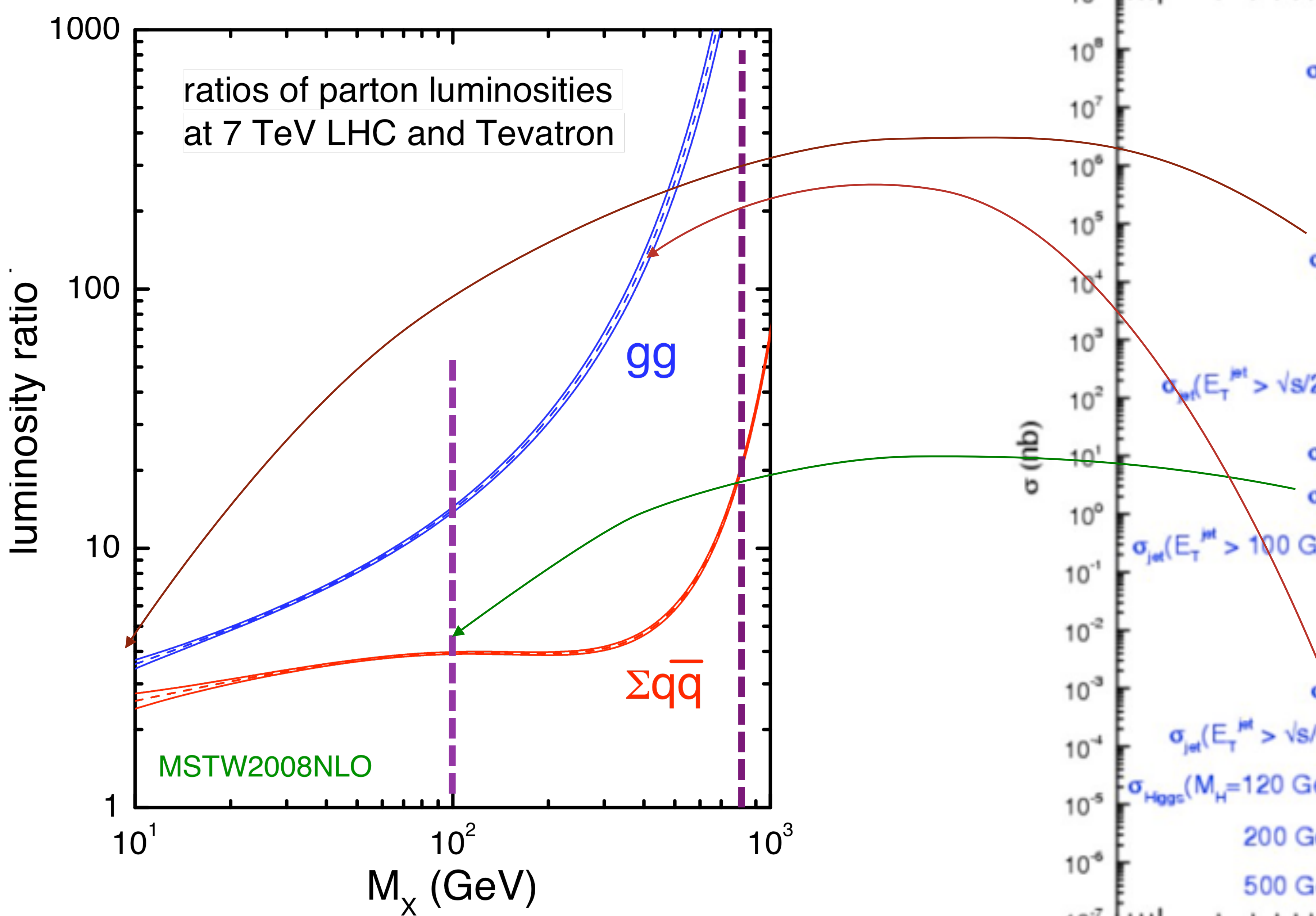

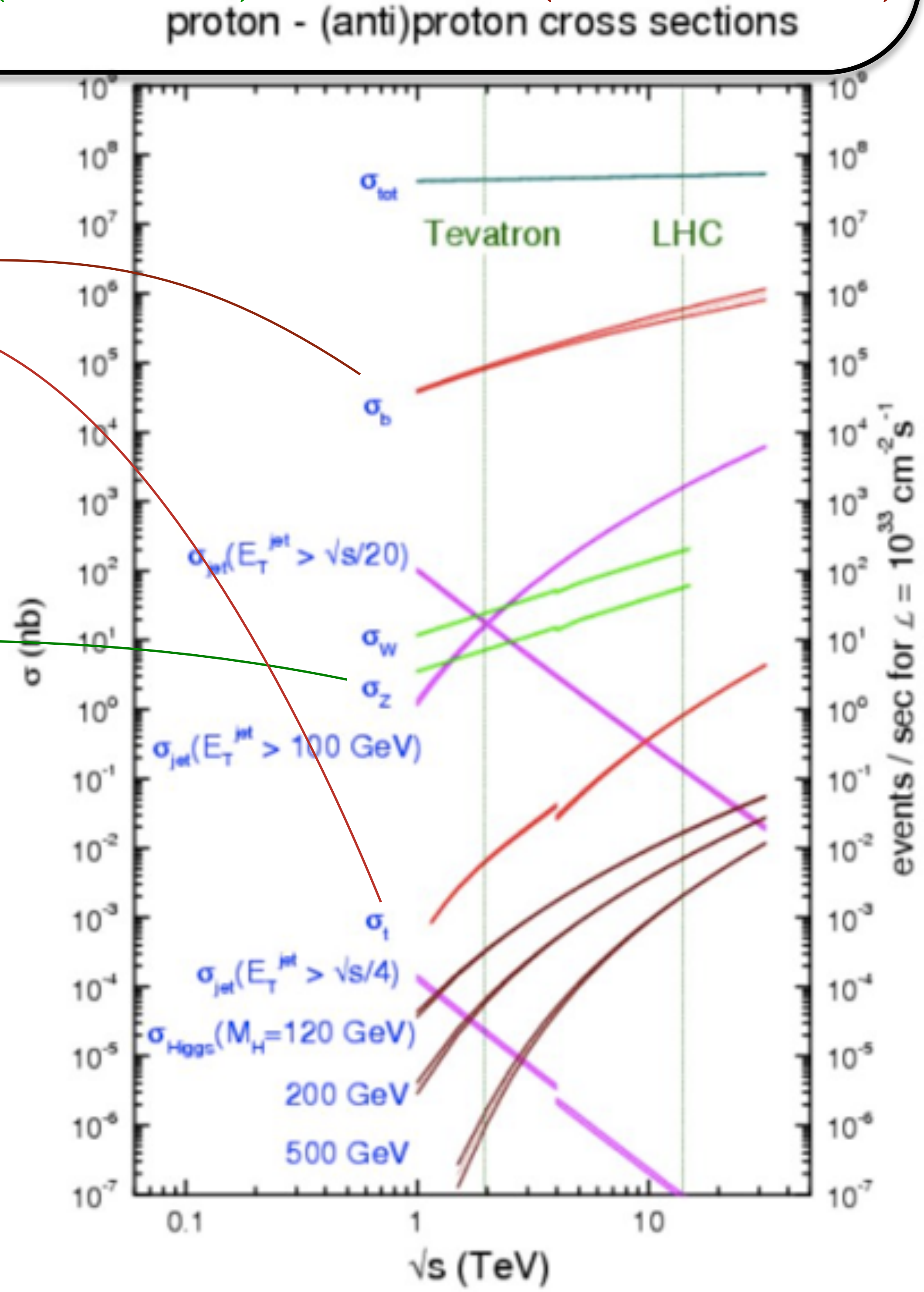

Perturbative expansion

$d\hat{\sigma}_{ab\to X}(\hat{s},\mu_F,\mu_R)$ **Parton-level cross section**

- The parton-level cross section can be computed as a series in perturbation theory, using the coupling constant as an expansion parameter, schematically:

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

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LO predictions

Perturbative expansion

$d\hat{\sigma}_{ab\to X}(\hat{s},\mu_F,\mu_R)$ **Parton-level cross section**

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LO predictions | NLO corrections | NNLO corrections | N3LO or NNNLO corrections

- Including higher corrections improves predictions and reduces theoretical uncertainties

Improved predictions

$$d\sigma = \sum_{a,b} \int dx_1 dx_2 \ f_a(x_1, \mu_F) f_b(x_2, \mu_F) \, d\hat{\sigma}_{ab\to X}(\hat{s}, \mu_F, \mu_R)$$

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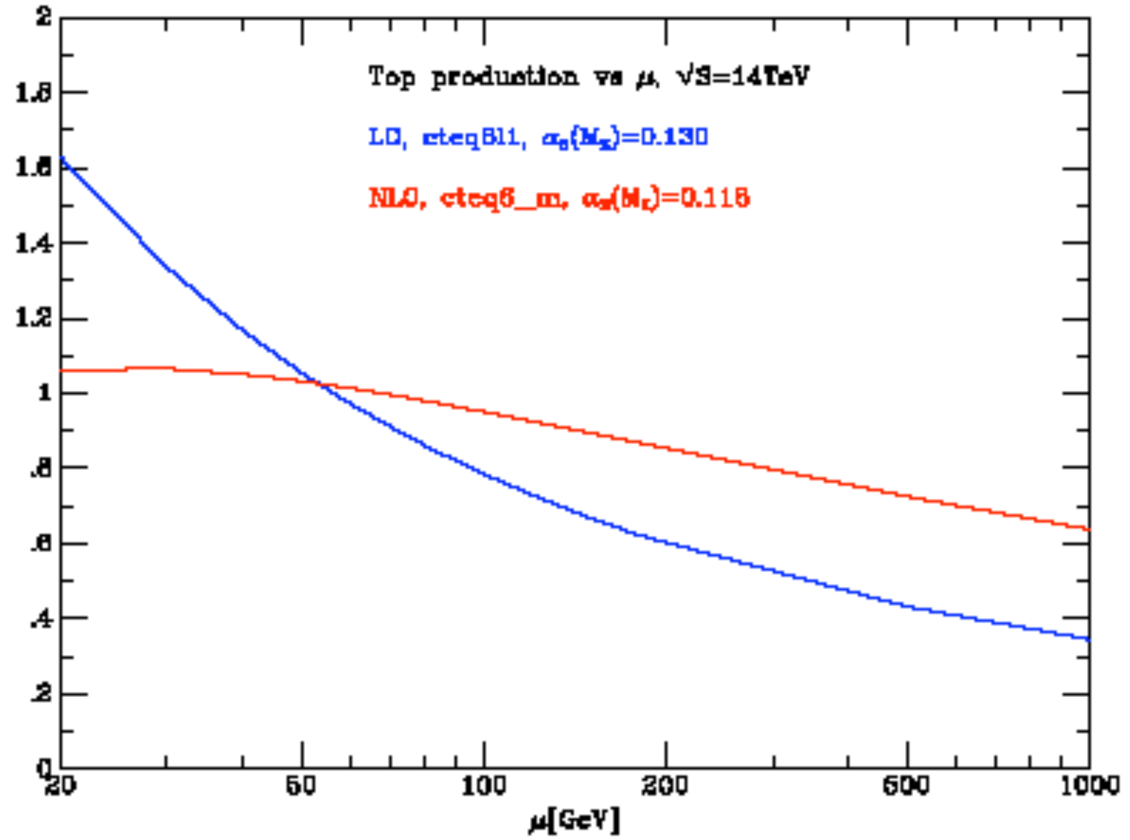
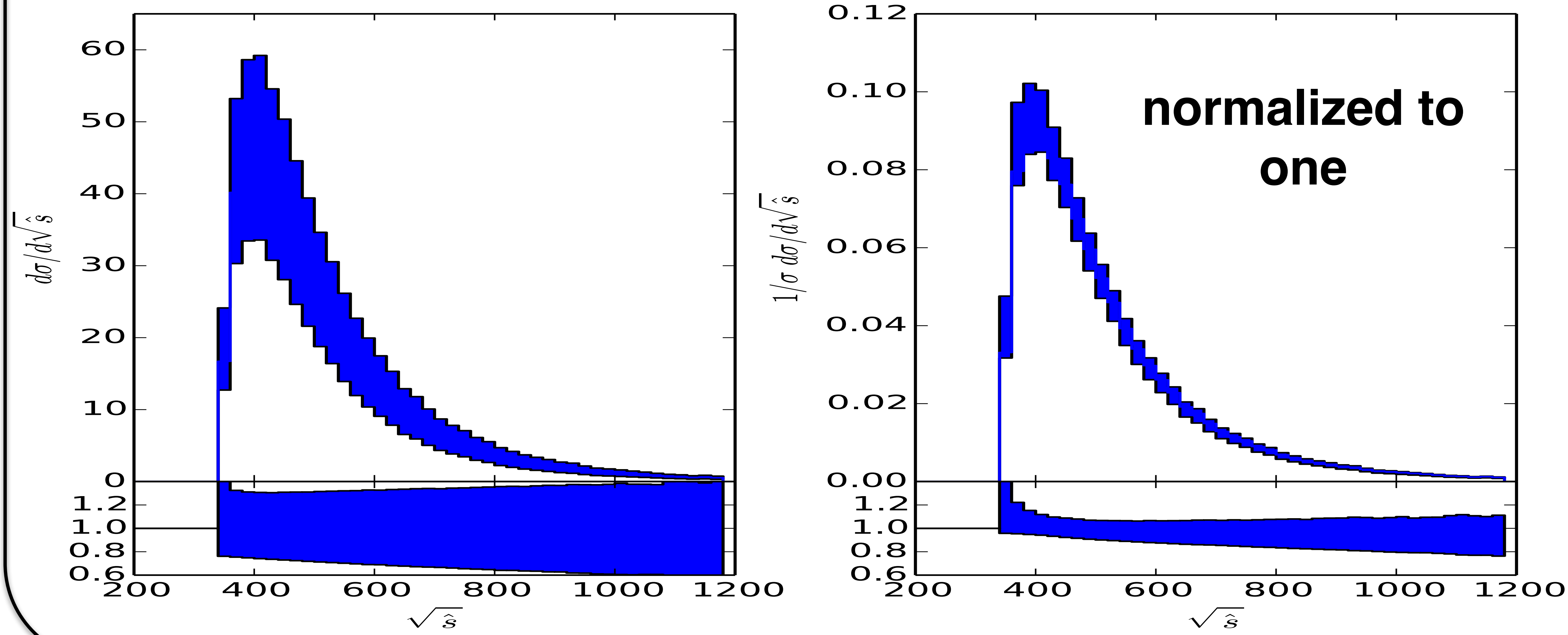
- Leading Order predictions can depend strongly on the renormalization and factorization scales
- Including higher order corrections reduces the dependence on these scales



LO

LO computation (top quark pair)



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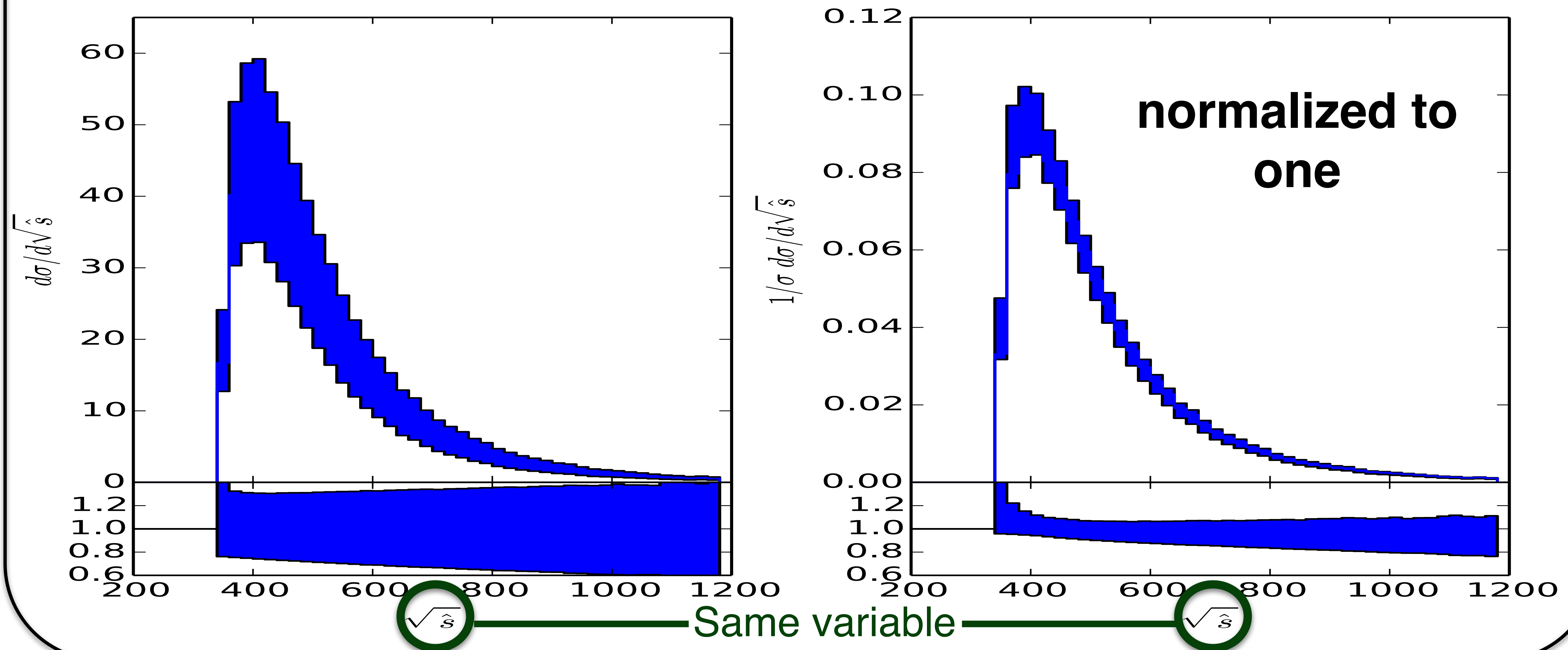

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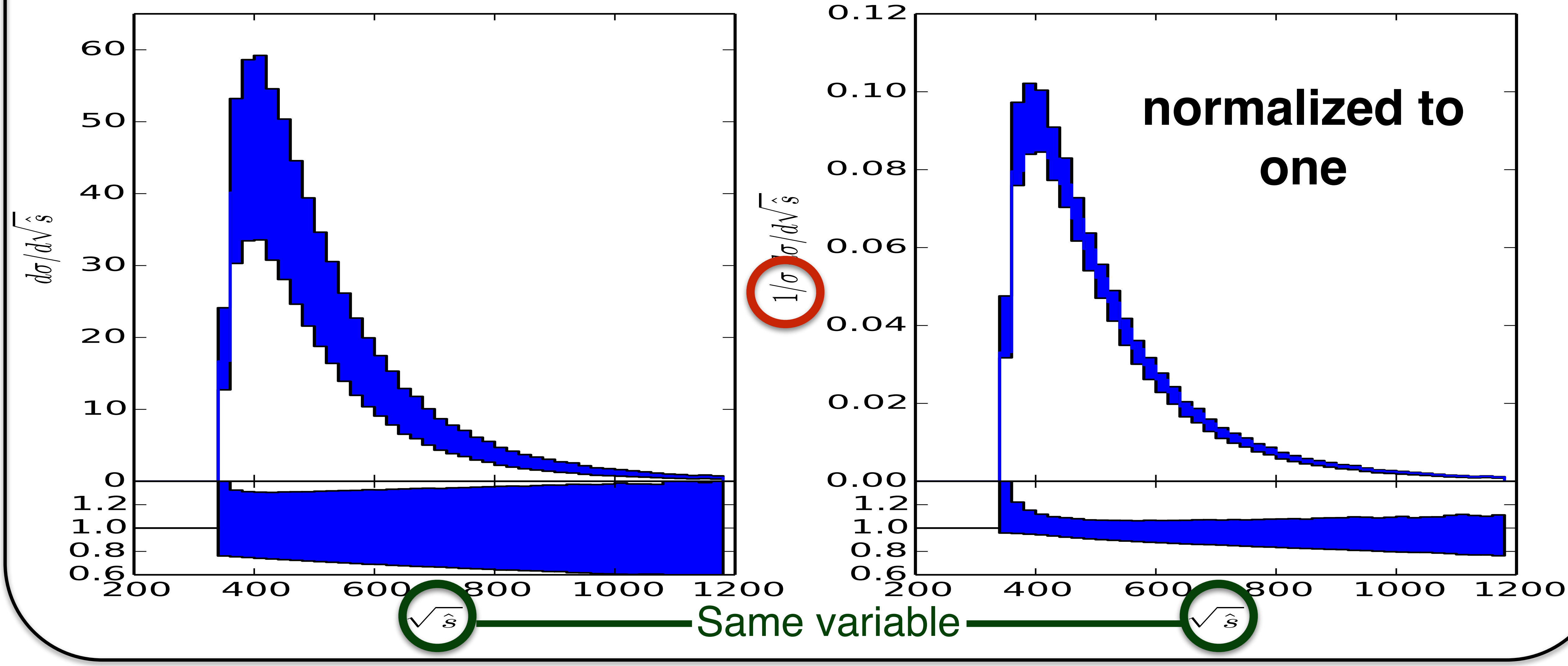

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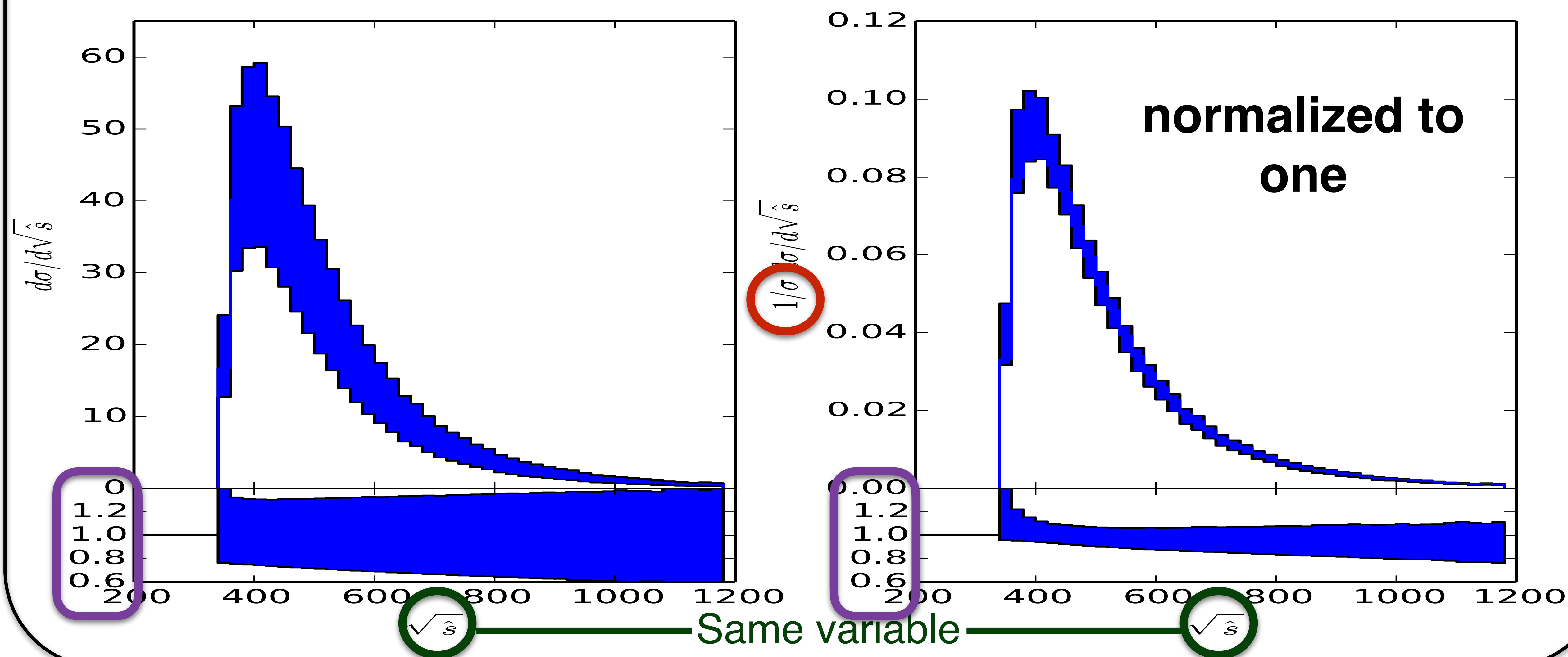

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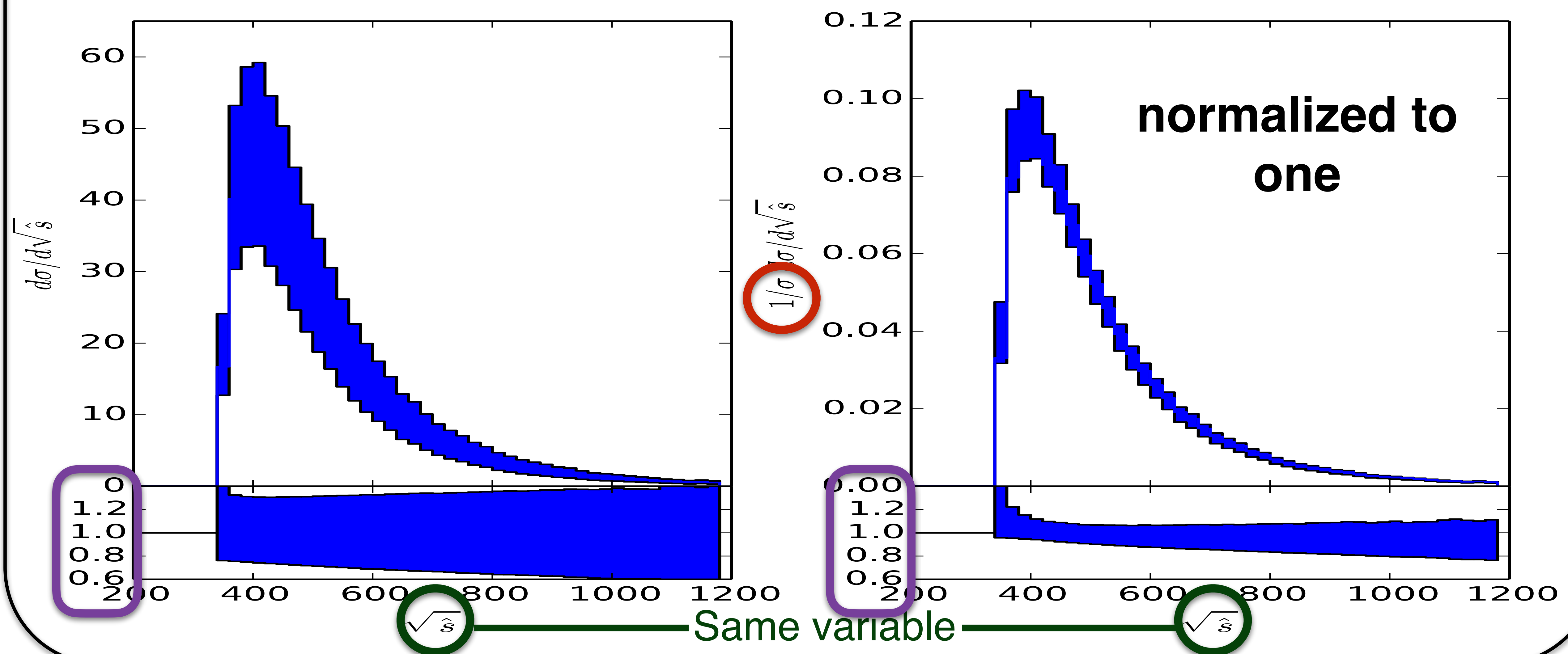

At LO:
- Large scale uncertainty
- but mainly in the Normalisation
- LO is good for shape

Question time

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Code d'événement
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To Remember

$$\sum_{a,b} \int dx_1 dx_2 d\Phi_{\mathrm{FS}}\, f_a(x_1, \mu_F) f_b(x_2, \mu_F)\, \hat{\sigma}_{ab\to X}(\hat{s}, \mu_F, \mu_R)$$

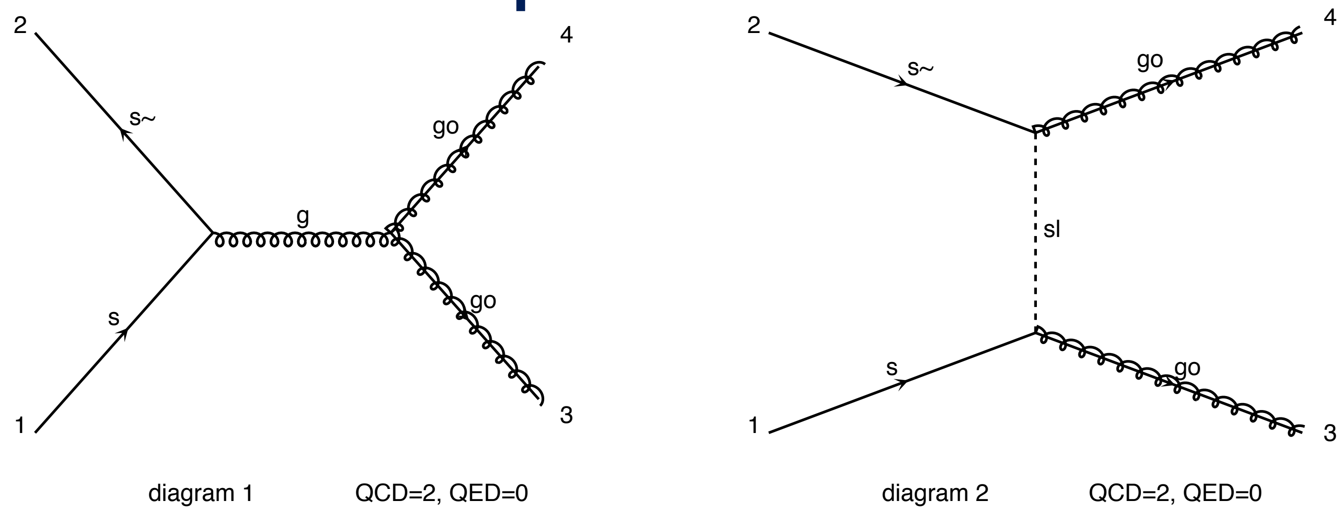
Phase-space integral — Parton density functions — Parton-level cross section

- PDF: content of the proton
  - ➡ Define the physics/processes that will dominate on your accelerator
- LO: good for shape
- NLO/NNLO: Reduce scale uncertainty
- Computation are inclusive (+ any jet) due to renormalization/factorization scale

Matrix-Element

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

- Determine the production mechanism



- Evaluate the matrix-element

$$|\mathcal{M}|^2$$ ➡Need Feynman Rules!

- Phase-Space Integration

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

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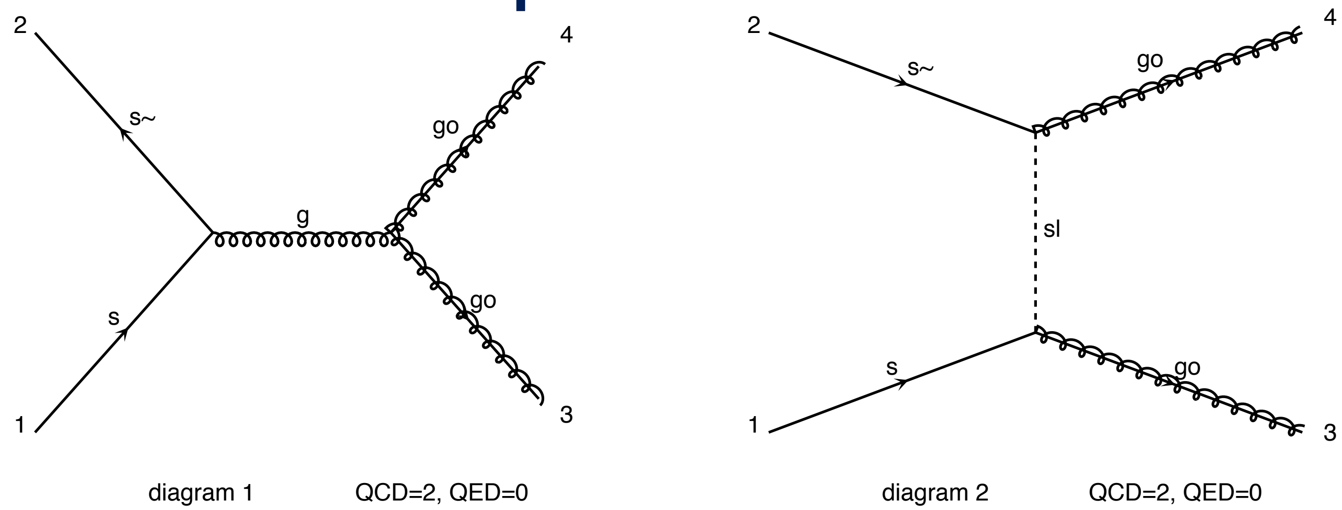

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Easy enough

Hard

Very Hard (in general)

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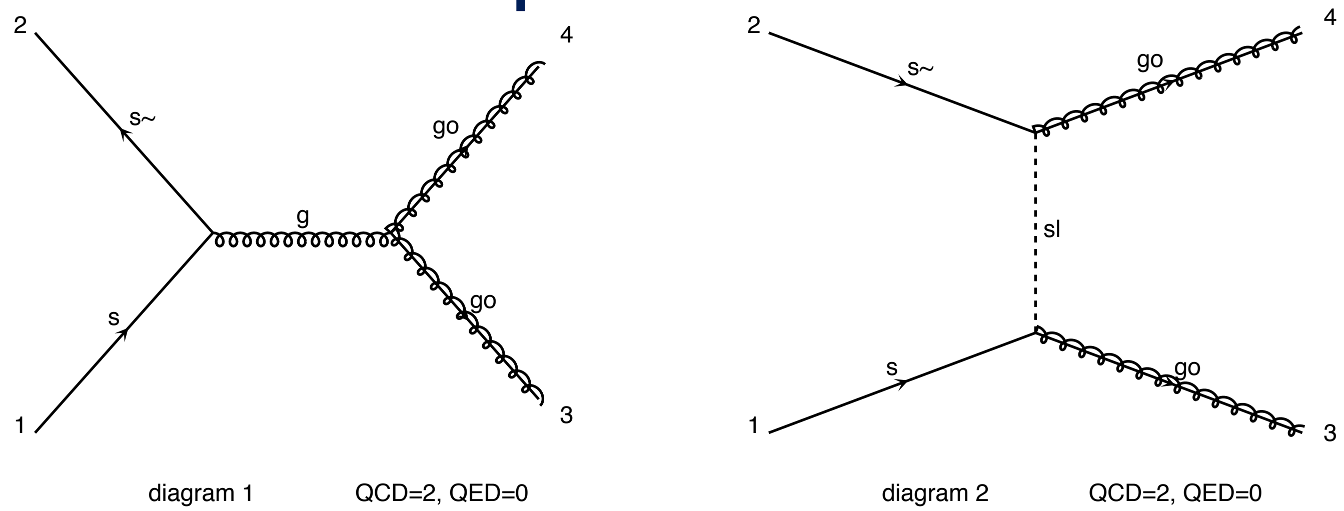

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Very Hard (in general)

Now

Matrix-Element

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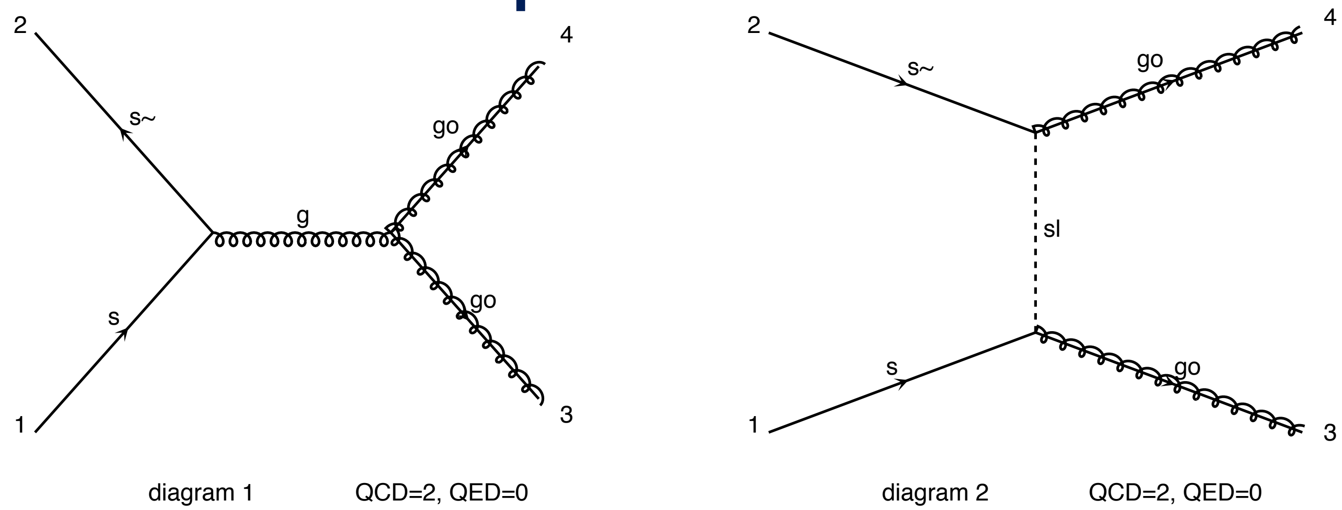
- Determine the production mechanism



Easy enough

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$|\mathcal{M}|^2$ ➡Need Feynman Rules!

Hard

Tommorow

- Phase-Space Integration

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

Very Hard (in general)

Now

Monte Carlo Integration

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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Monte Carlo Integration

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General and flexible method is needed

Monte Carlo Integration

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

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

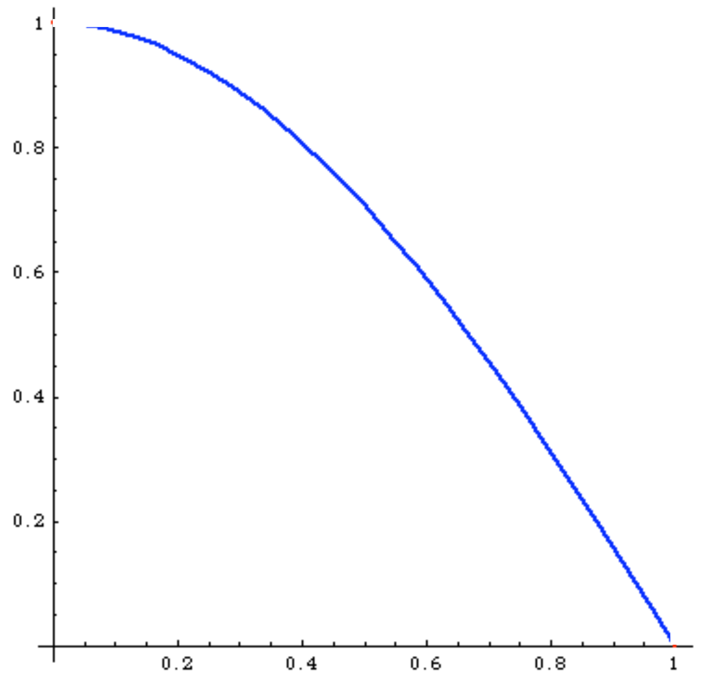
$$Dim[\Phi(n)] \sim 3n$$

General and flexible method is needed

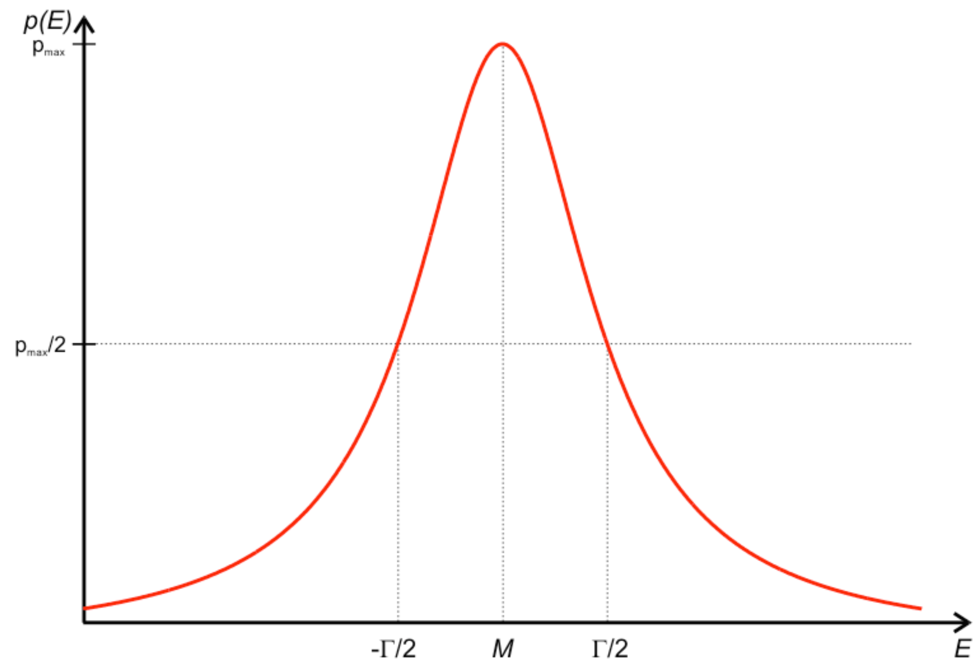
Not only integrating but also **generates events**

Integration

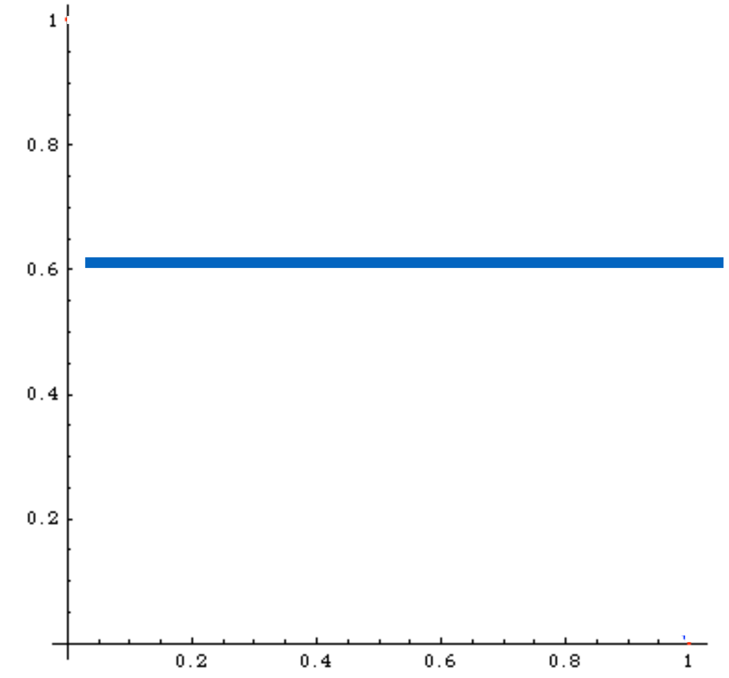
$$I = \int_0^1 dx \cos\frac{\pi}{2}x$$



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



$$\int dx\, C$$



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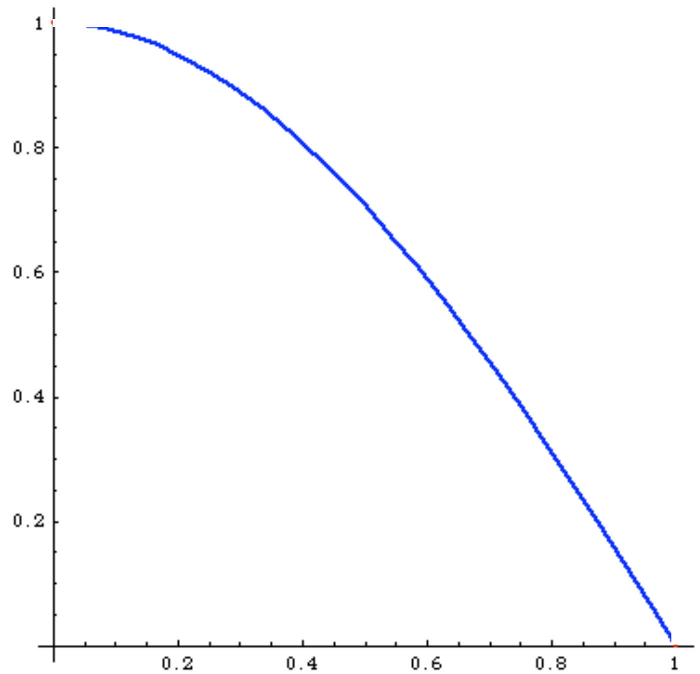

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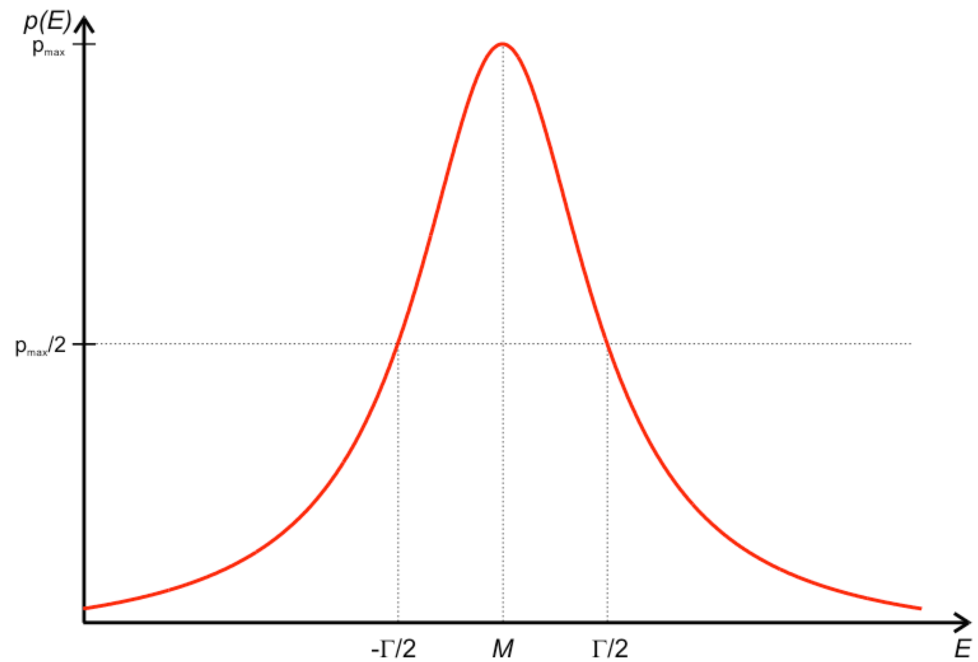

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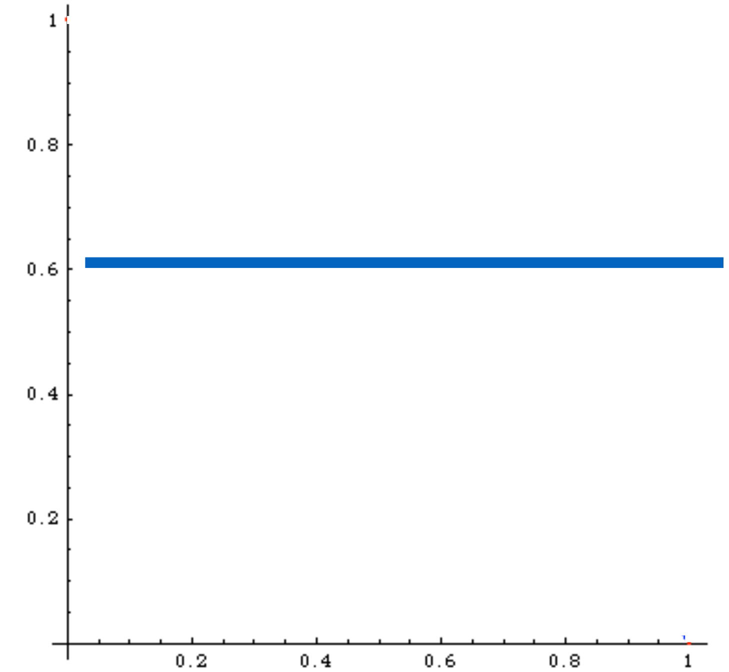

Method of evaluation

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

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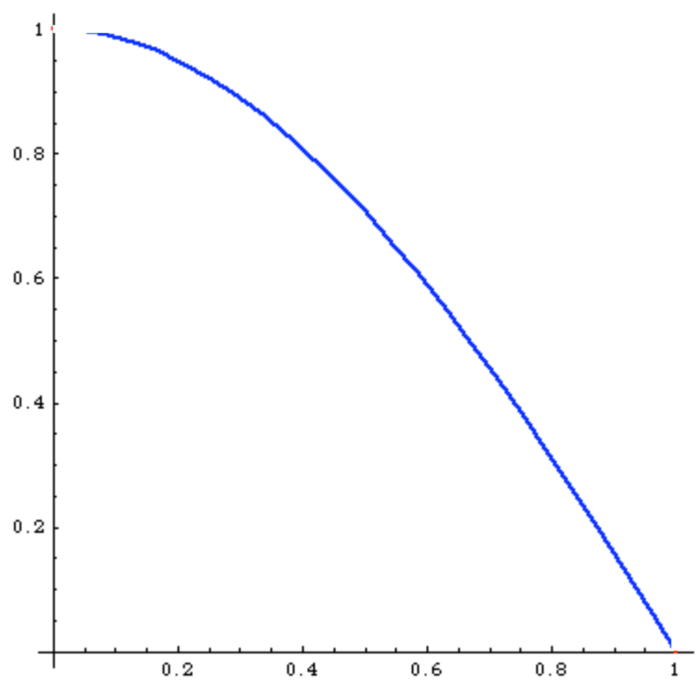

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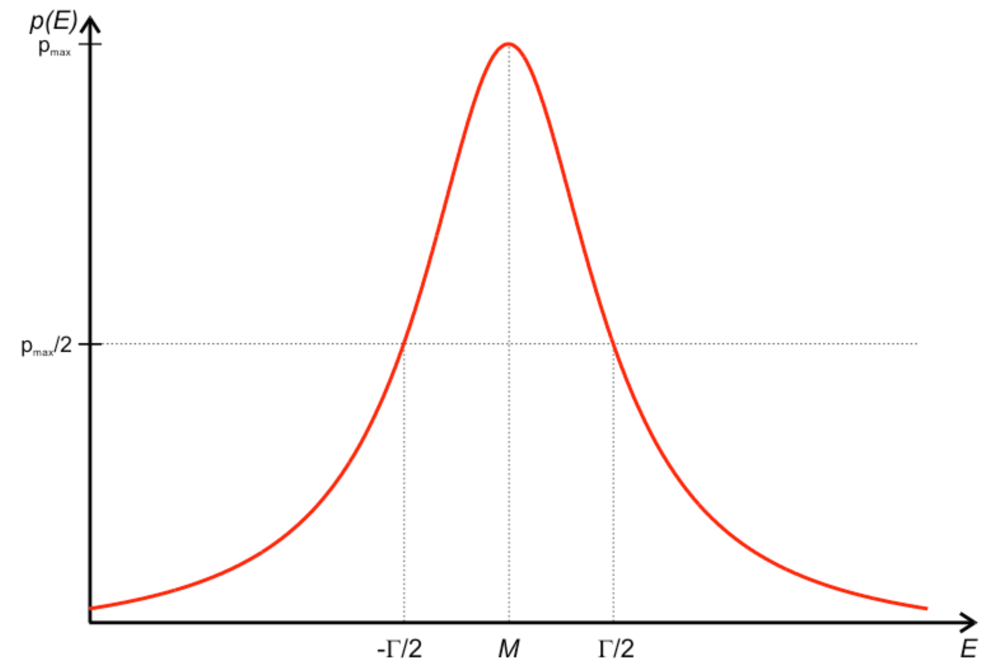
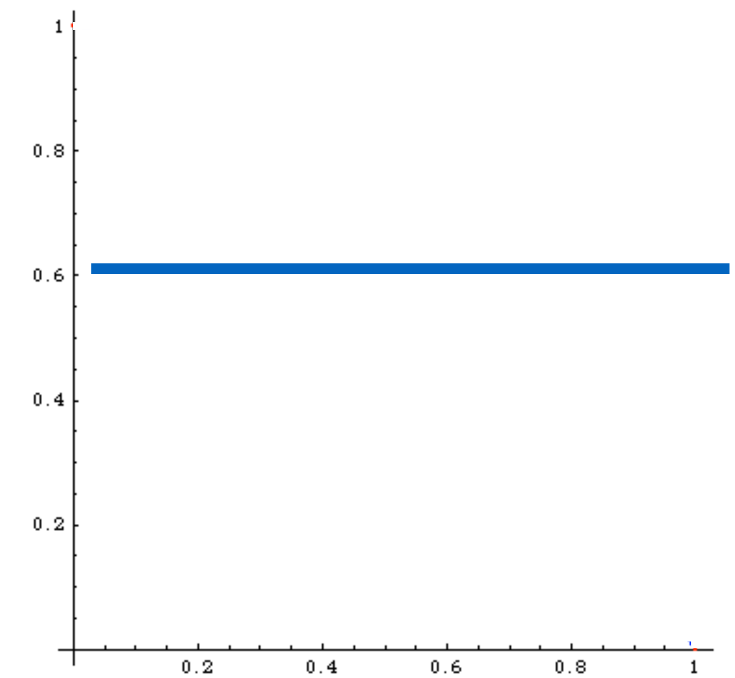


$$\int dx\, C$$



	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

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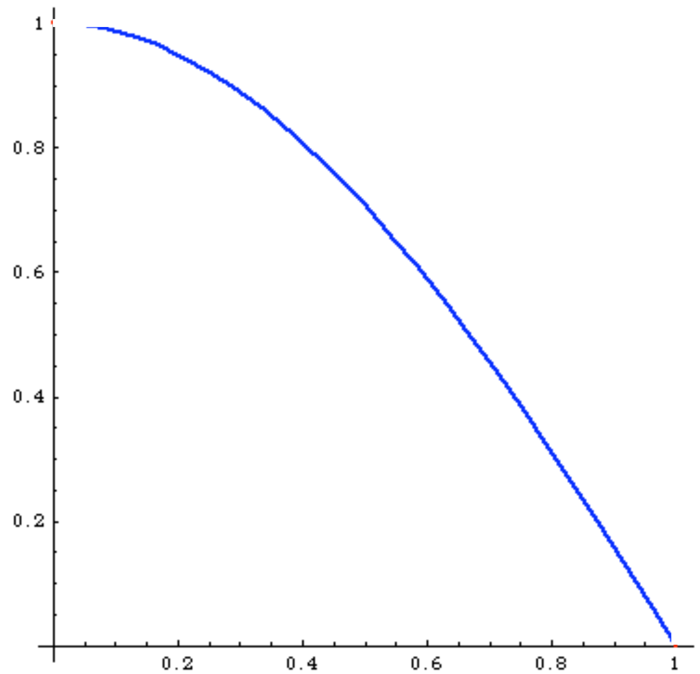
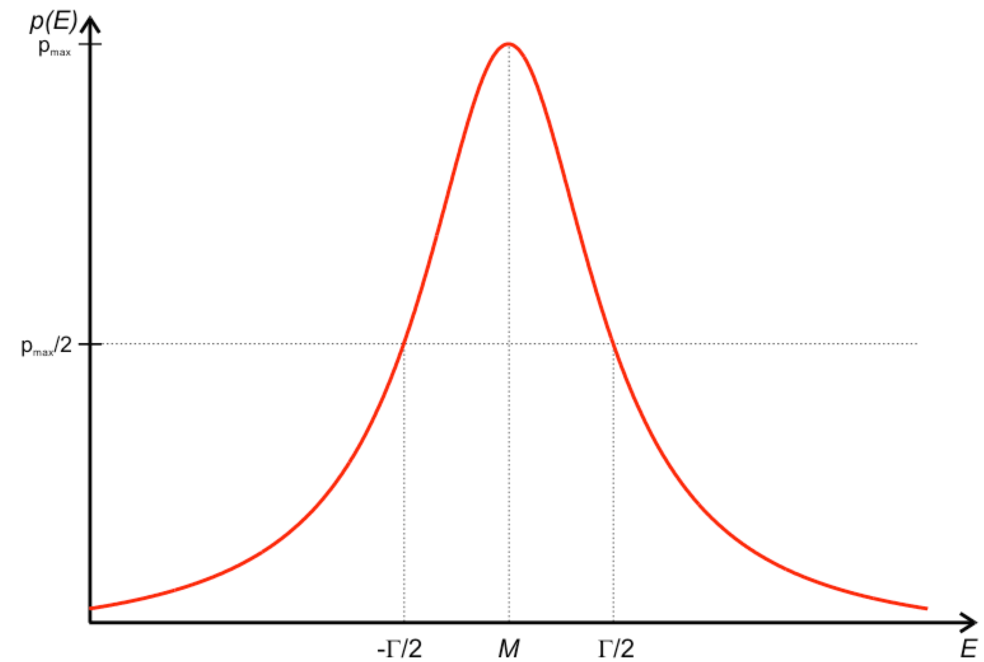
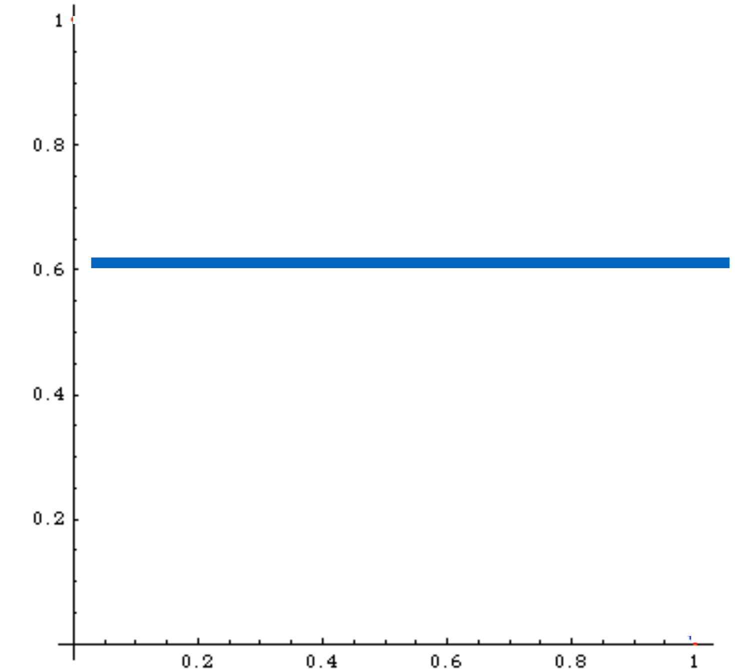


$$\int \frac{dq^2}{(q^2 - M^2 + iM\Gamma)^2}$$



$$\int dx\, C$$



Method of evaluation

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

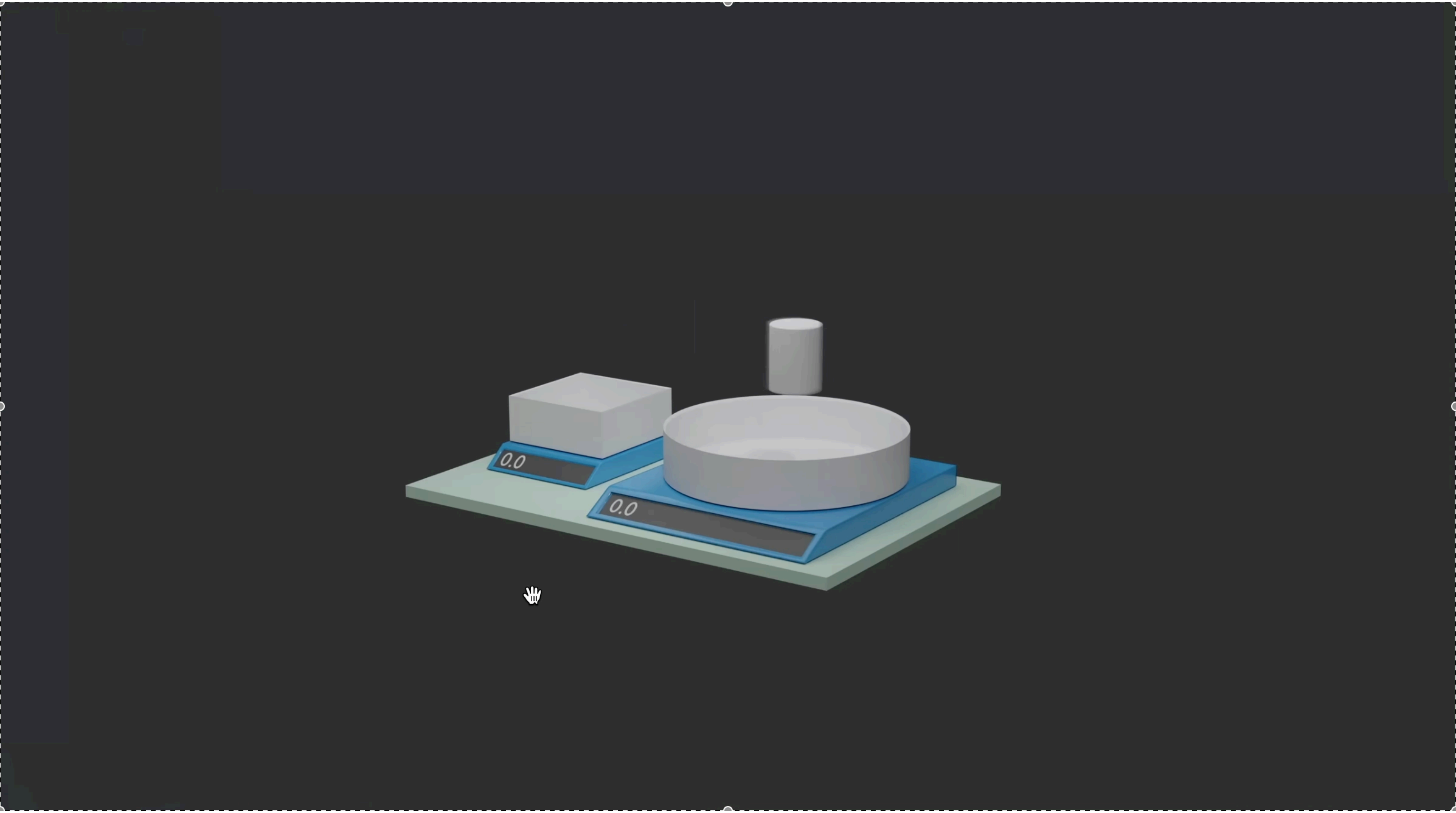
More Dimension →

$1/\sqrt{N}$

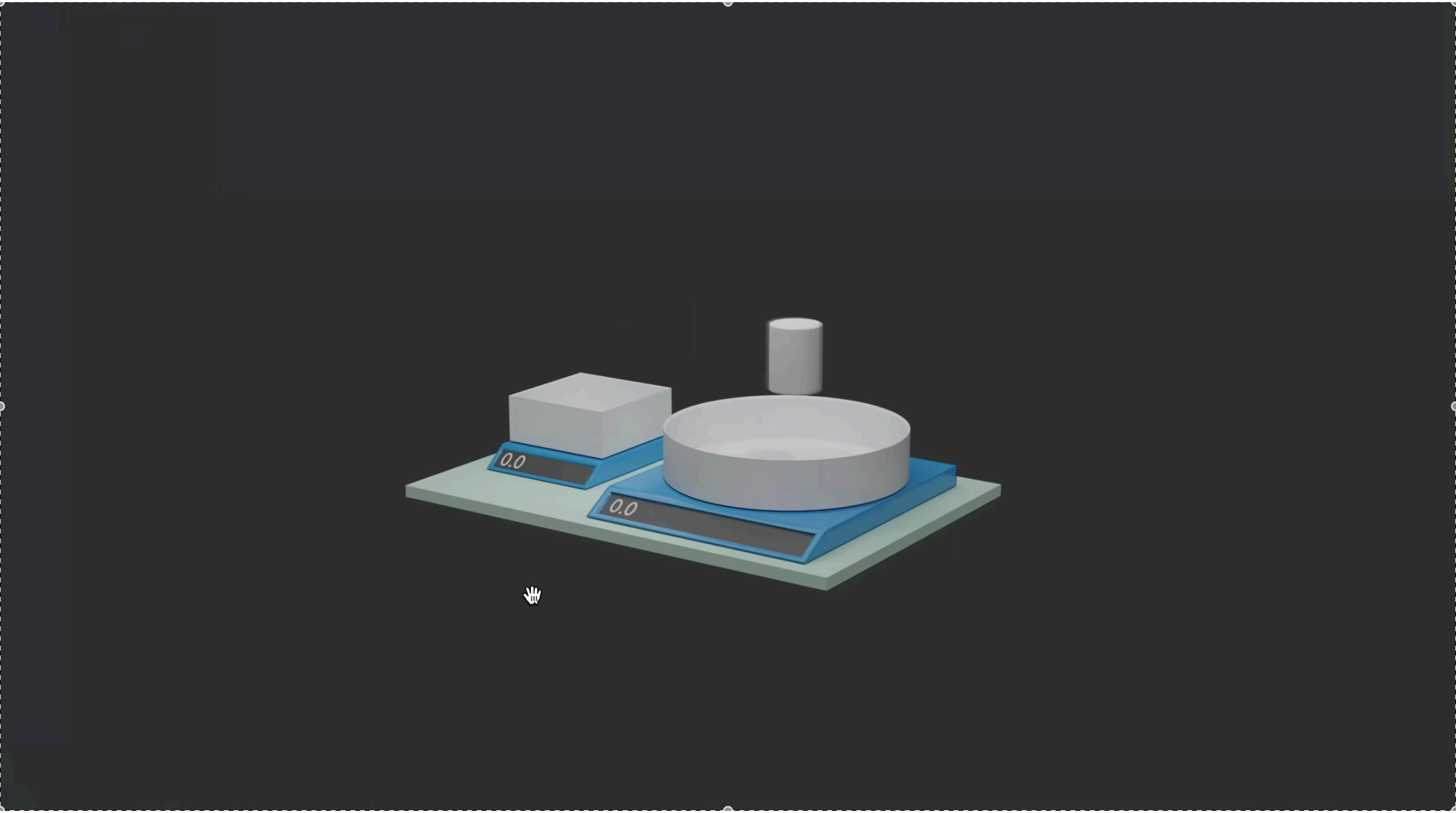
$1/N^{2/d}$

$1/N^{4/d}$

Monte-Carlo



Monte-Carlo



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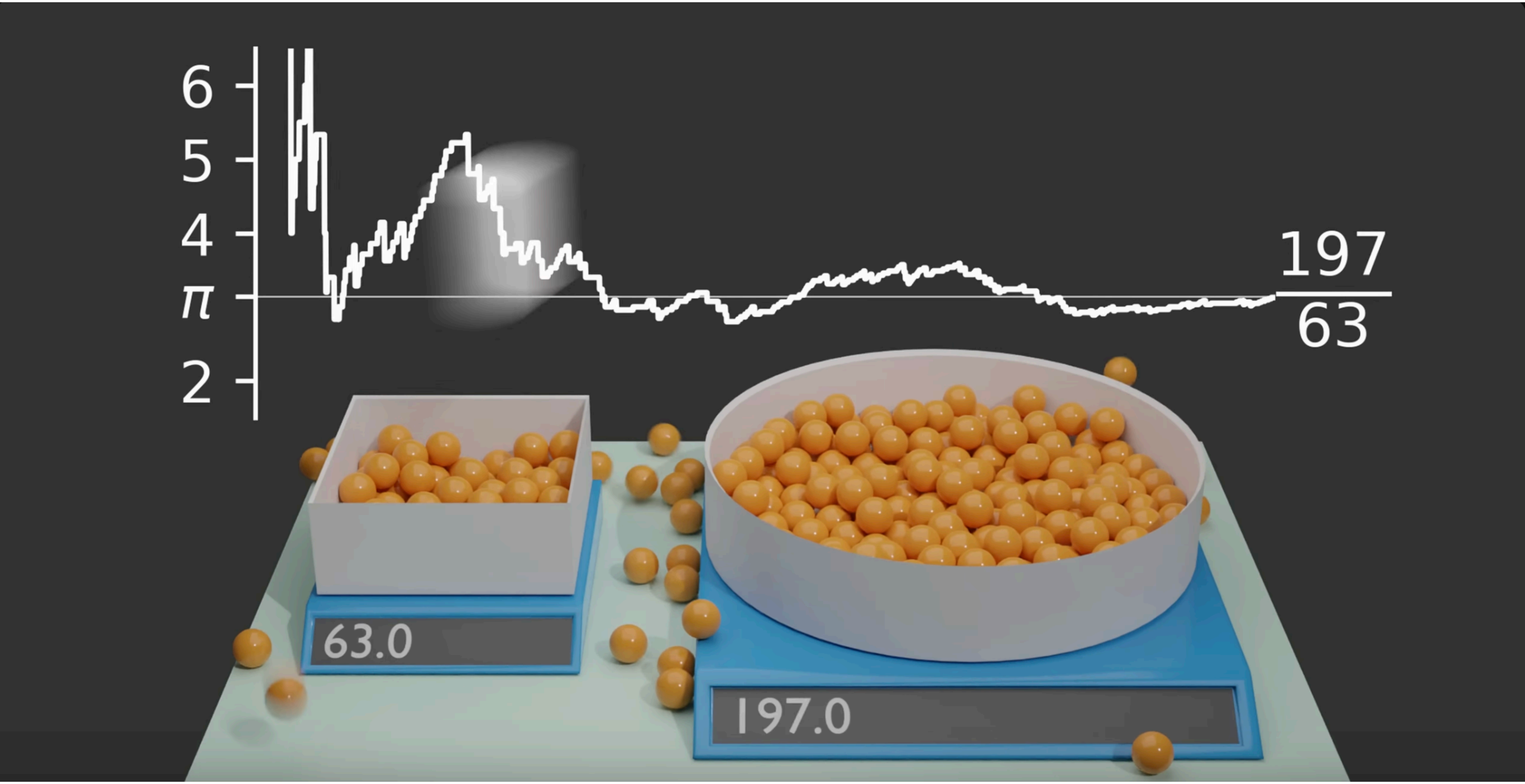
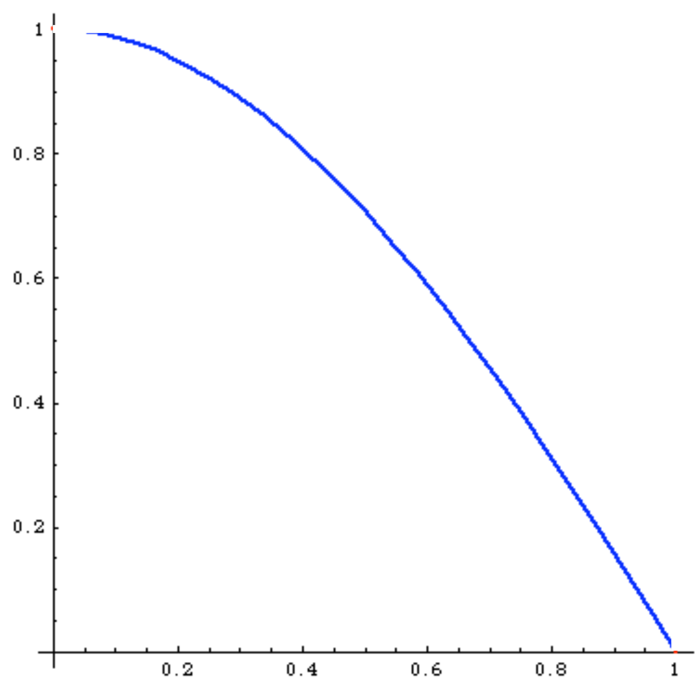
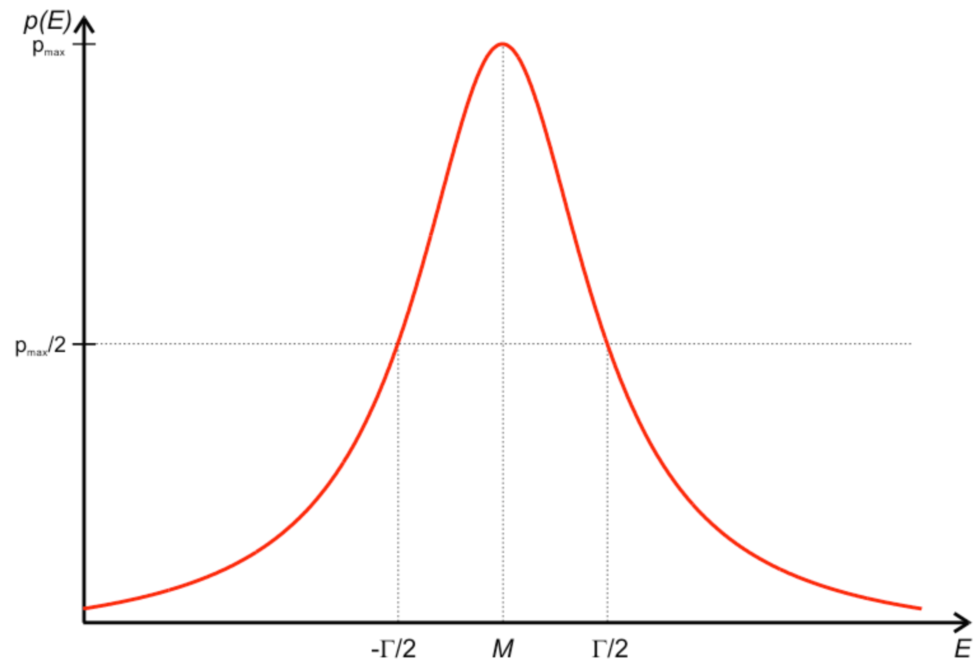


Integration

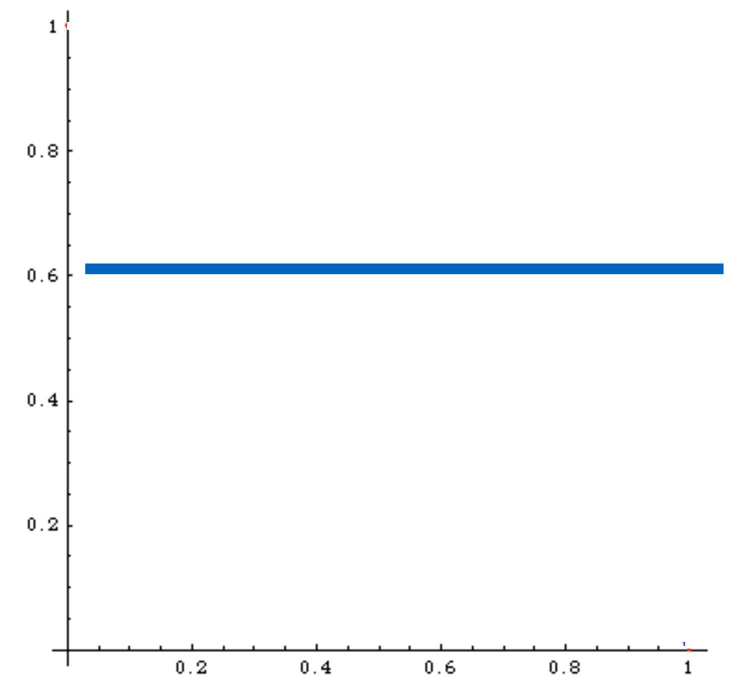
$$I = \int_0^1 dx \cos\frac{\pi}{2}x$$



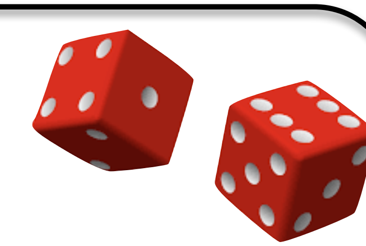
$$\int \frac{dq^2}{(q^2 - M^2 + iM\Gamma)^2}$$



$$\int dx\, C$$



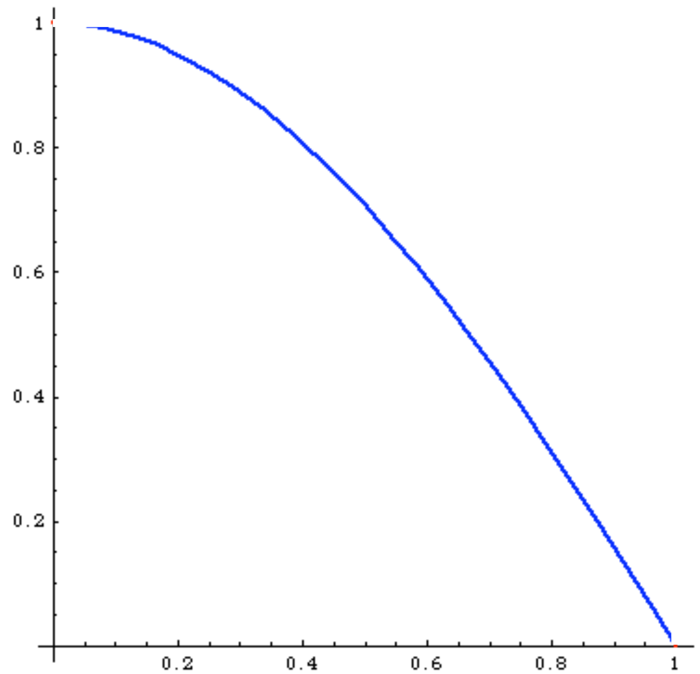
$$I = \int_{x_1}^{x_2} f(x)dx \quad \Rightarrow \quad I_N = (x_2 - x_1)\frac{1}{N}\sum_{i=1}^{N} f(x)$$



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

Integration

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



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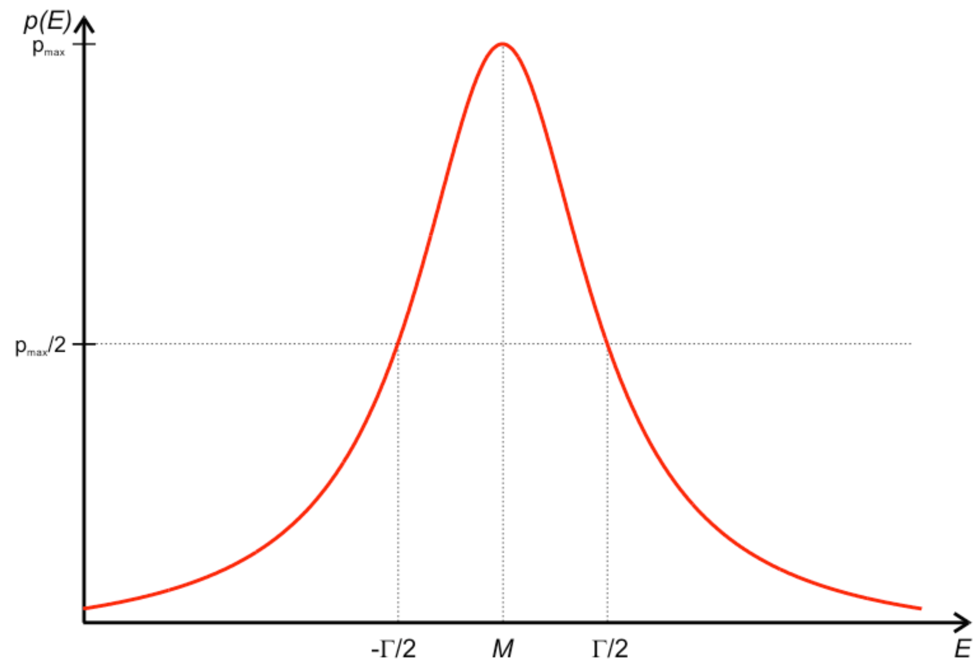
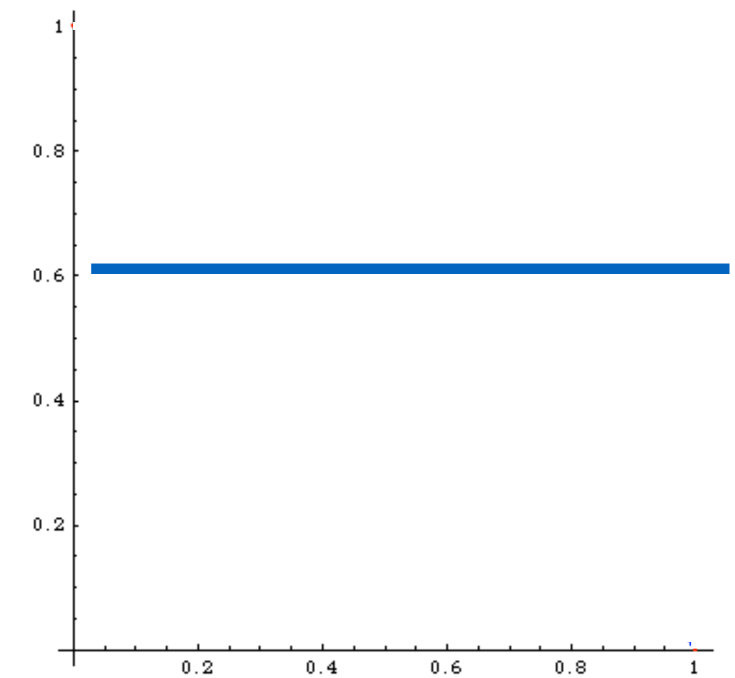
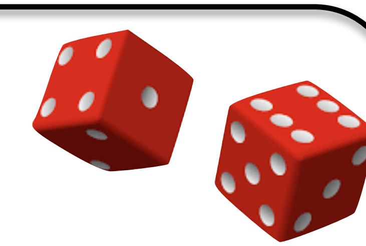


$$\int dx\, C$$



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

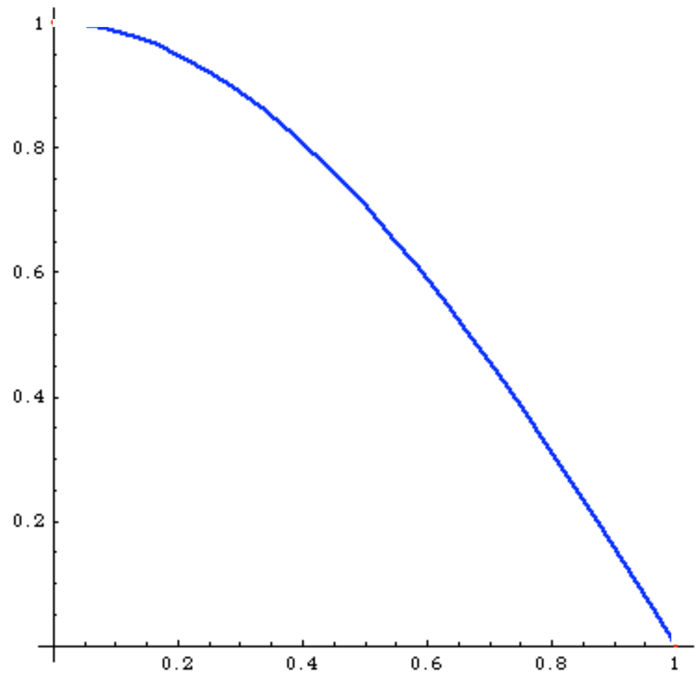


$$V = (x_2 - x_1)\int_{x_1}^{x_2} [f(x)]^2 dx - I^2 \rightarrow V_N = (x_2 - x_1)^2 \frac{1}{N}\sum_{i=1}^{N}[f(x)]^2 - I_N^2$$

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

Integration

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



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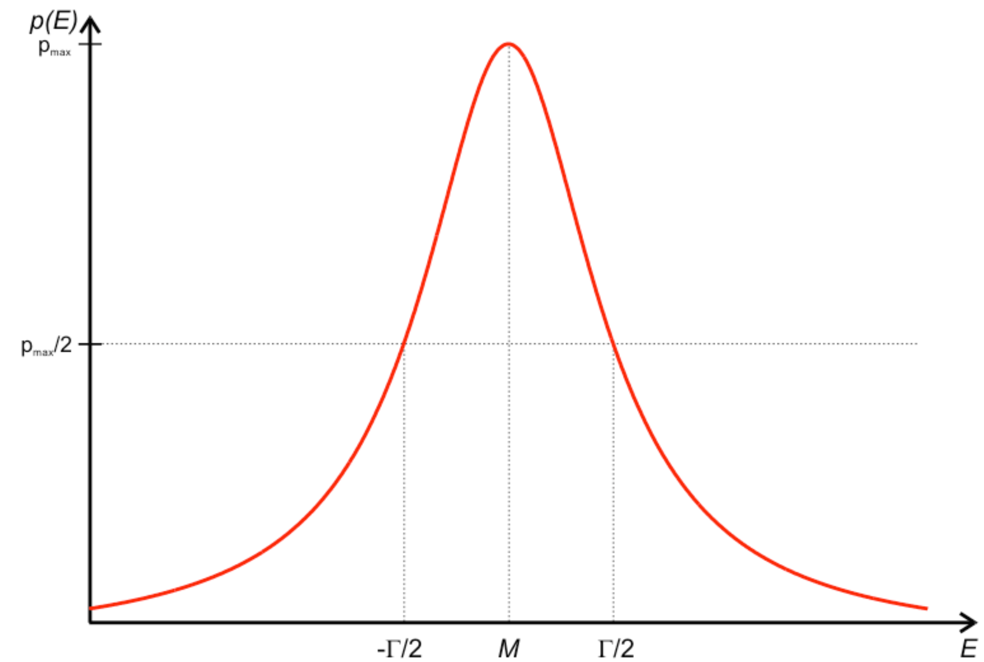

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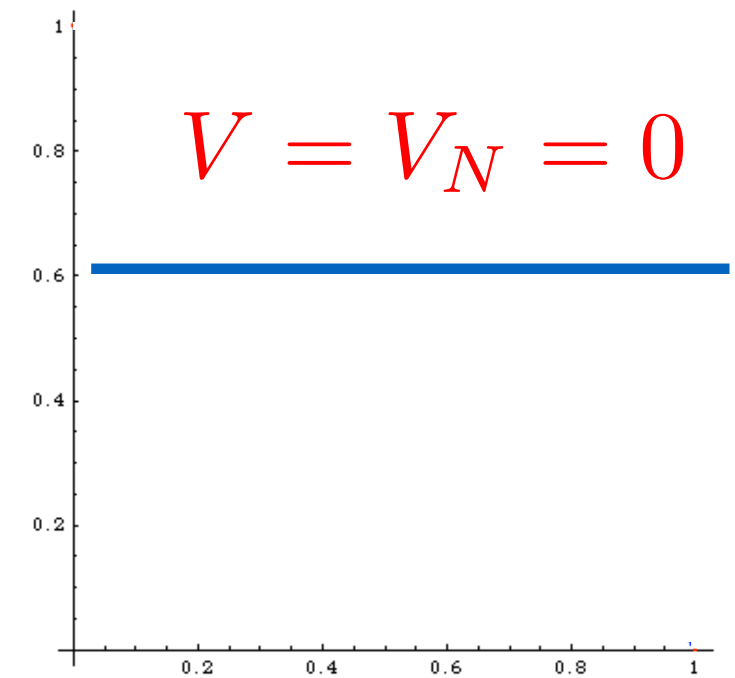
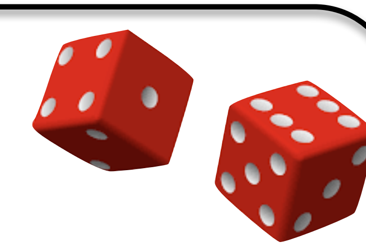


$$I = \int_{x_1}^{x_2} f(x) dx \quad \Rightarrow \quad I_N = (x_2 - x_1) \frac{1}{N} \sum_{i=1}^{N} f(x)$$



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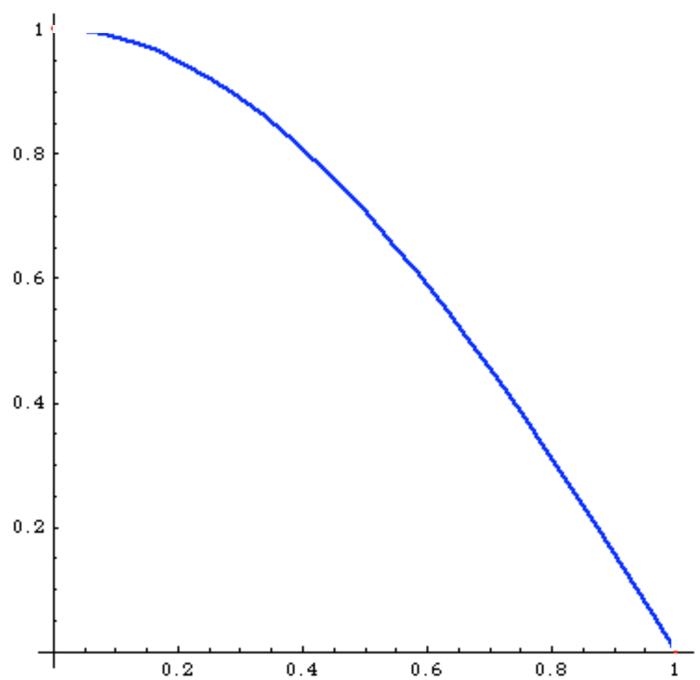
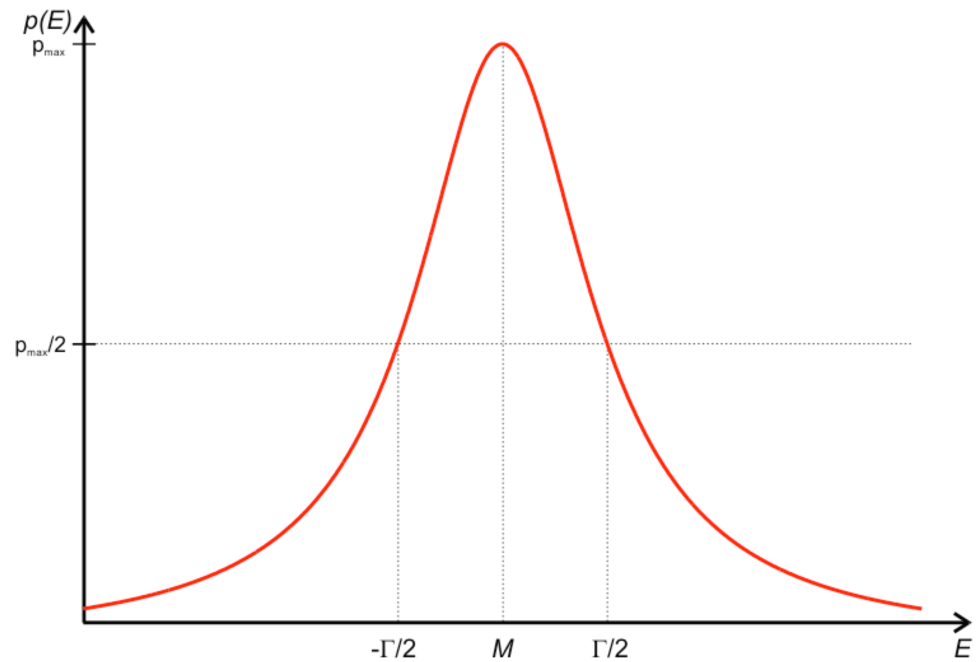
Integration

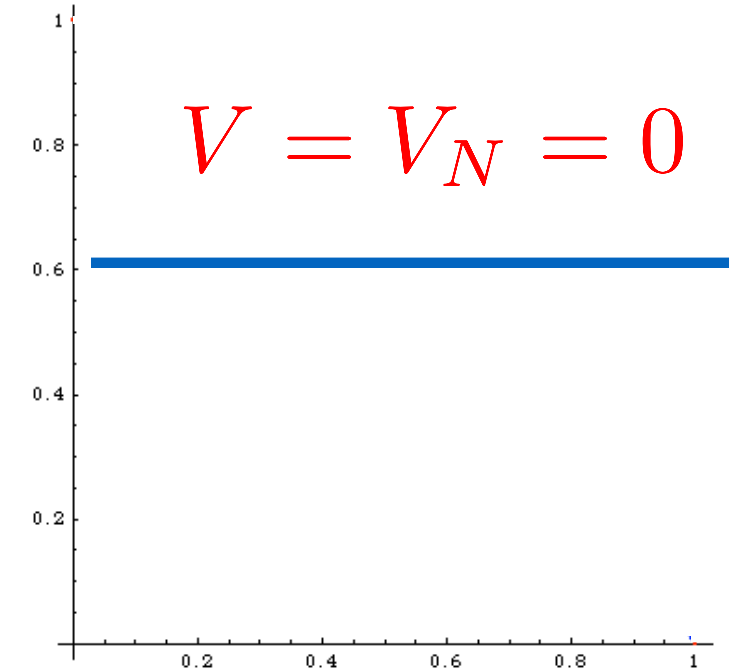
$$I = \int_0^1 dx \cos \frac{\pi}{2} x$$



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

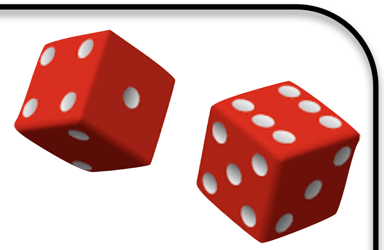


$$\int dx\, C$$



$$V = V_N = 0$$

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

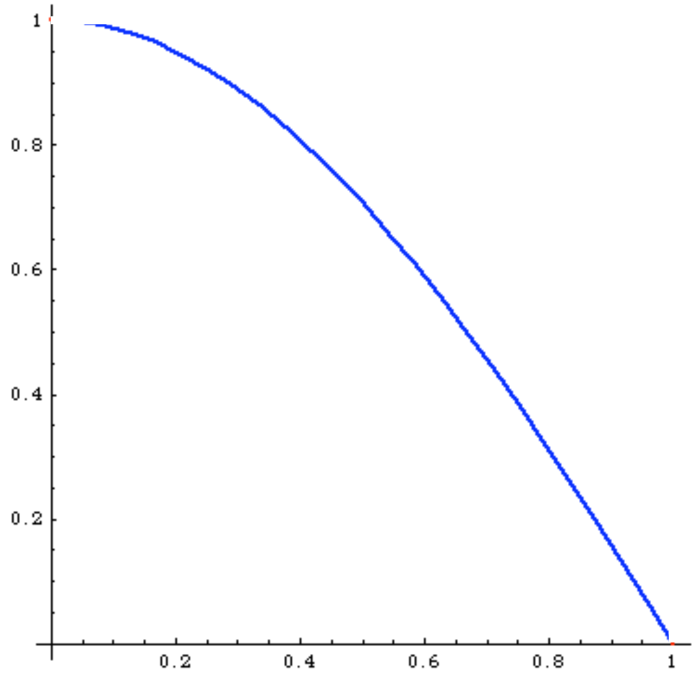


$$V = (x_2 - x_1)\int_{x_1}^{x_2} [f(x)]^2 dx - I^2 \;\Rightarrow\; V_N = (x_2 - x_1)^2 \frac{1}{N}\sum_{i=1}^{N} [f(x)]^2 - I_N^2$$

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

Can be minimized!

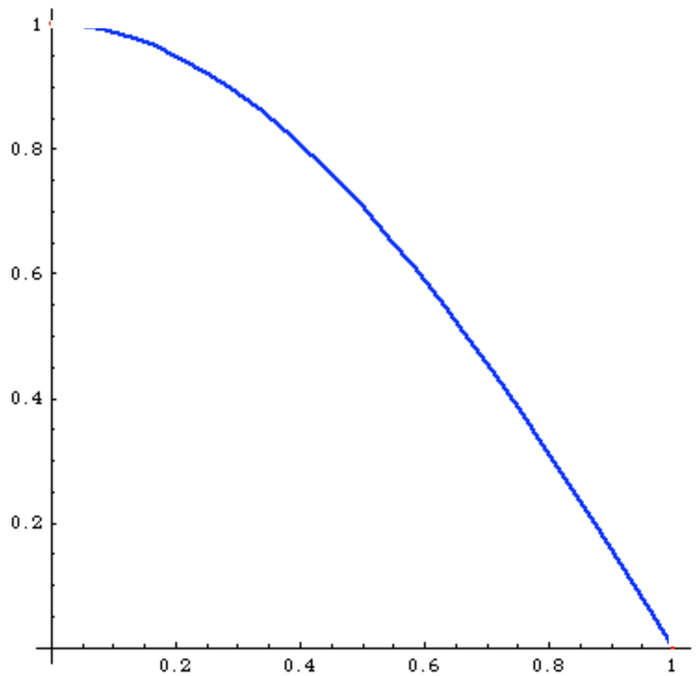
Importance Sampling



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

$$I_N = 0.637 \pm 0.307/\sqrt{N}$$

Importance Sampling



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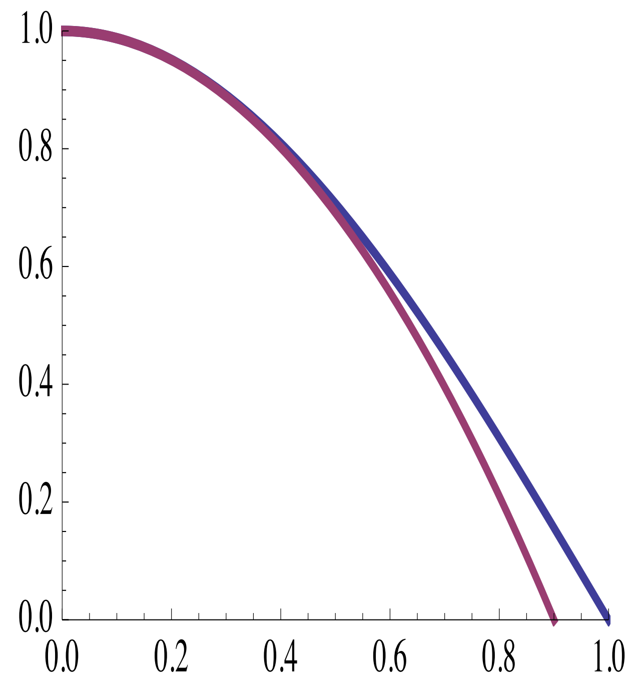
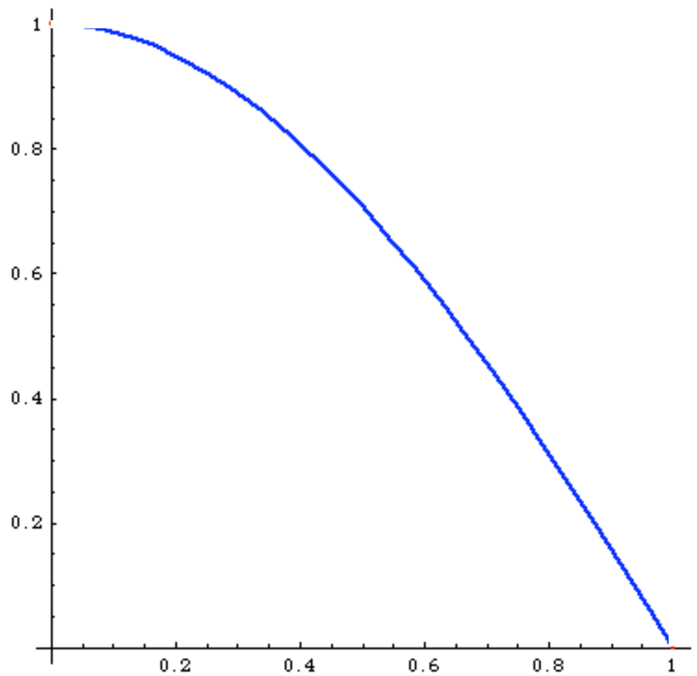


$$I = \int_0^1 dx(1-cx^2)\frac{\cos\left(\frac{\pi}{2}x\right)}{(1-cx^2)}$$

Importance Sampling



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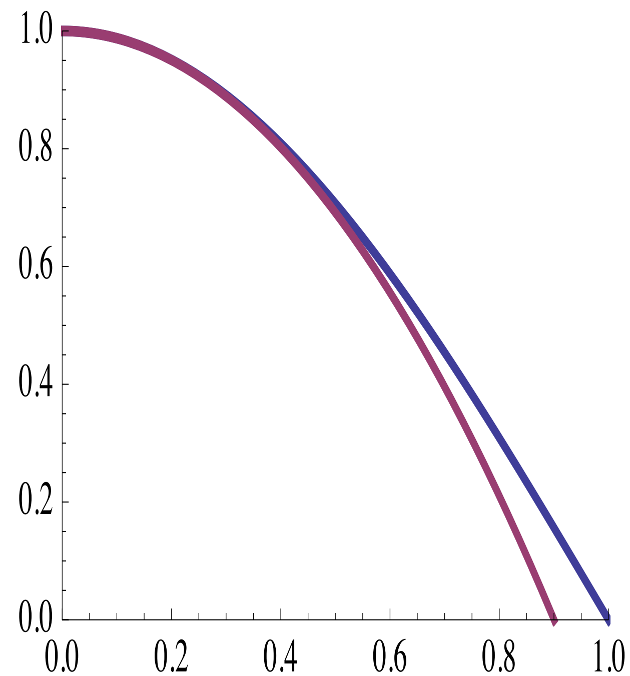
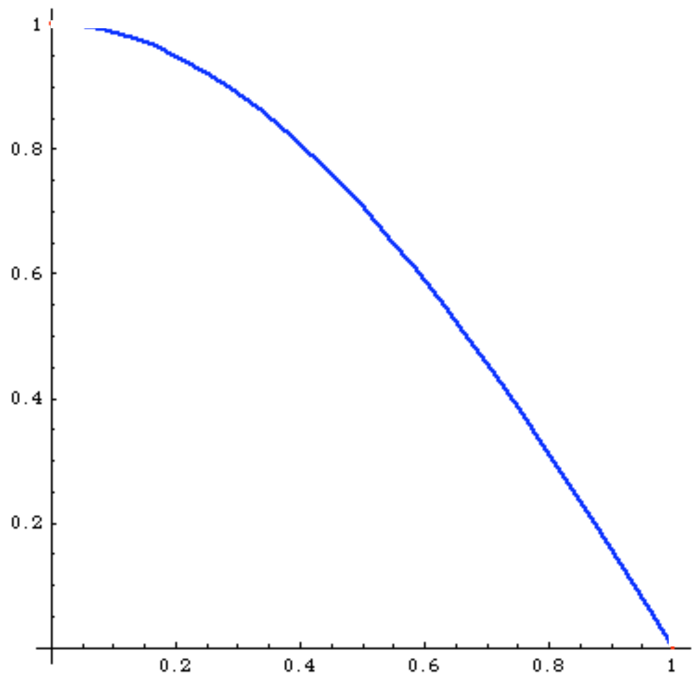


$$I = \int_0^1 dx(1 - cx^2) \frac{\cos\left(\frac{\pi}{2}x\right)}{(1 - cx^2)} = \int_{\xi_1}^{\xi_2} d\xi \frac{\cos \frac{\pi}{2} x[\xi]}{1 - x[\xi]^2 c}$$

Importance Sampling



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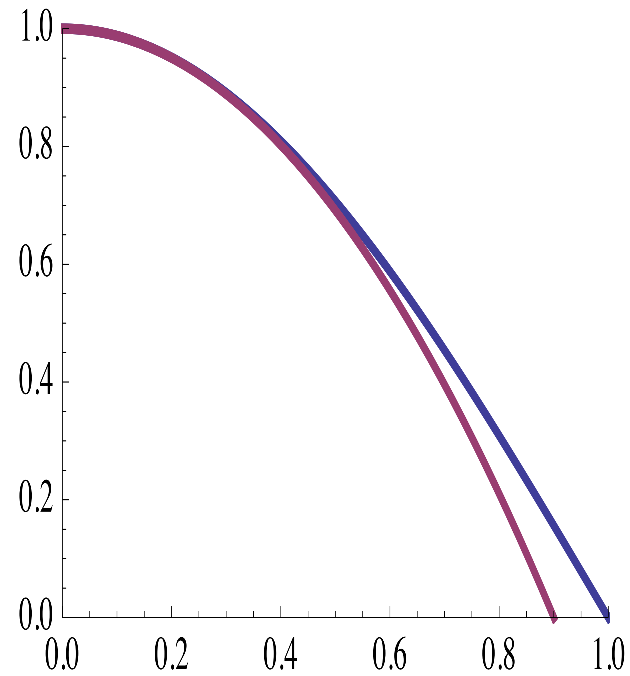
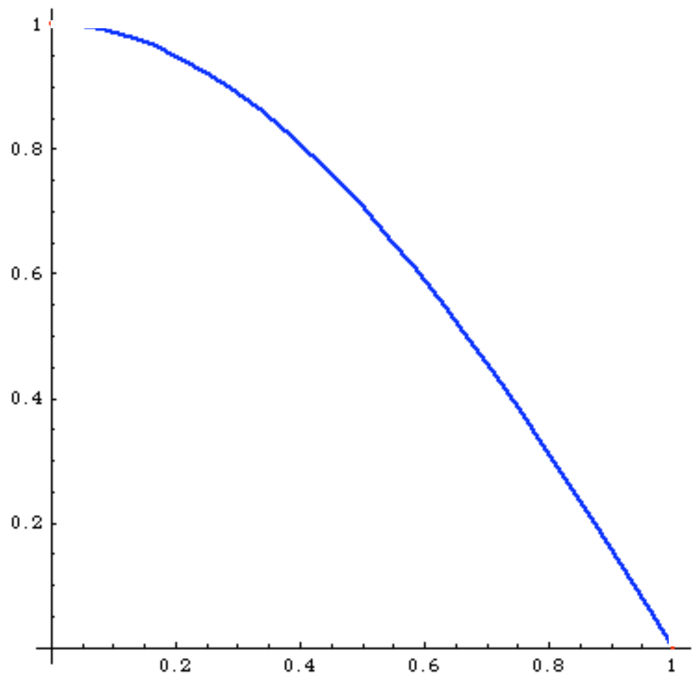


$$I = \int_0^1 dx(1-cx^2)\frac{\cos\left(\frac{\pi}{2}x\right)}{(1-cx^2)} = \int_{\xi_1}^{\xi_2} d\xi \frac{\cos\frac{\pi}{2}x[\xi]}{1-x[\xi]^2 c}$$

$\simeq 1$

Importance Sampling



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

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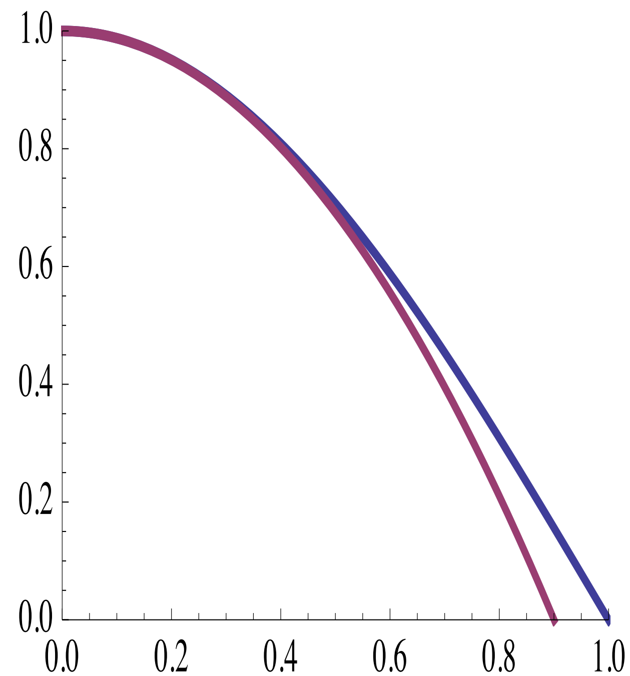

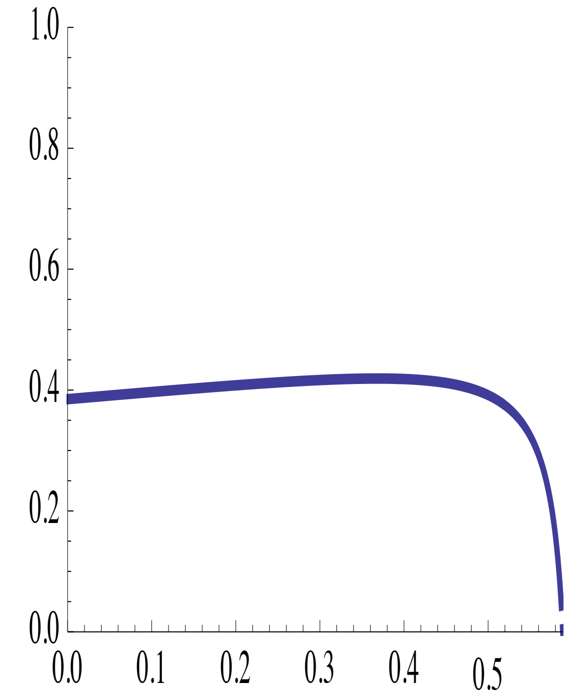

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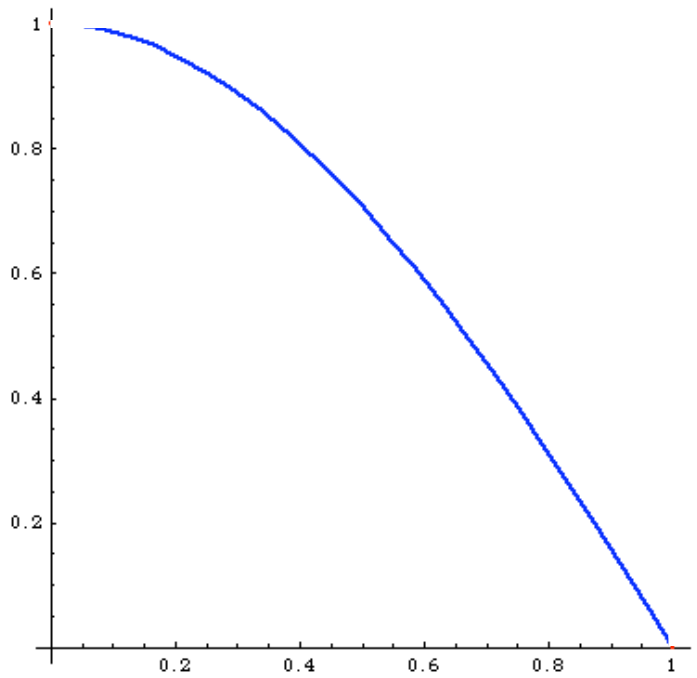

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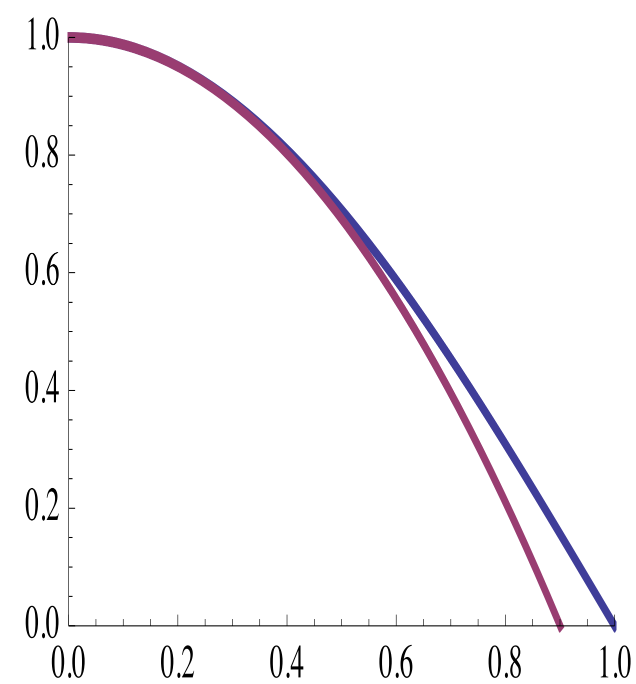

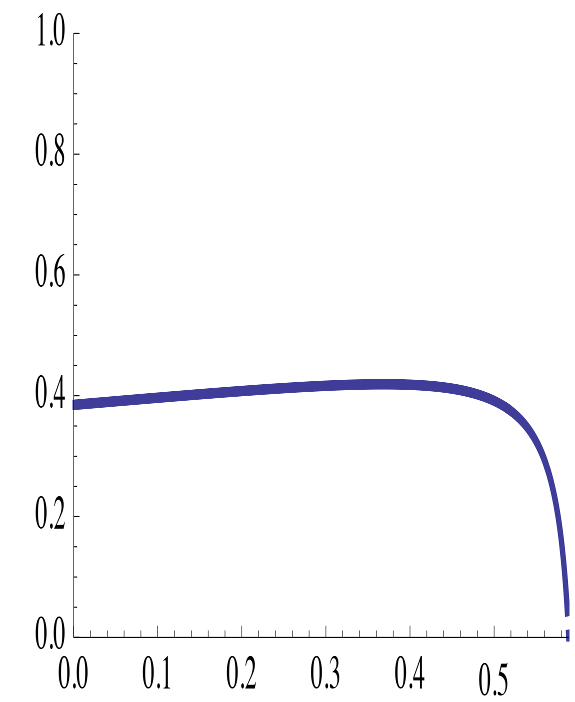

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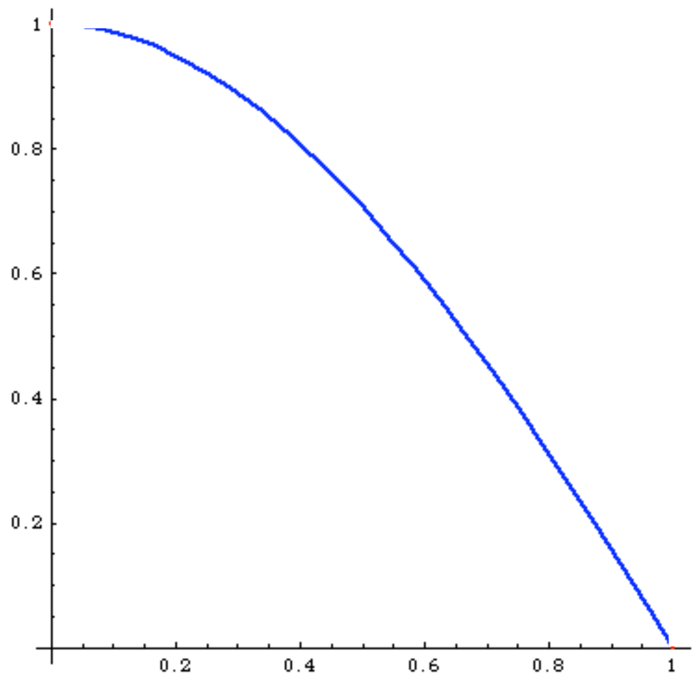
$\simeq 1$

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

Importance Sampling



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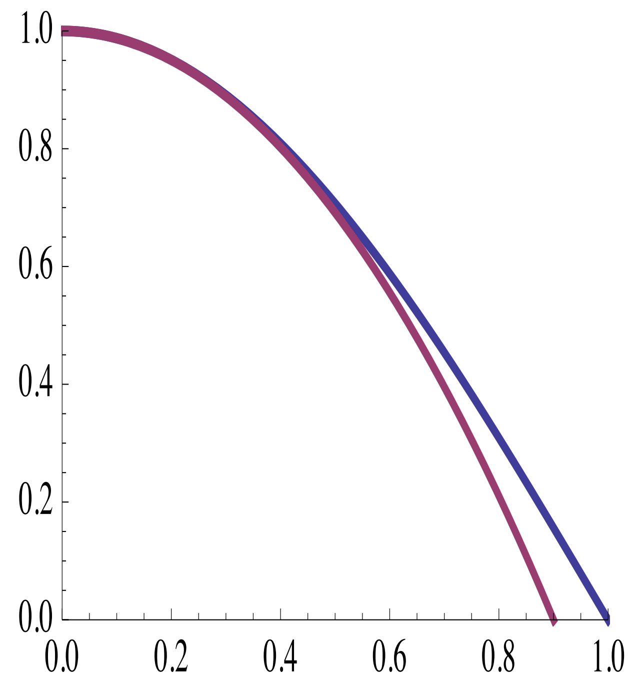
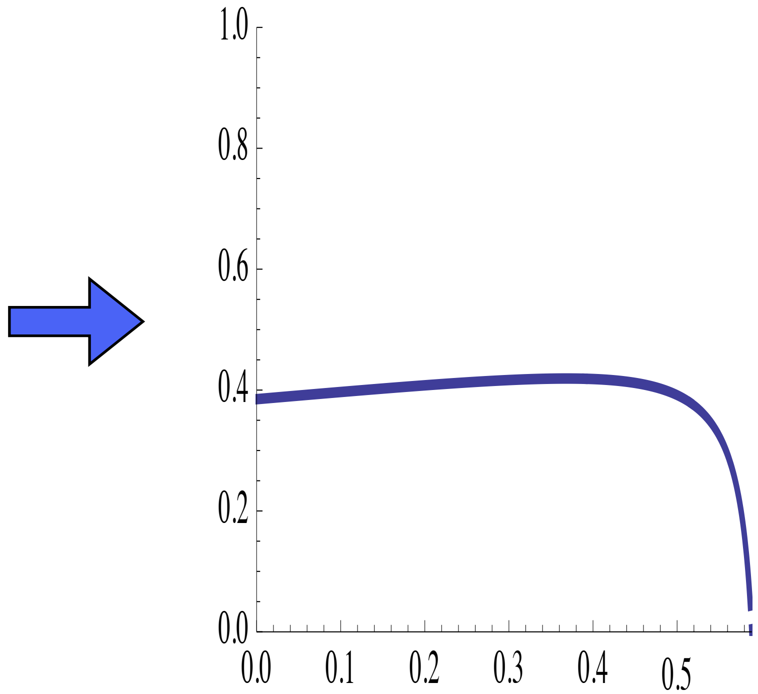
$$I_N = 0.637 \pm 0.307/\sqrt{N}$$





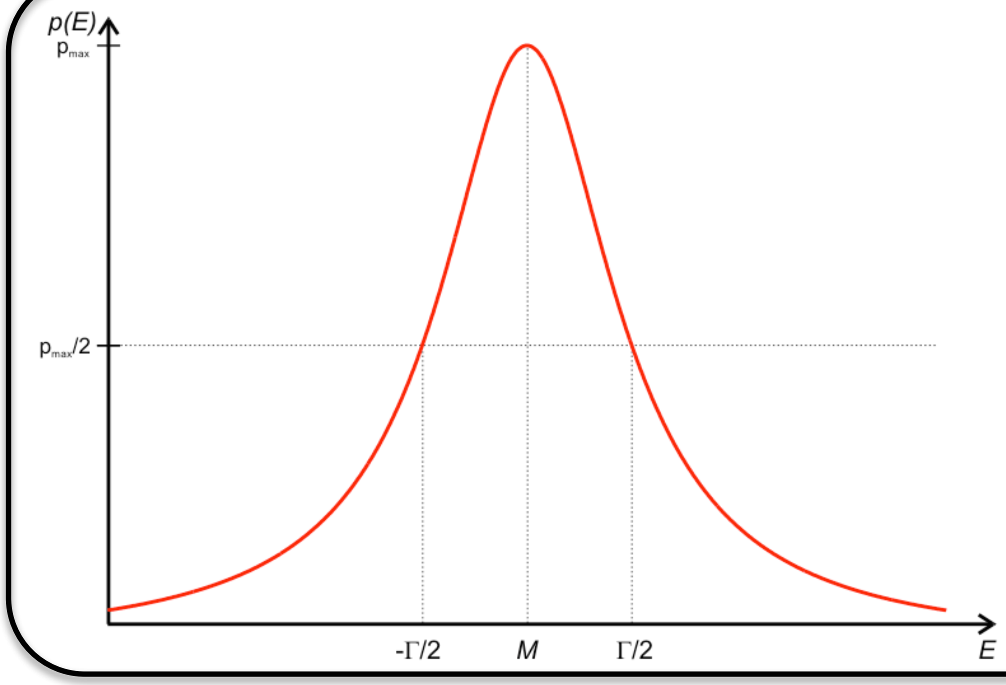
$$I = \int_0^1 dx(1 - cx^2)\frac{\cos\left(\frac{\pi}{2}x\right)}{(1 - cx^2)} = \int_{\xi_1}^{\xi_2} d\xi \frac{\cos\frac{\pi}{2}x[\xi]}{1 - x[\xi]^2 c}$$

$\simeq 1$

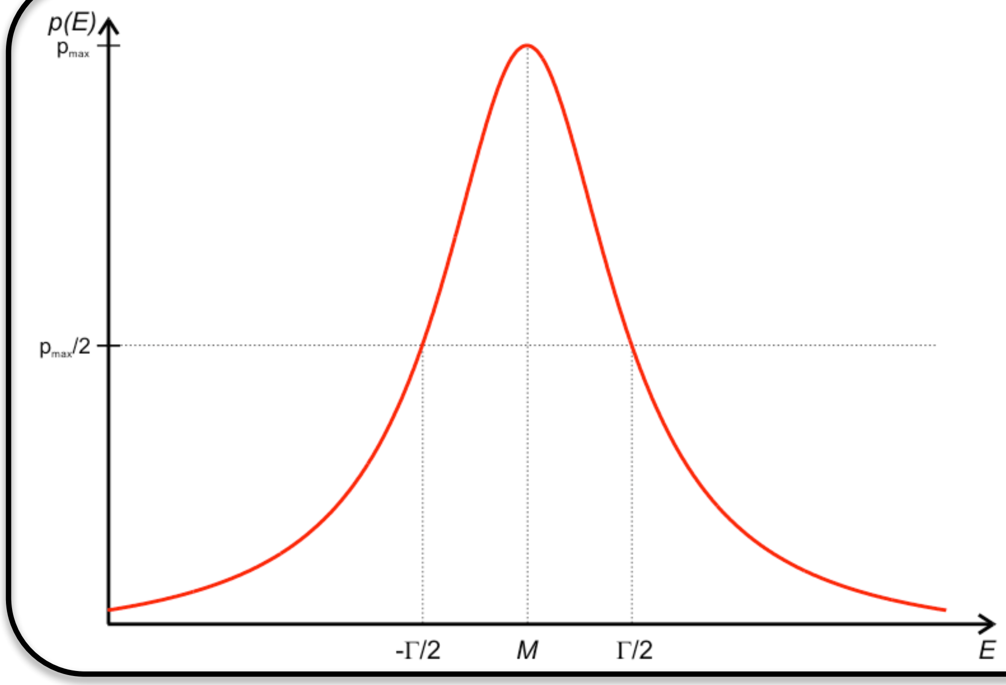
$$I_N = 0.637 \pm 0.031/\sqrt{N}$$

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

Importance Sampling



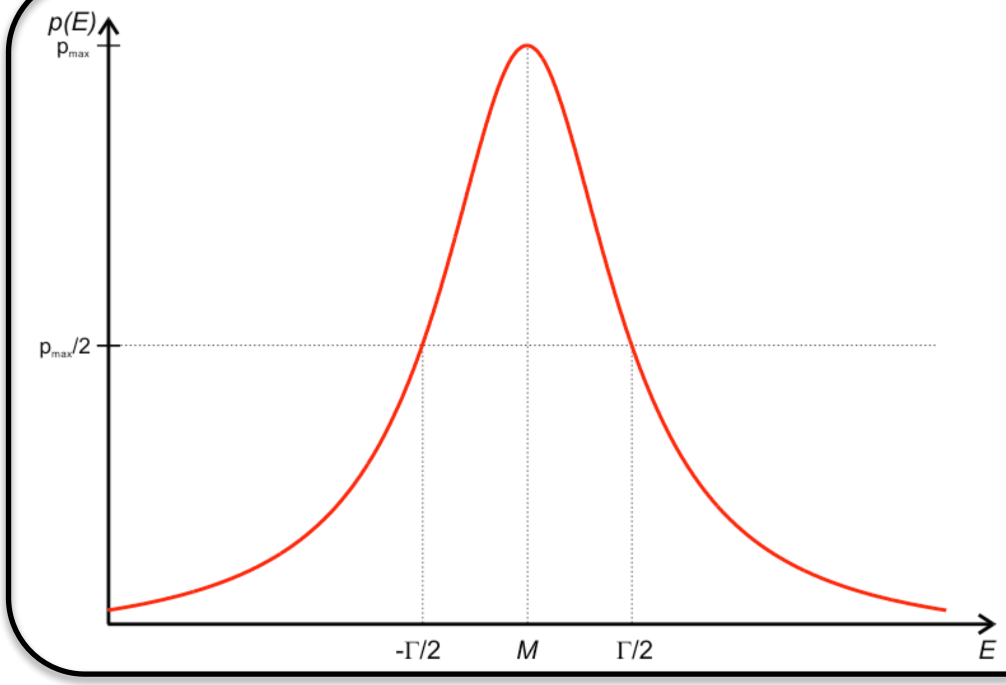
Importance Sampling



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

$$\xi = arctan\left(\frac{q^2 - M^2}{\Gamma M}\right)$$

Importance Sampling



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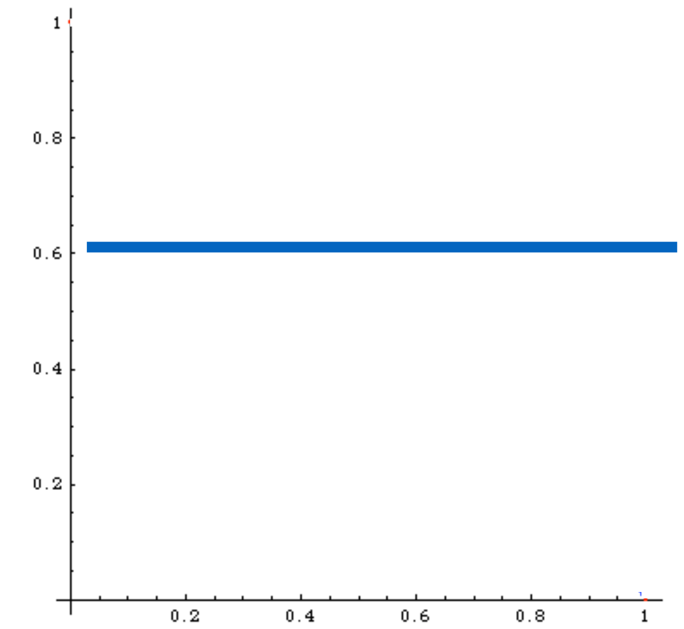
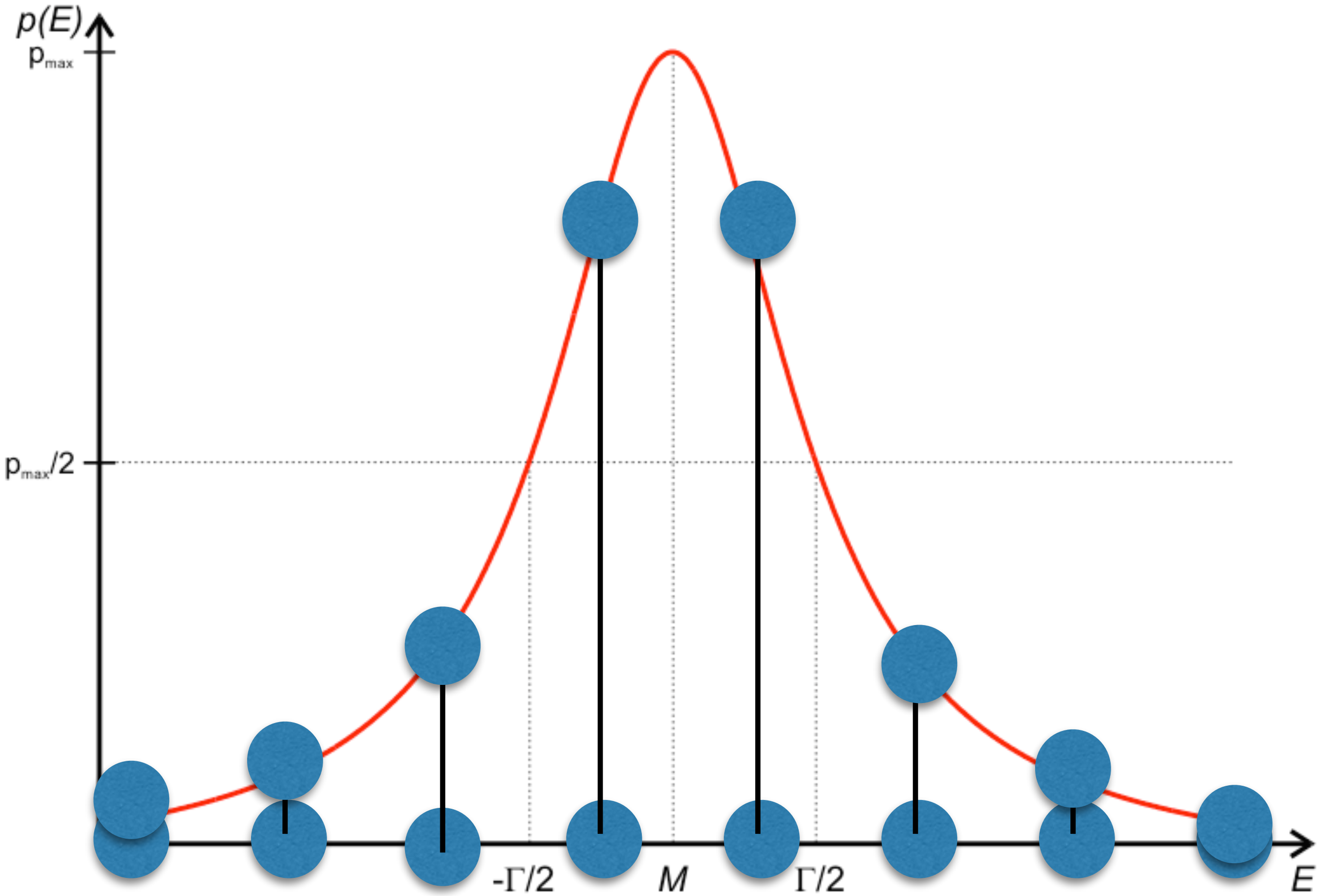


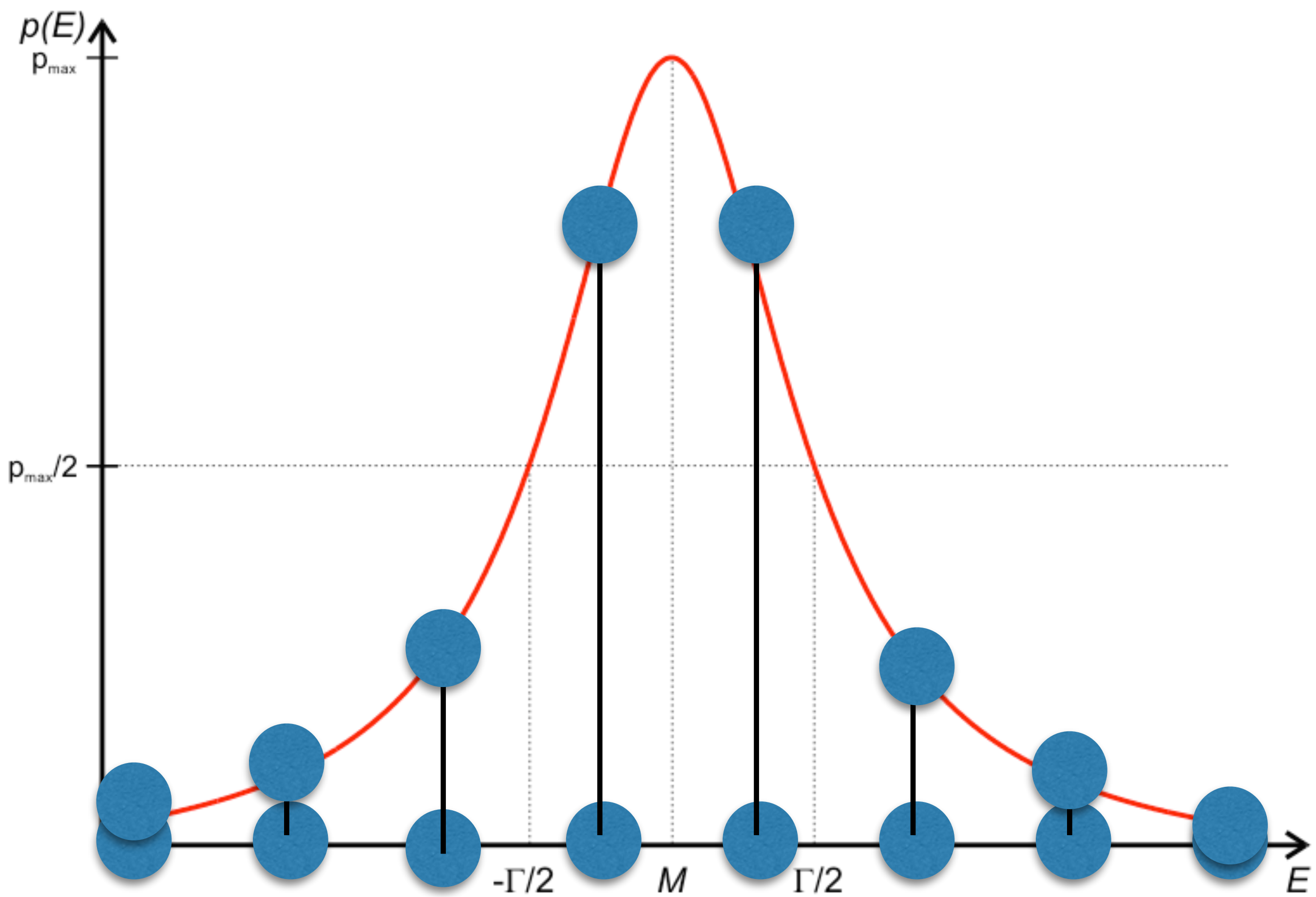
Why importance?

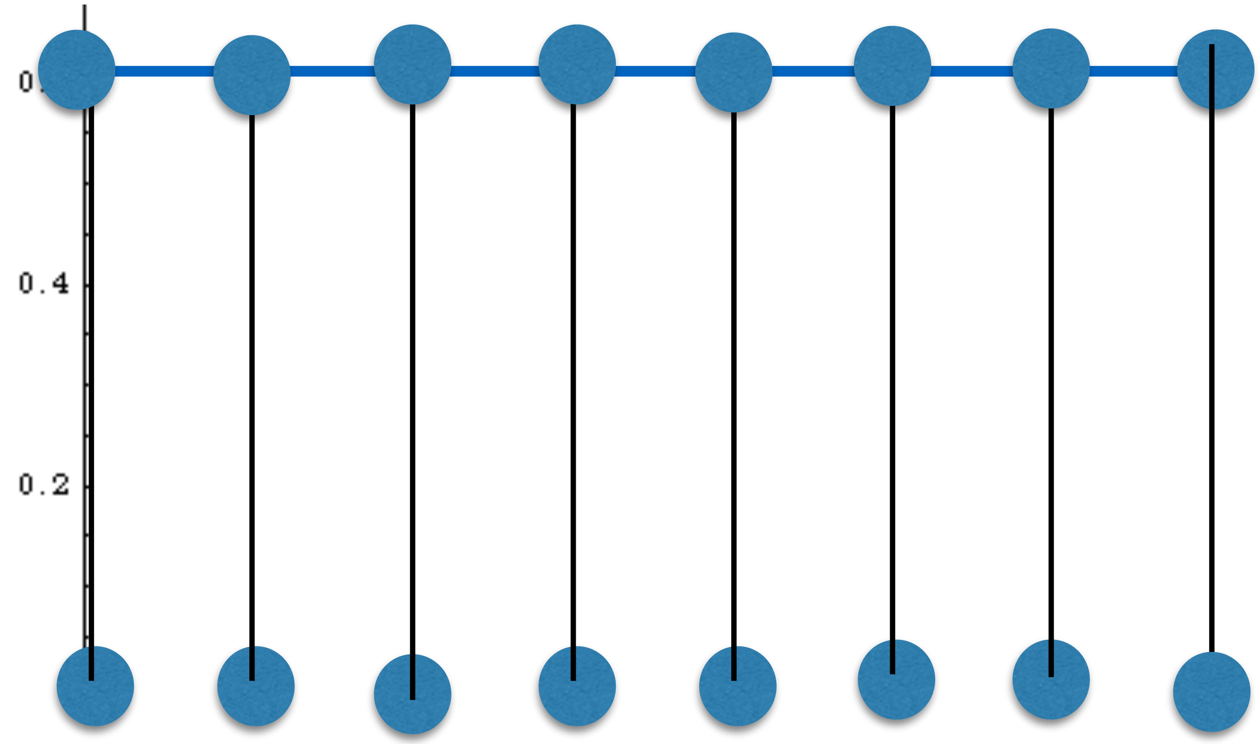


Why Importance Sampling?

We probe more often the region where the function is high!

Why importance?





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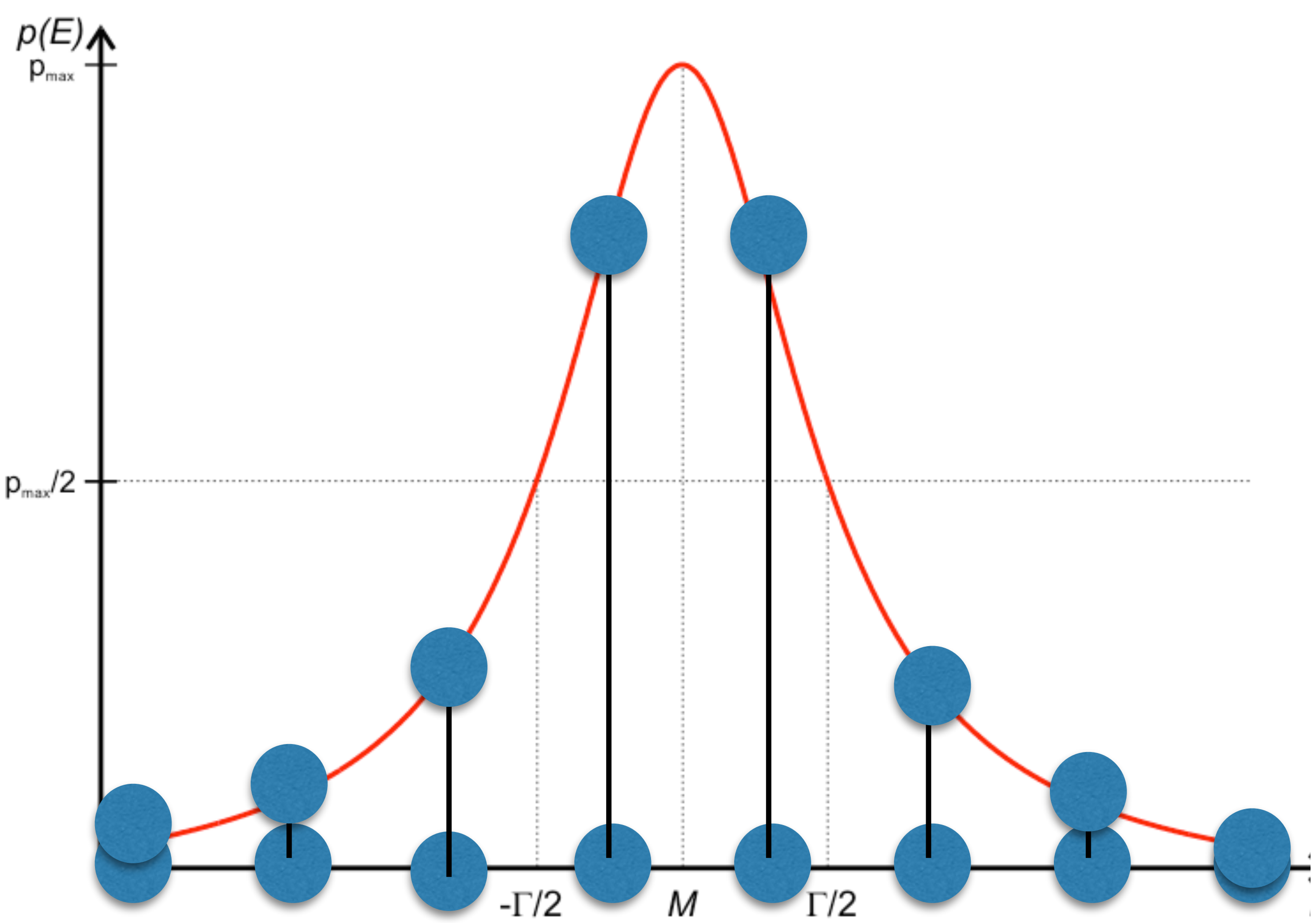
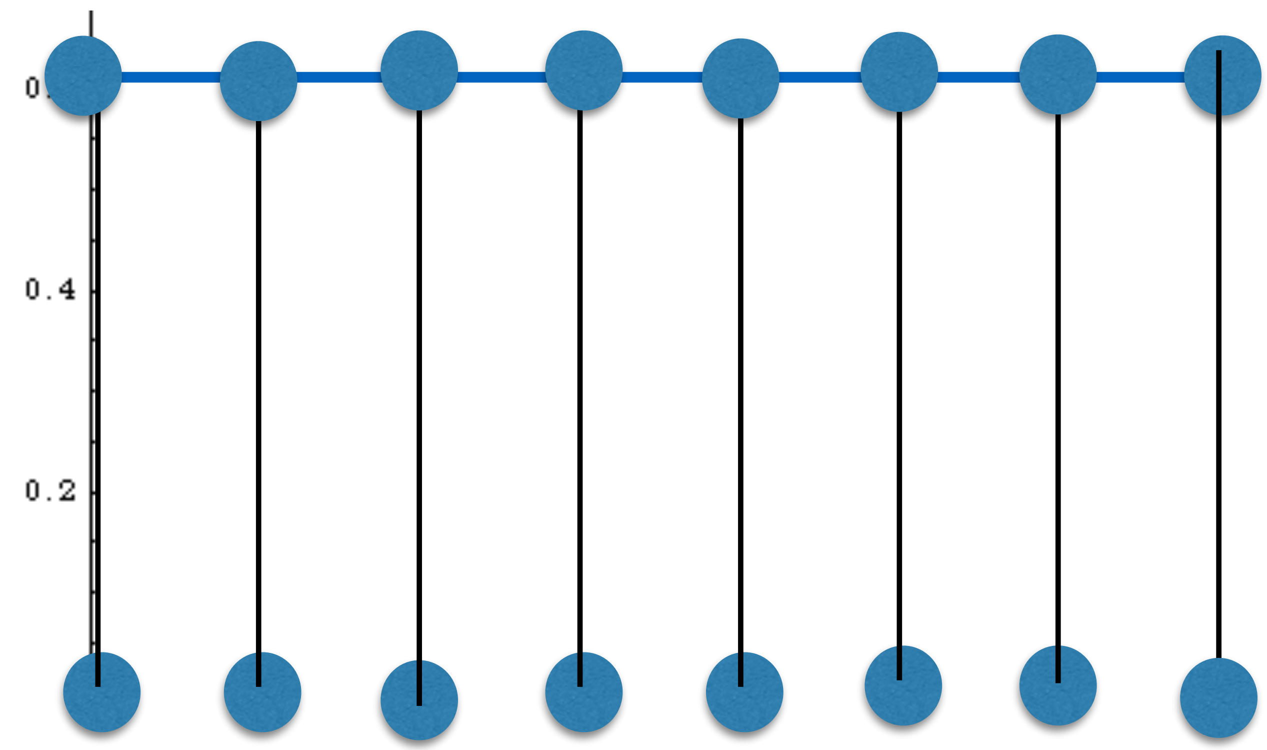
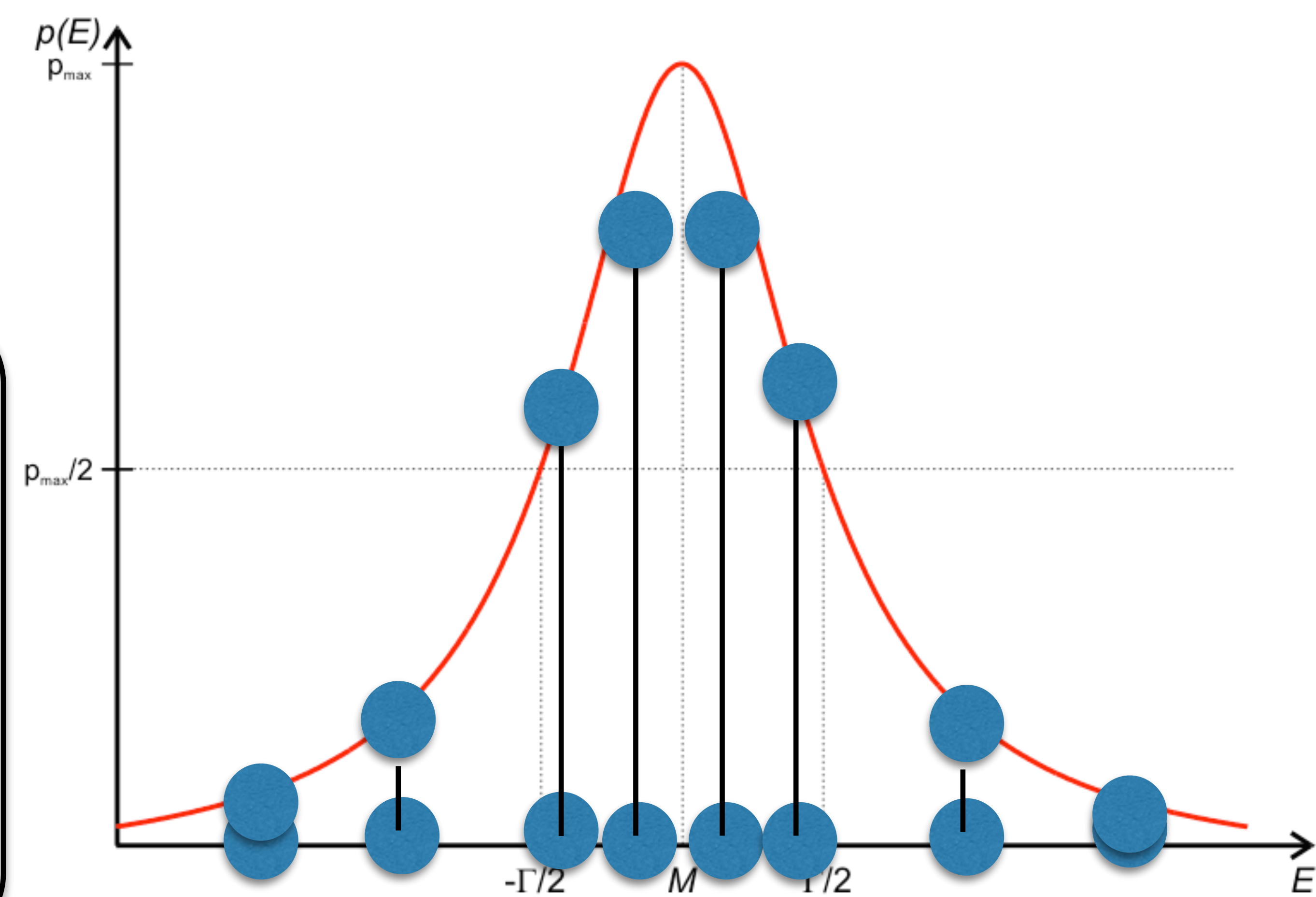






Why Importance Sampling?

We probe more often the region where the function is high!

Question time

1 Allez sur wooclap.com

2 Entrez le code d'événement dans le bandeau supérieur

Code d'événement

MADGRAPH

Activer les réponses par SMS

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.

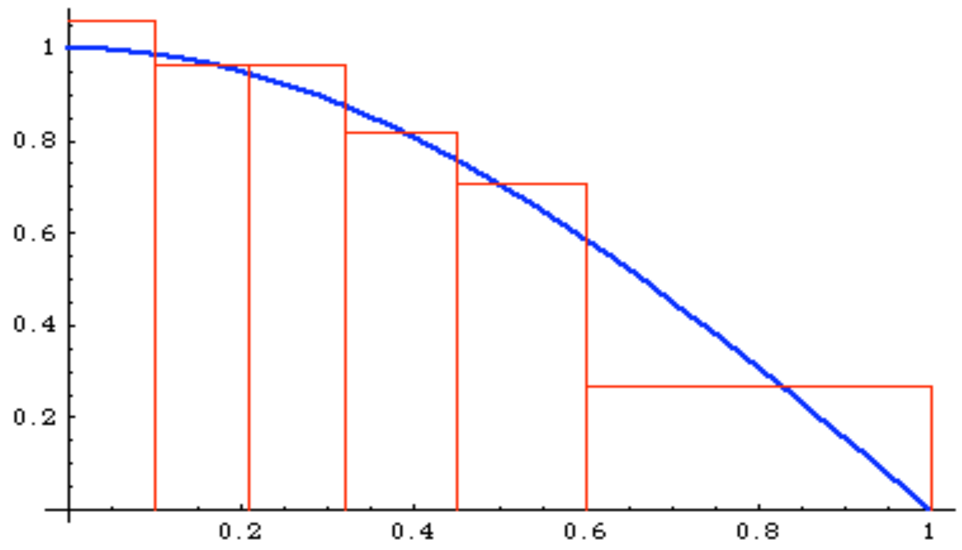
Adaptative Monte-Carlo

- Create an approximation of the function on the flight!

VEGAS

Adaptative Monte-Carlo

- Create an approximation of the function on the flight!



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.

VEGAS

More than one Dimension

- VEGAS works only with 1(few) dimension

  ➡memory problem

VEGAS

More than one Dimension

- VEGAS works only with 1(few) dimension
  - ➡memory problem

Solution

- Use projection on the axis

$$\vec{p}(x) = p(x) \cdot p(y) \cdot p(z) \ldots$$

VEGAS

More than one Dimension

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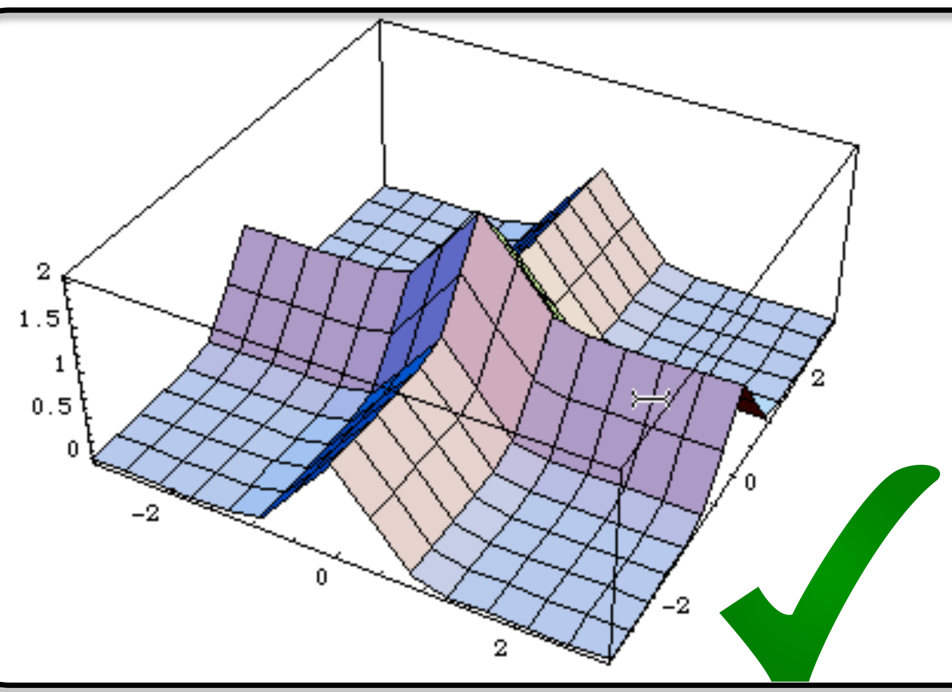

VEGAS

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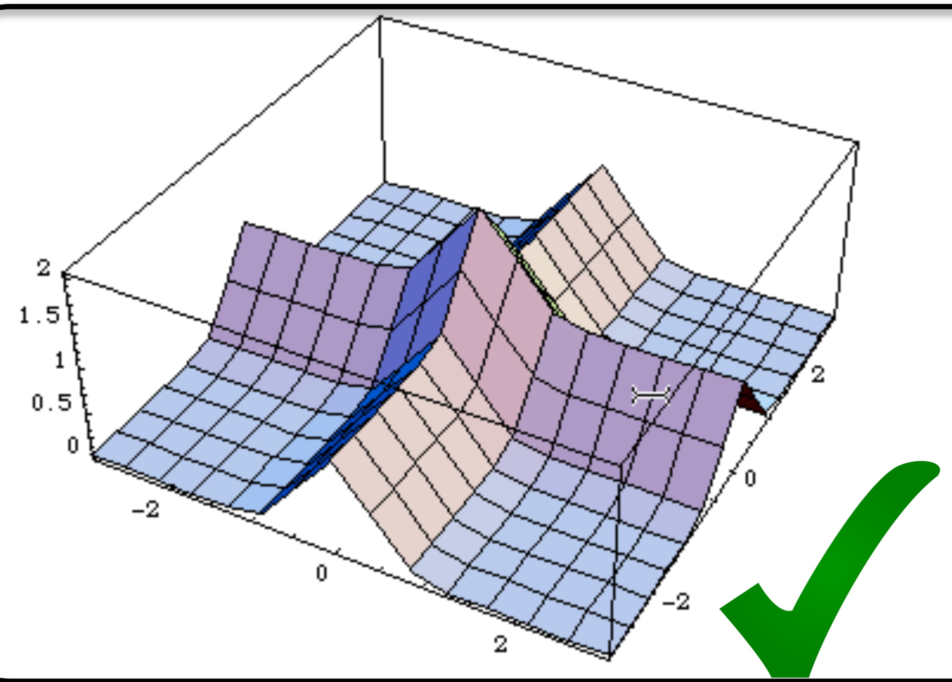
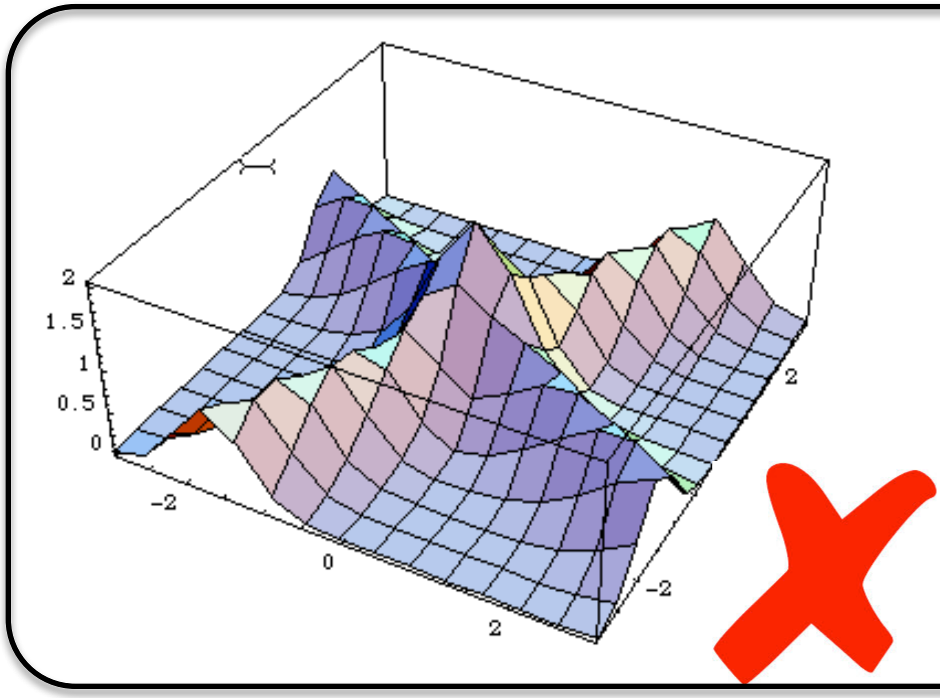
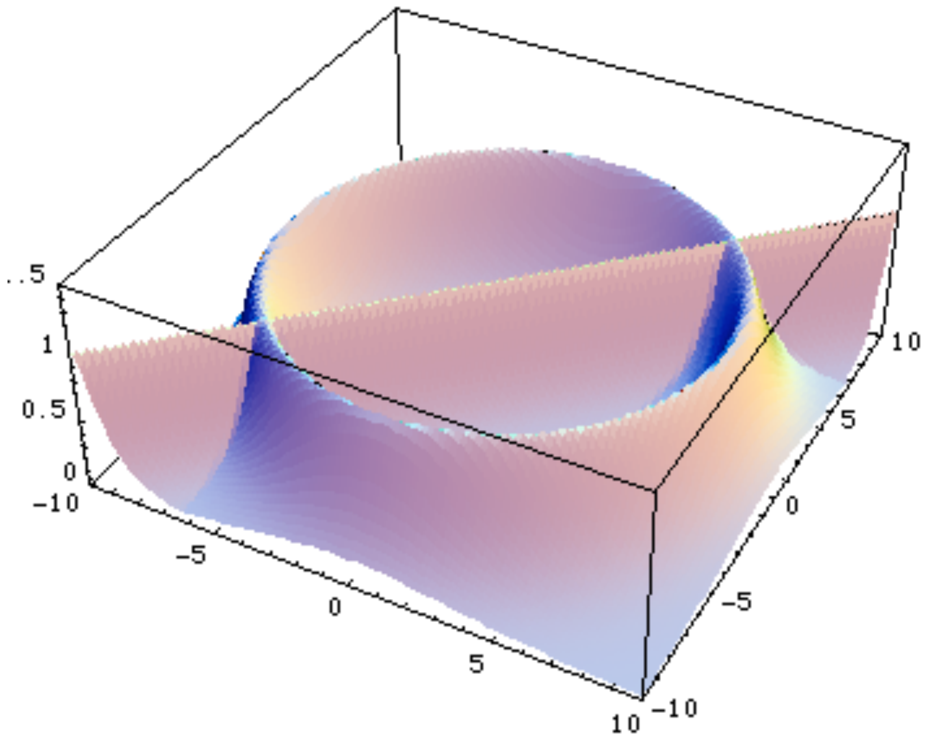




- We need to ensure the factorization !

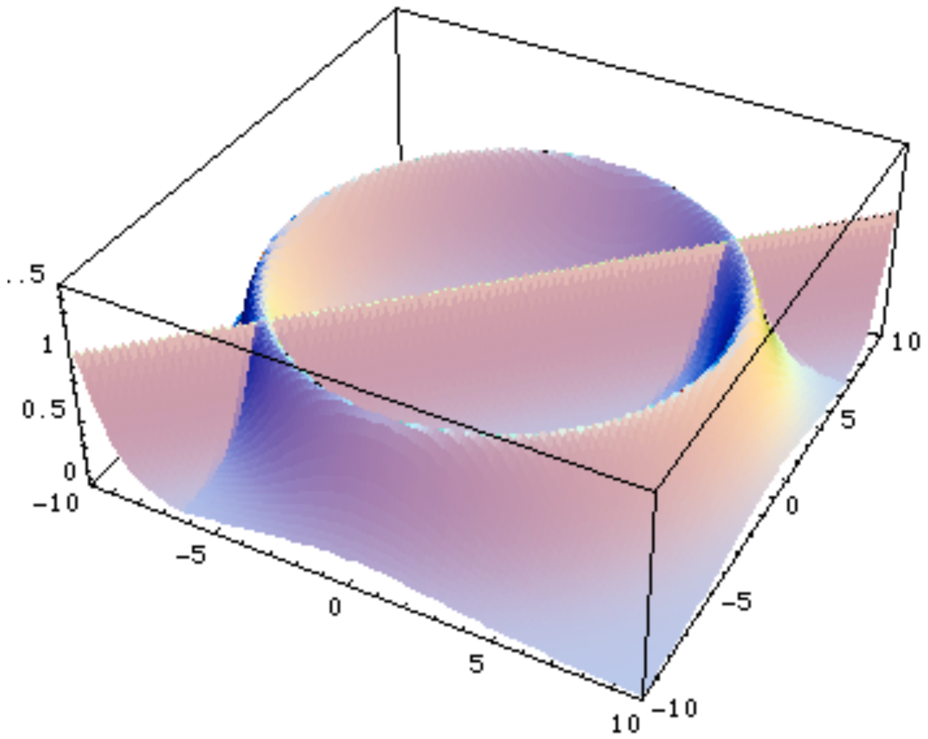
➡Additional change of variable

Multi-channel



What do we do if there is no transformation that aligns all integrand peaks to the chosen axes? Vegas is bound to fail!

Multi-channel



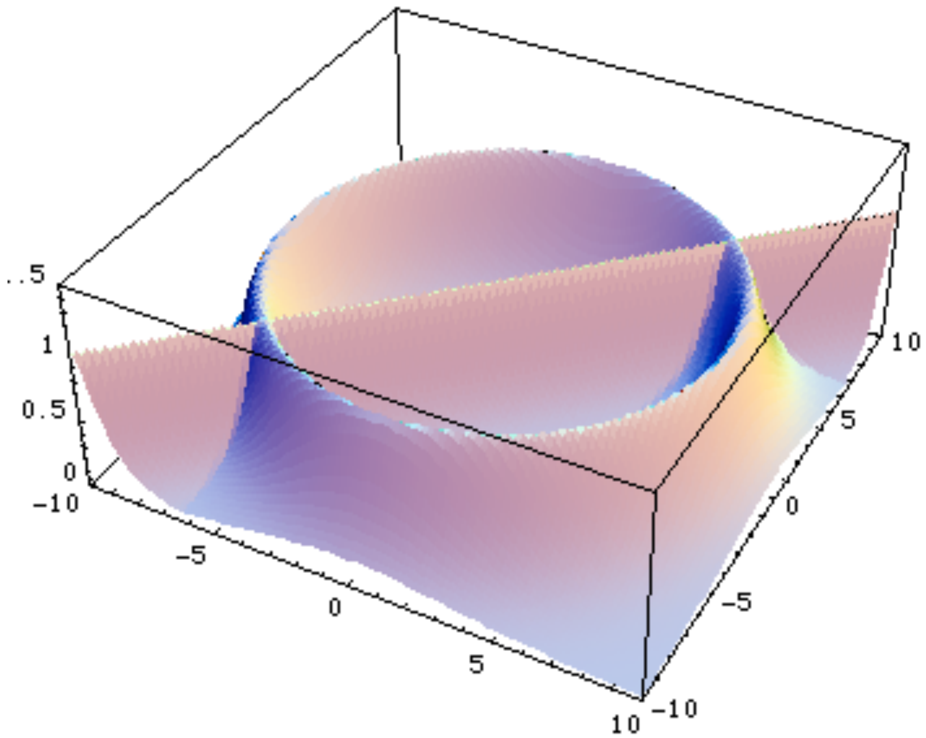
What do we do if there is no transformation that aligns all integrand peaks to the chosen axes?
Vegas is bound to fail!

Solution: use different transformations = channels

$$p(x) = \sum_{i=1}^{n} \alpha_i p_i(x) \qquad \text{with} \qquad \sum_{i=1}^{n} \alpha_i = 1$$

with each $p_i(x)$ taking care of one "peak" at the time

Multi-channel

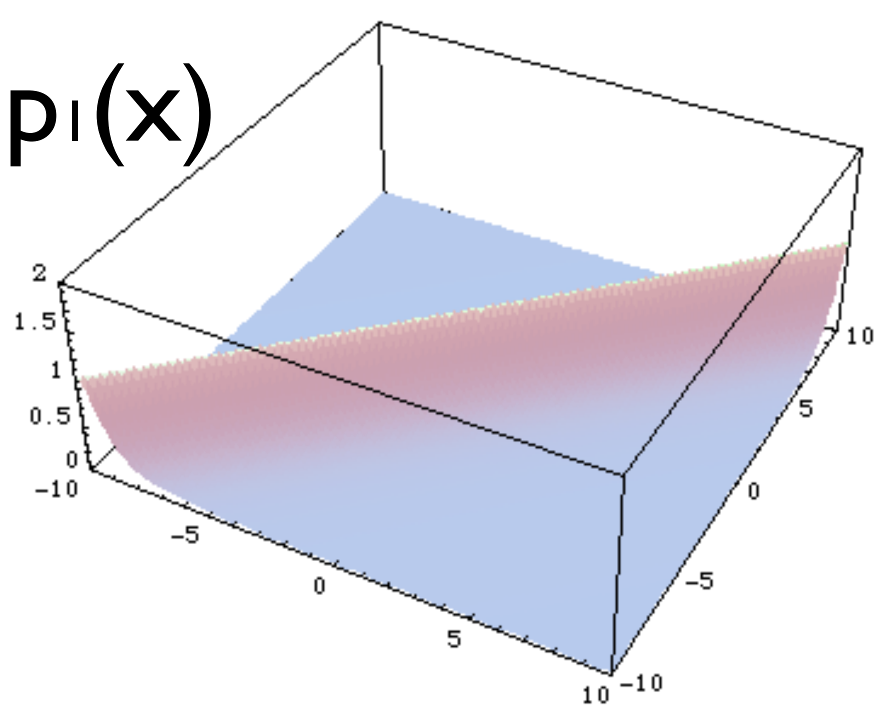


$$p(x) = \sum_{i=1}^{n} \alpha_i p_i(x)$$

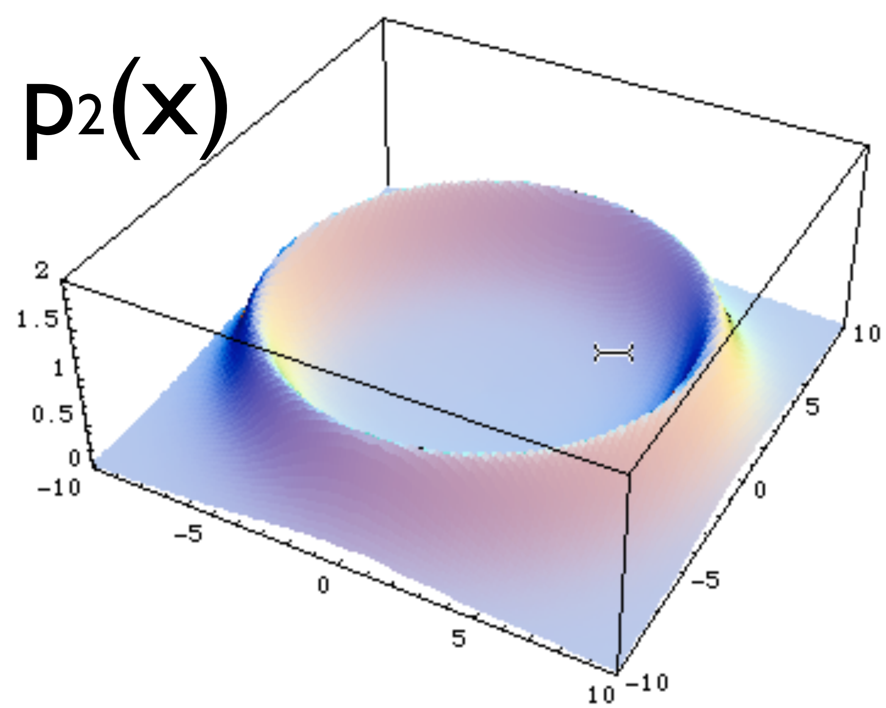
with

$$\sum_{i=1}^{n} \alpha_i = 1$$

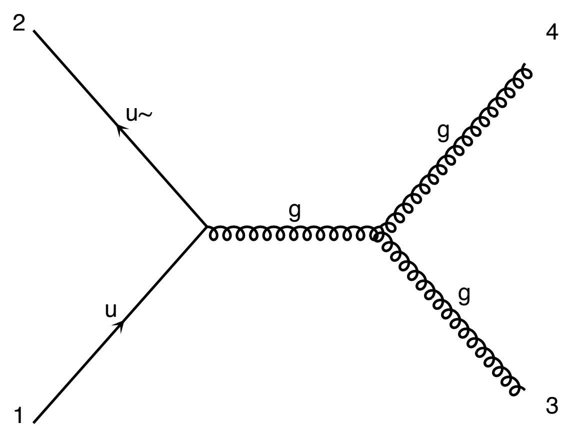
$p_1(x)$

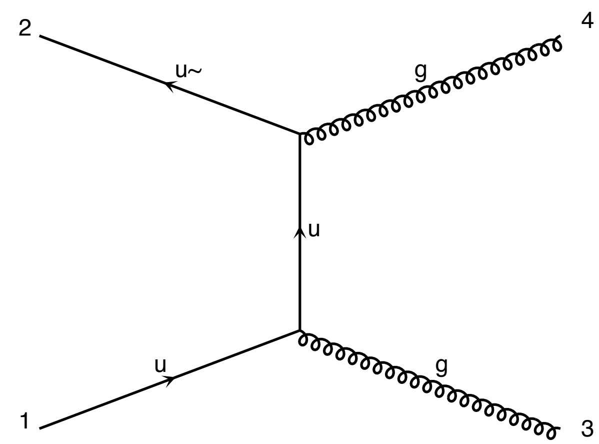


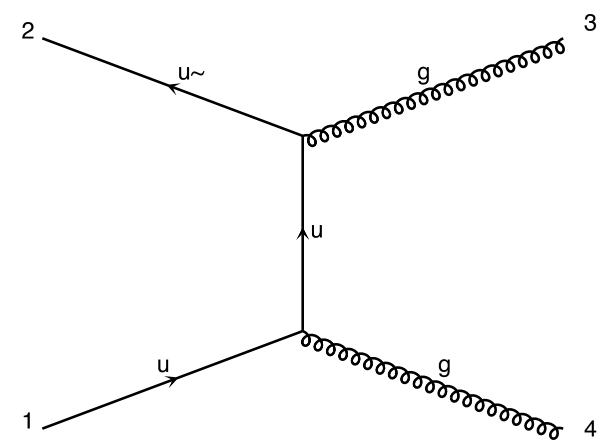
$p_2(x)$



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.

*Method used in MadGraph

Trick in MadEvent: Split the complexity

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

*Method used in MadGraph

Trick in MadEvent: Split the complexity

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≈ 1

- Any single diagram is "easy" to integrate (pole structures/suitable integration variables known from the propagators)
- Divide integration into pieces, based on diagrams
- All other peaks taken care of by denominator sum

*Method used in MadGraph

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≈ 1

- Any single diagram is "easy" to integrate (pole structures/suitable integration variables known from the propagators)
- Divide integration into pieces, based on diagrams
- All other peaks taken care of by denominator sum

N Integral

- Errors add in quadrature so no extra cost
- "Weight" functions already calculated during $|M|^2$ calculation
- 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

Question time

1 Allez sur wooclap.com

2 Entrez le code d'événement dans le bandeau supérieur

Code d'événement
MADGRAPH

Activer les réponses par SMS

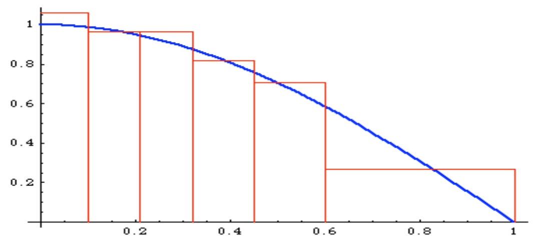
To Remember

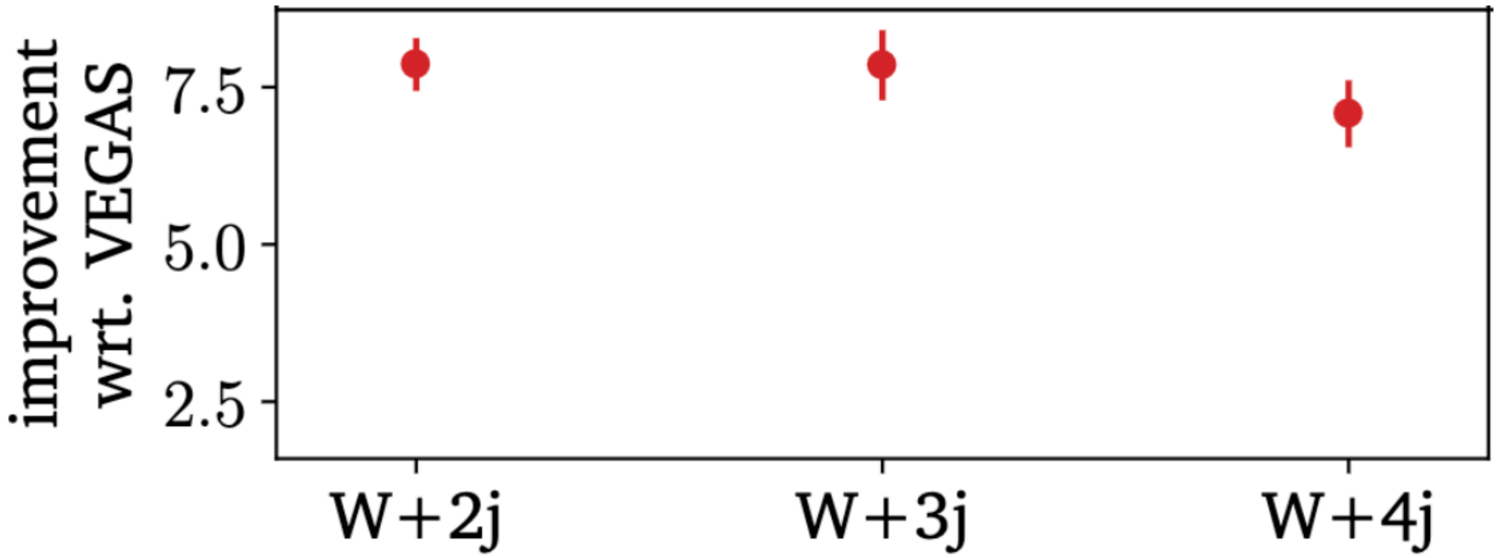
- Phase-Space integration is difficult
- We need to know the function
  - ➡ Be careful with cuts
- MadGraph split the integral in different contribution linked to the Feynman Diagram
  - ➡ Those are not the contribution of a given diagram

Can we do Better?

- Importance sampling/VEGAS is learning a function
  - ➡ HOT TOPIC: Machine Learning
  - ➡ Lot of work in progress

VEGAS





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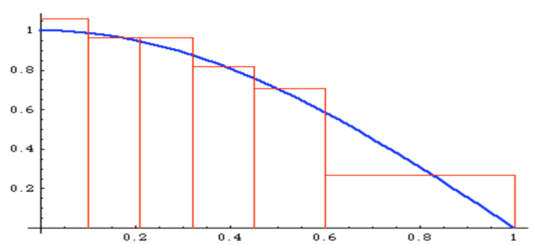
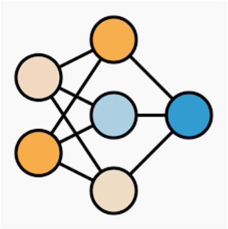
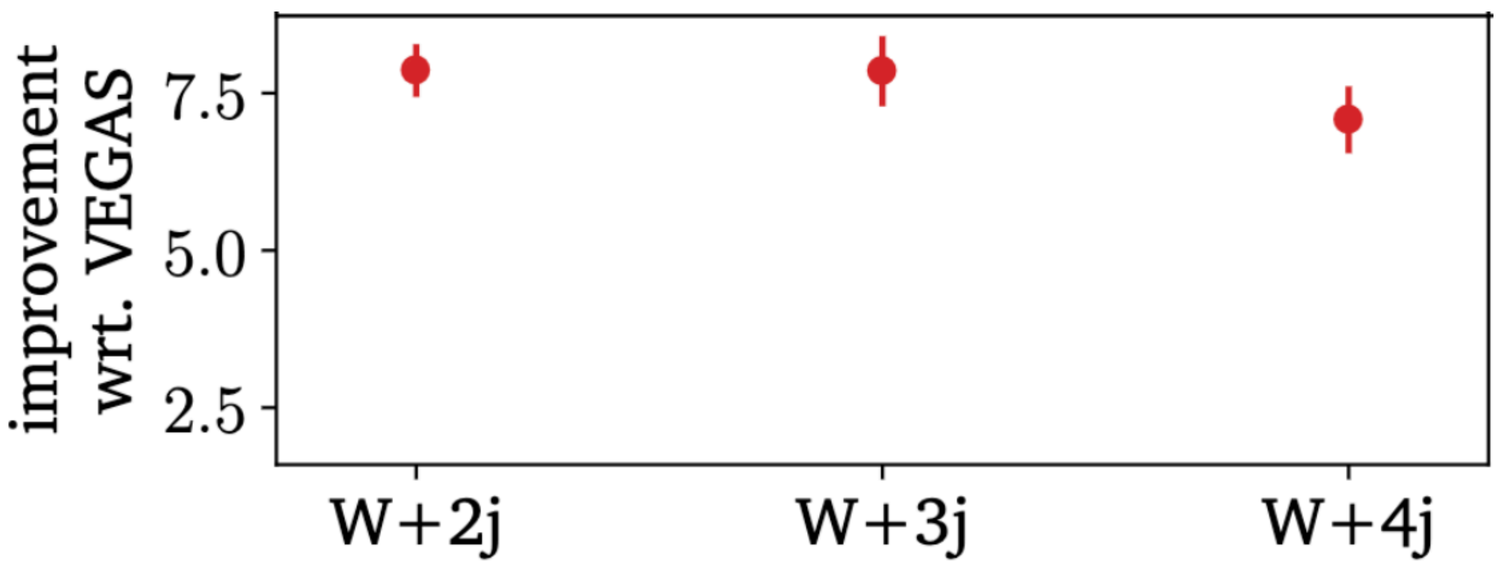
VEGAS

MADNIS



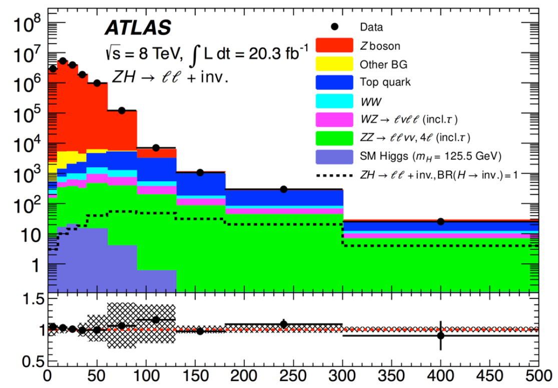




Event Generation

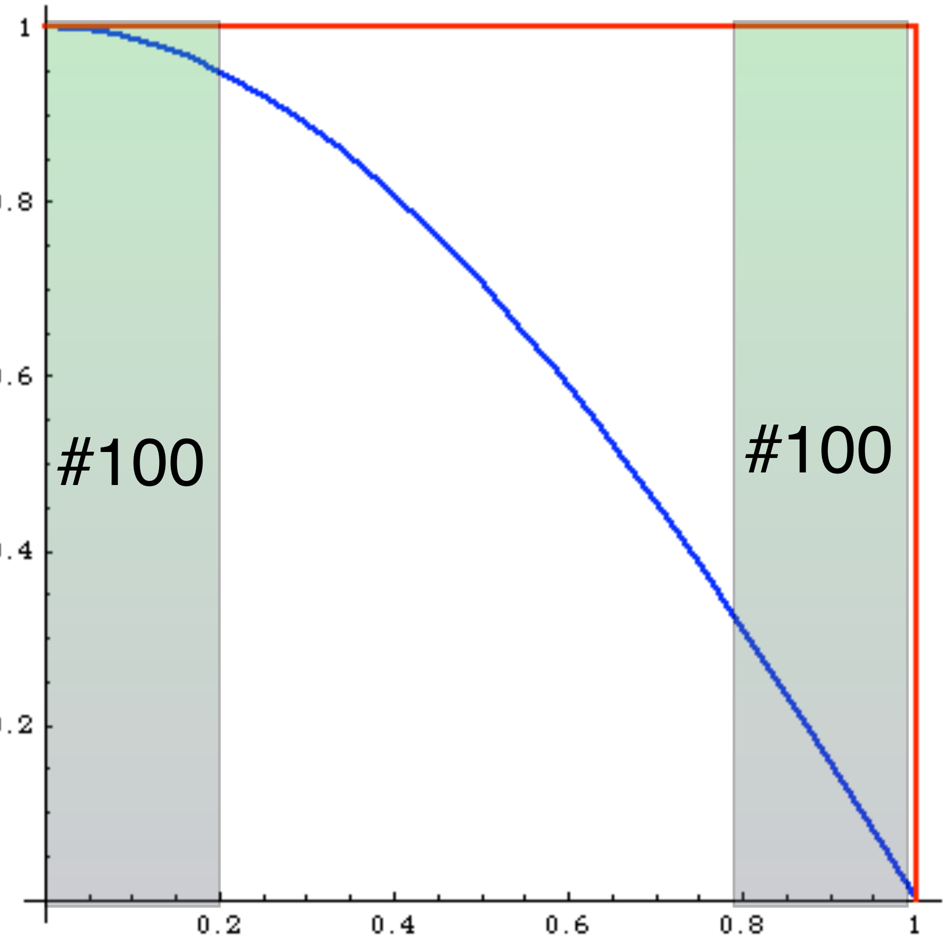
What is the goal?

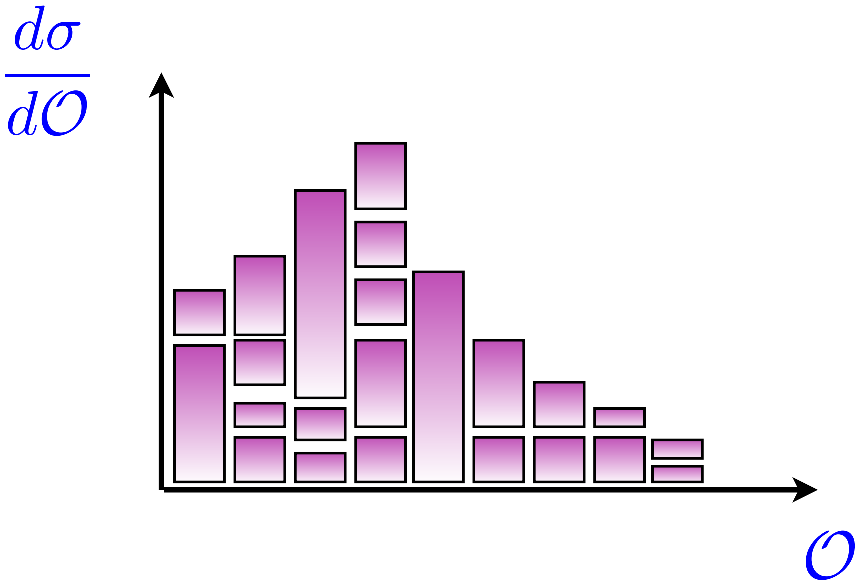
- Cross-section
  - But large theoretical uncertainty



- Differential Cross-Section
  - Provided as sample of events
  - Sample size is problematic
    - Those events will need to have full detector simulation

How to get sample?

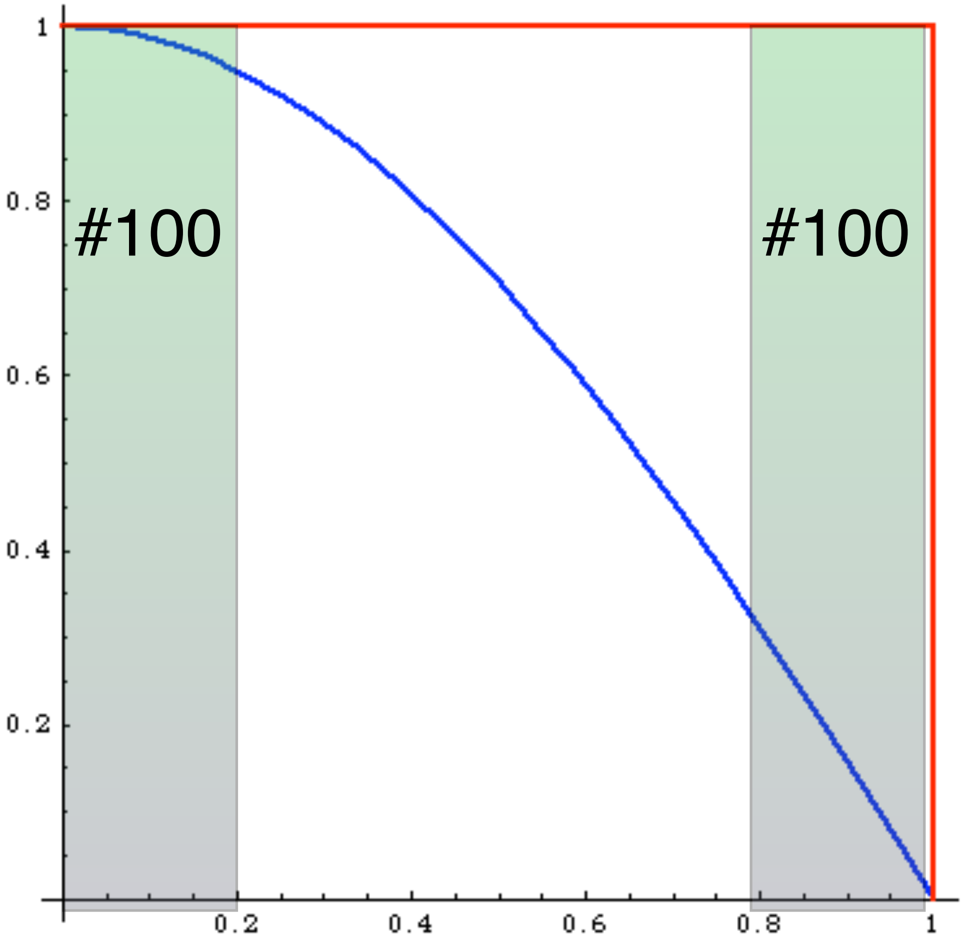




- Monte-Carlo integration use random points
    - We can keep those
        - (Uncorrelated) sample

- Points not distributed as the real function
- Need to keep track of the importance of each point (weight)
- Typically a lot of event have low information

Do we need to keep small weight?



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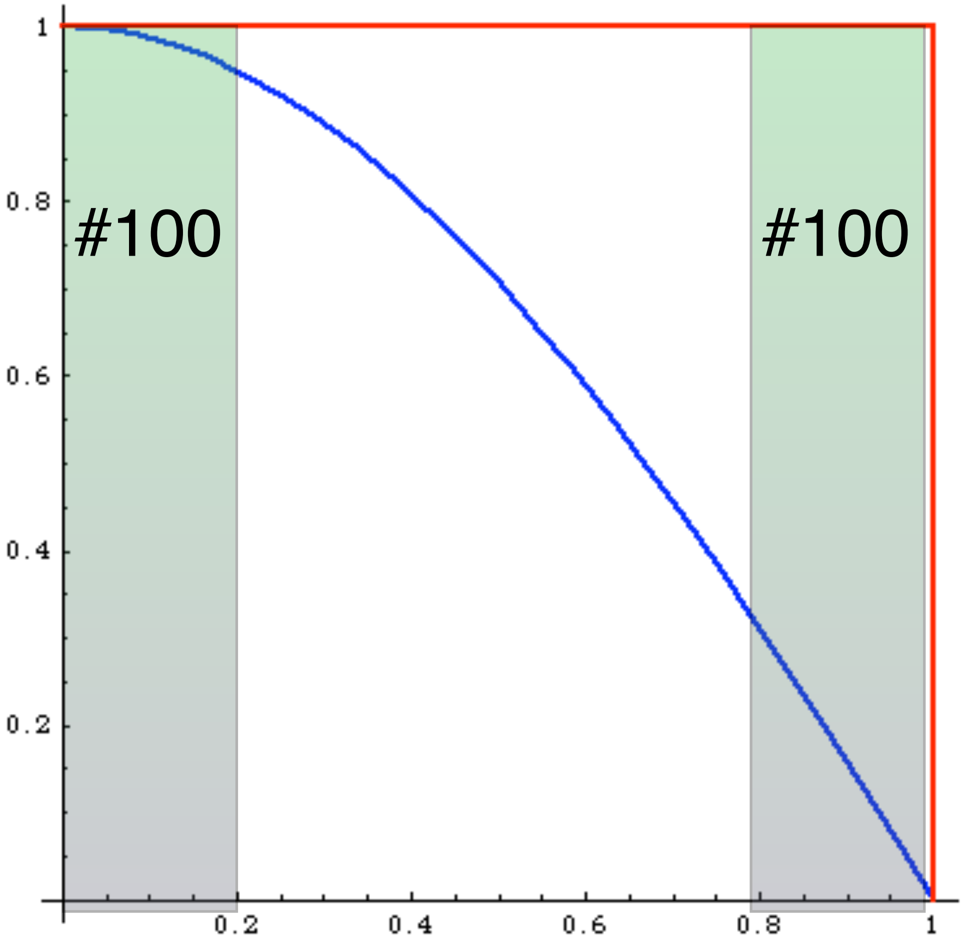

- Let’s put a minimum
    - Discard events below the minimum

Do we need to keep small weight?

threshold

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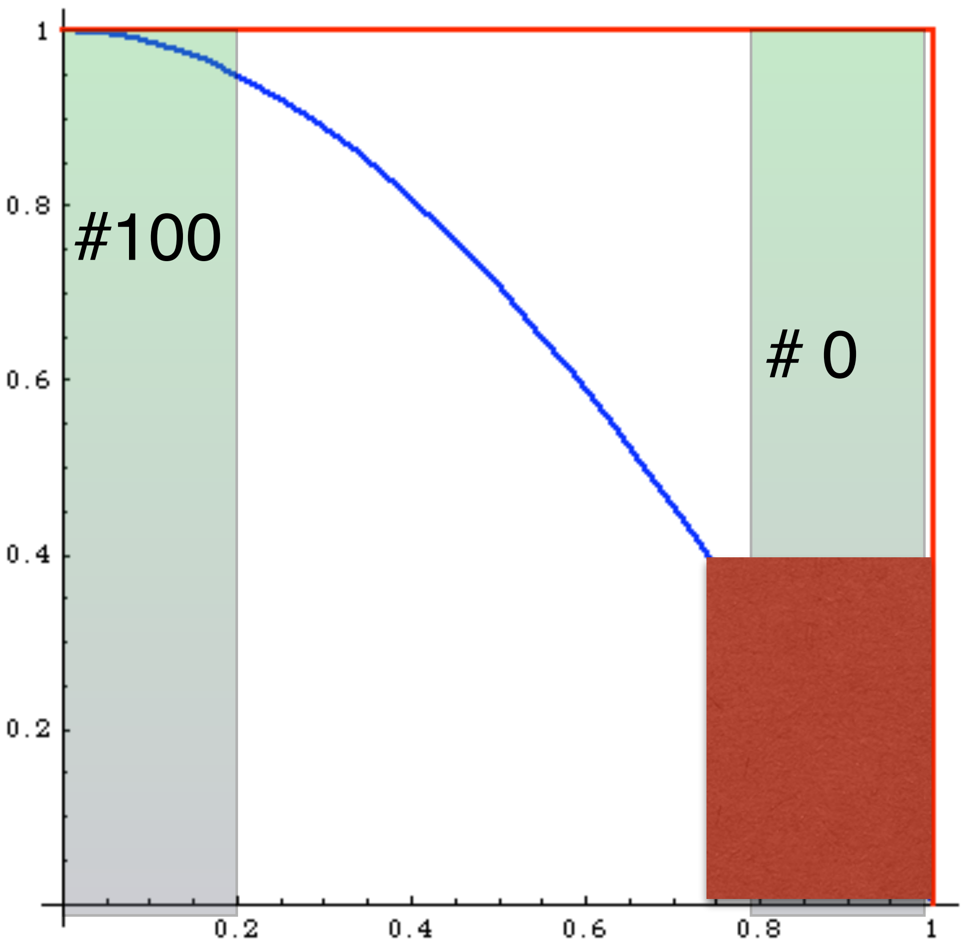
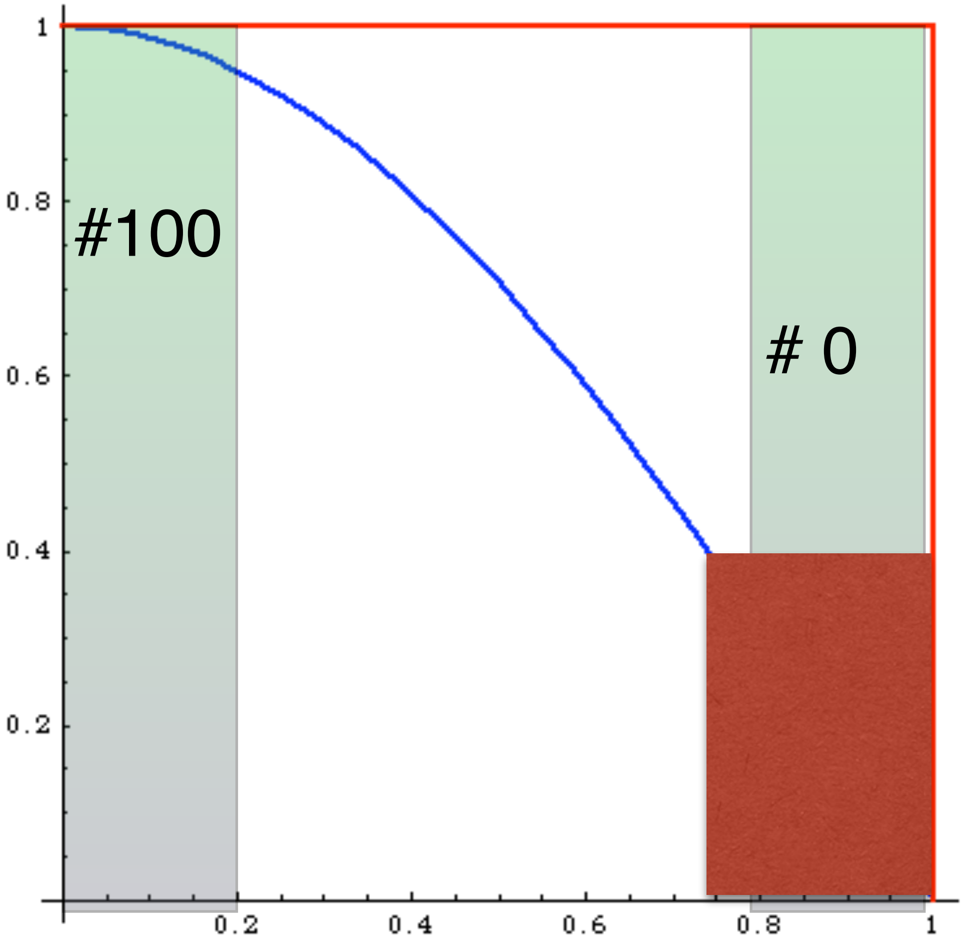
  - Discard events below the minimum



Do we need to keep small weight?

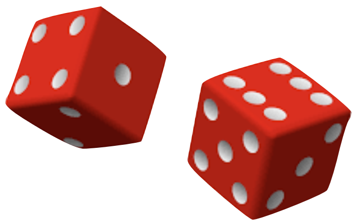
threshold

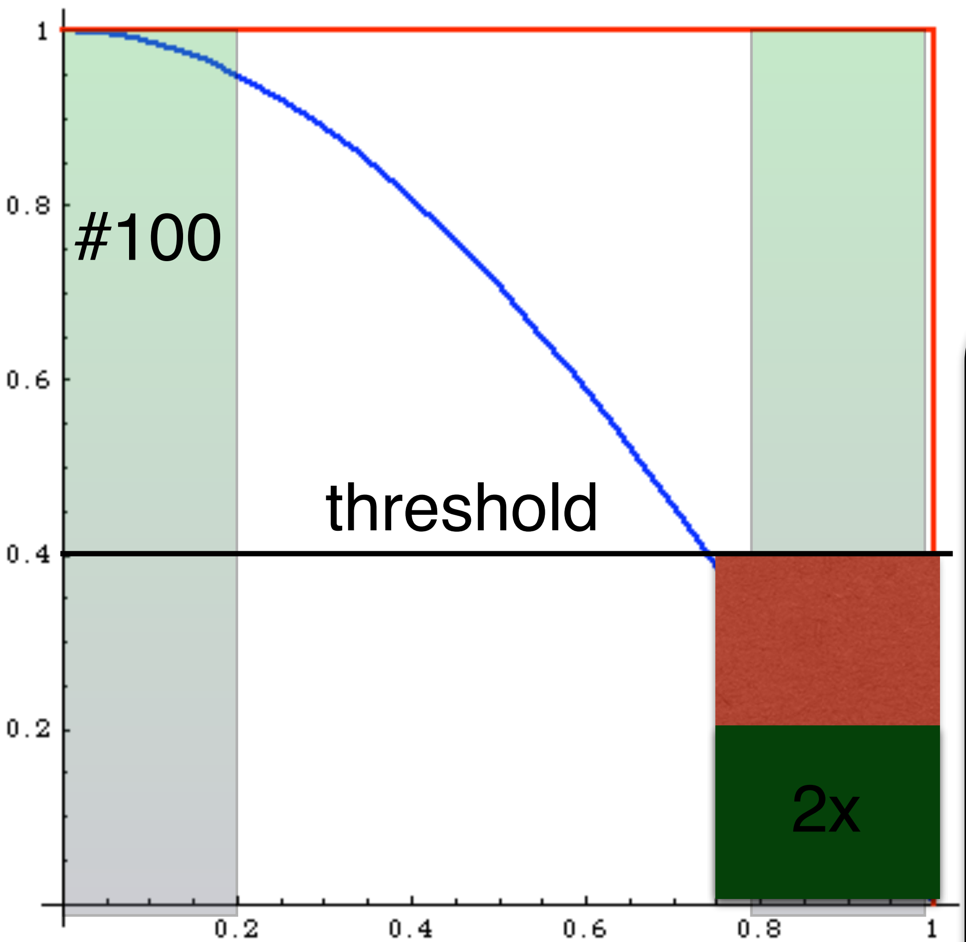
- Let's put a minimum
  - Discard events below the minimum
  - NO! We loose cross-section/ bias ourself



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

Do we need to keep small weight?



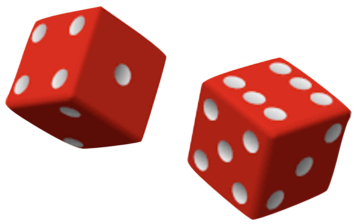


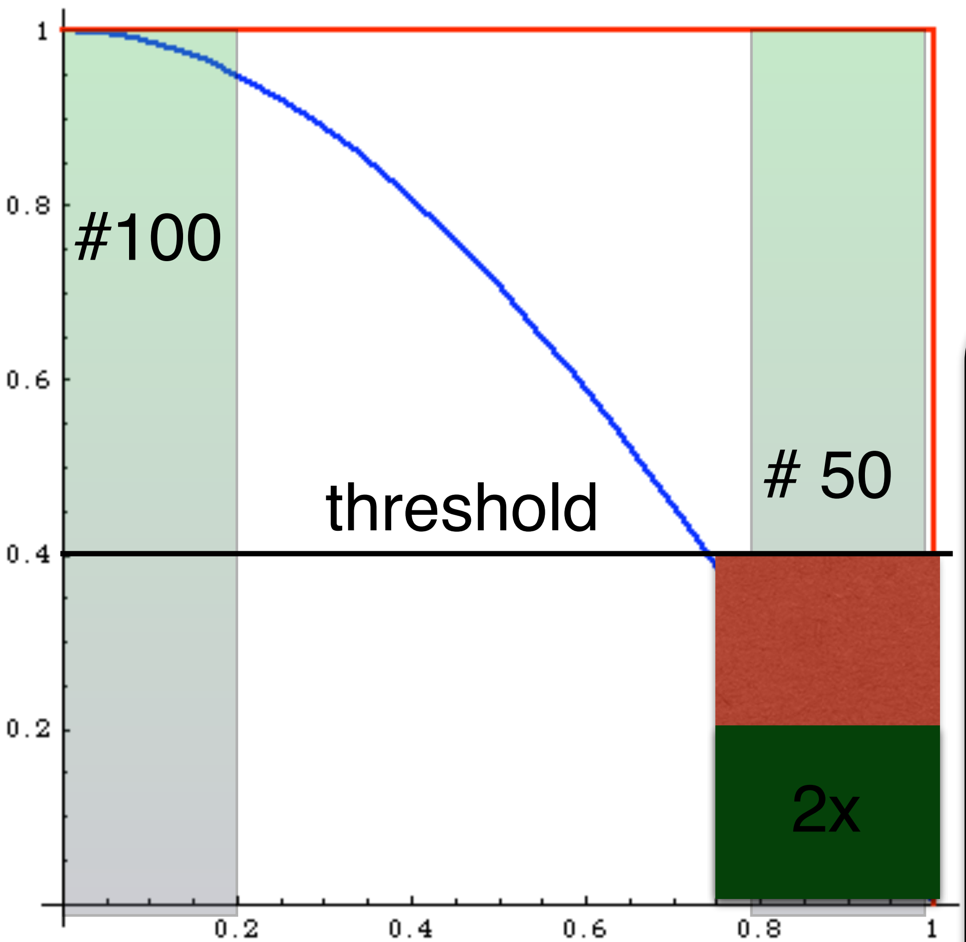
$$\int f(x)dx = \frac{1}{N}\sum_{i=1}^{N} f(x_i)$$

- Let’s put a minimum
  - Discard events below the minimum
  - NO! We loose cross-section/ bias ourself

- Let’s put a minimum
  - But keep 50% of the events below

Do we need to keep small weight?





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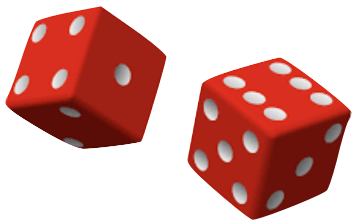
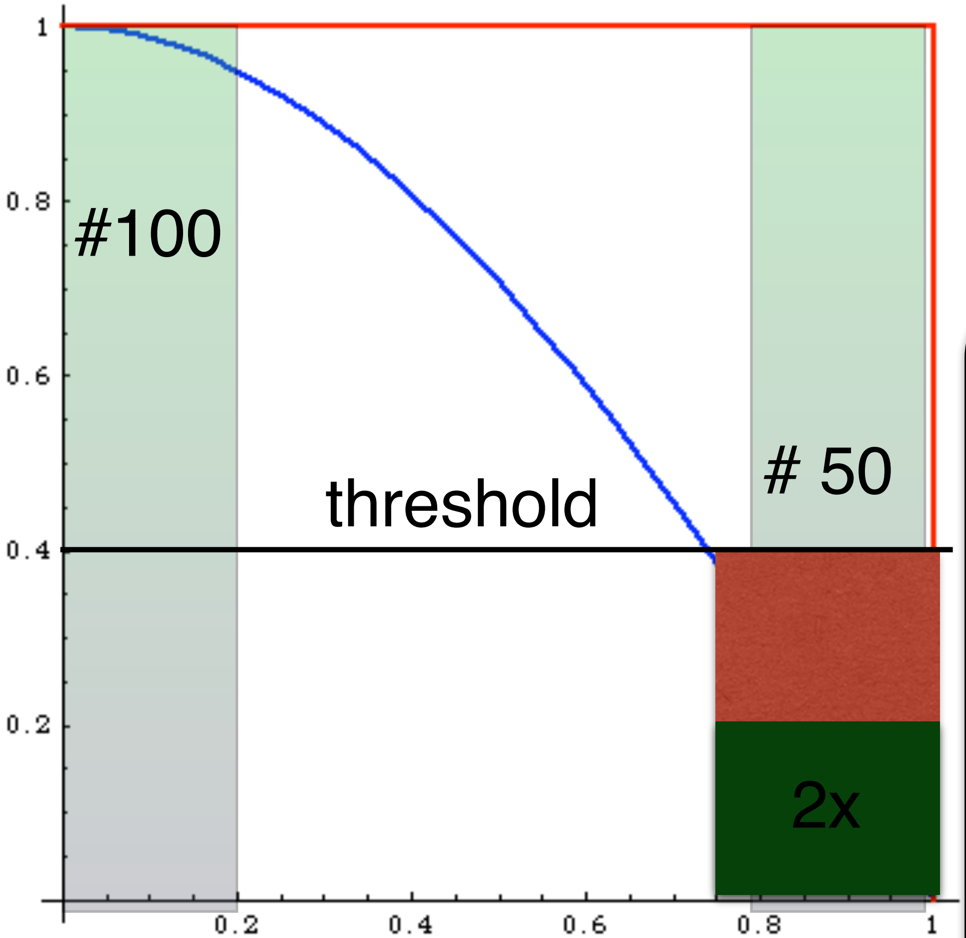


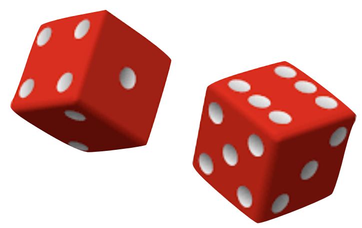


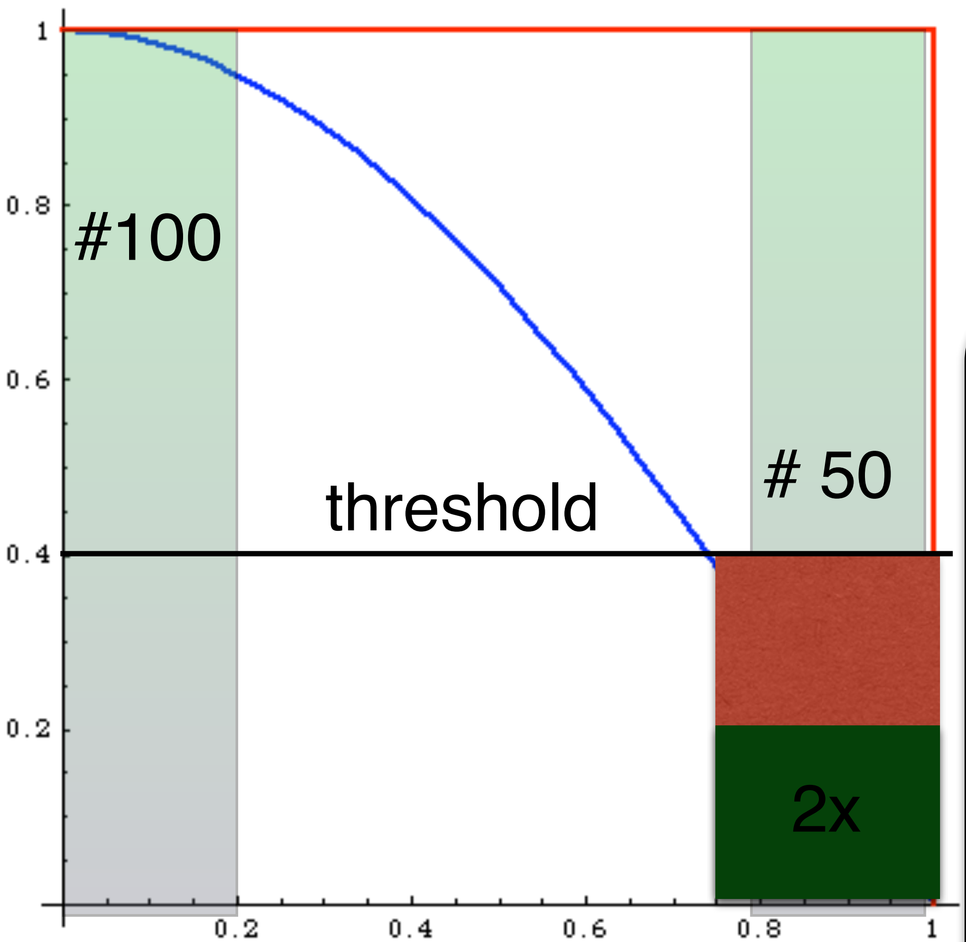
$$\int f(x)dx = \frac{1}{N}\sum_{i=1}^{N} f(x_i)$$

- Let’s put a minimum
    - Discard events below the minimum
    - NO! We loose cross-section/ bias ourself

- Let’s put a minimum
    - But keep 50% of the events below
    - Multiply the weight of each event by 2 (preserve cross-section)

Do we need to keep small weight?





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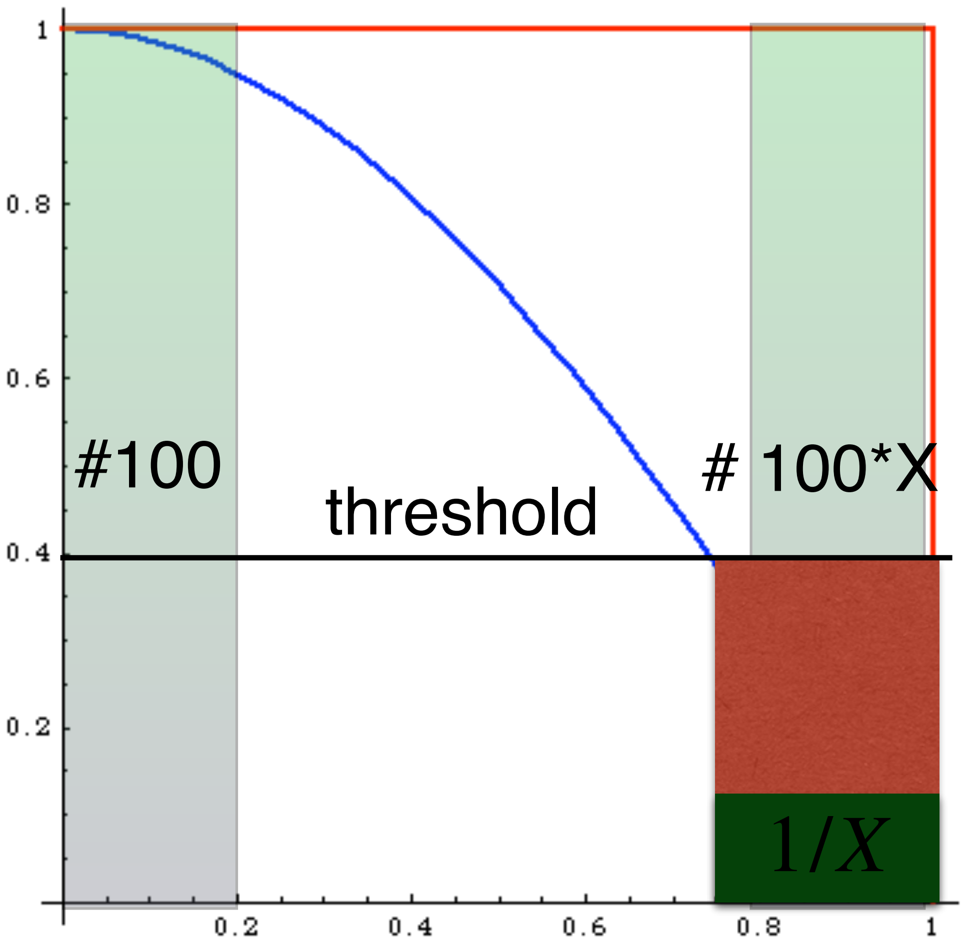
  - Discard events below the minimum
  - NO! We loose cross-section/ bias ourself

- Let's put a minimum
  - But keep 50% of the events below
  - Multiply the weight of each event by 2 (preserve cross-section)
  - We loose information
  - But we gain in file size

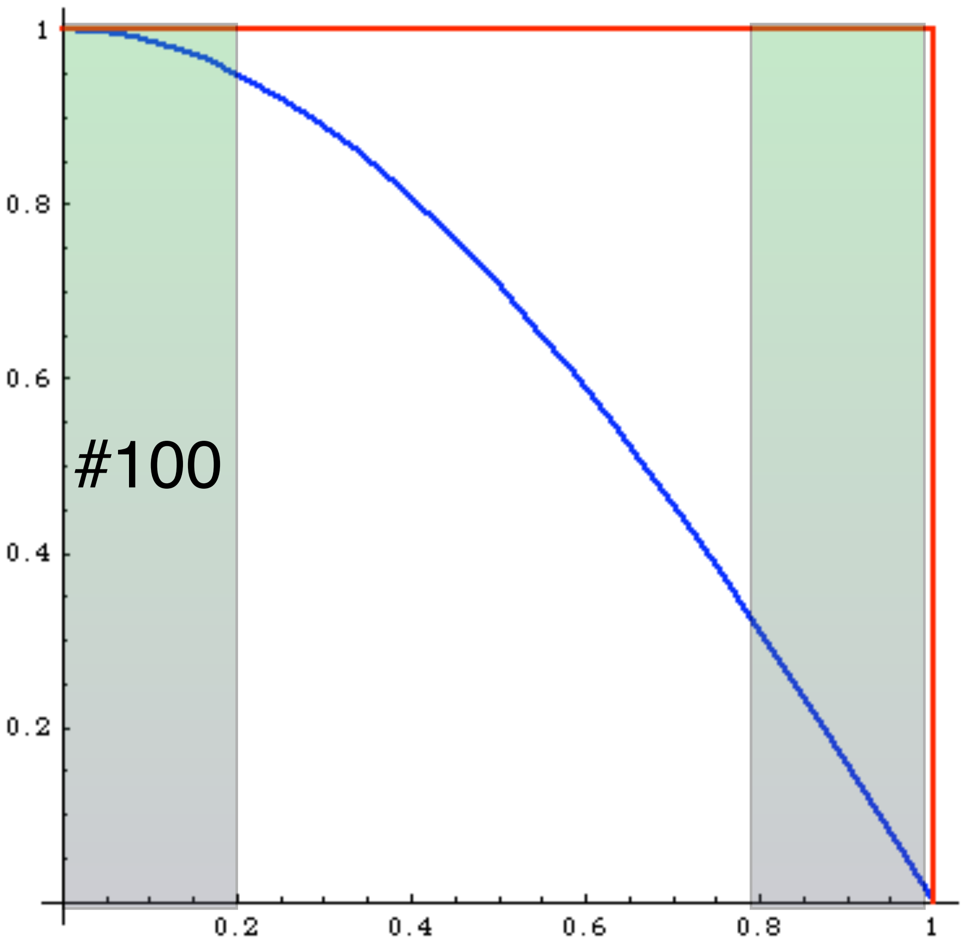
Do we need to keep small weight?



- Let's put a threshold
  - But keep X*100% of the events below
  - Multiply the weight of each event by 1/X (preserve cross-section)

Do we need to keep small weight?

- Let's put a threshold
  - But keep X*100% of the events below
  - Multiply the weight of each event by 1/X (preserve cross-section)



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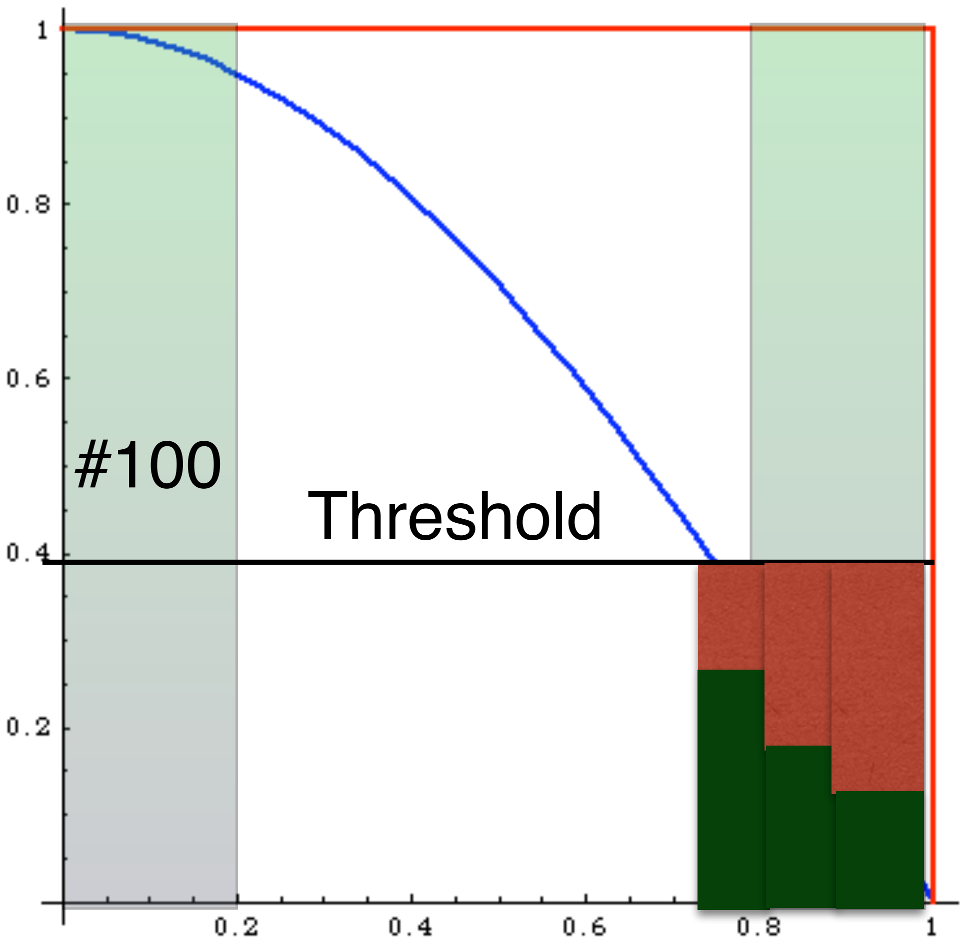
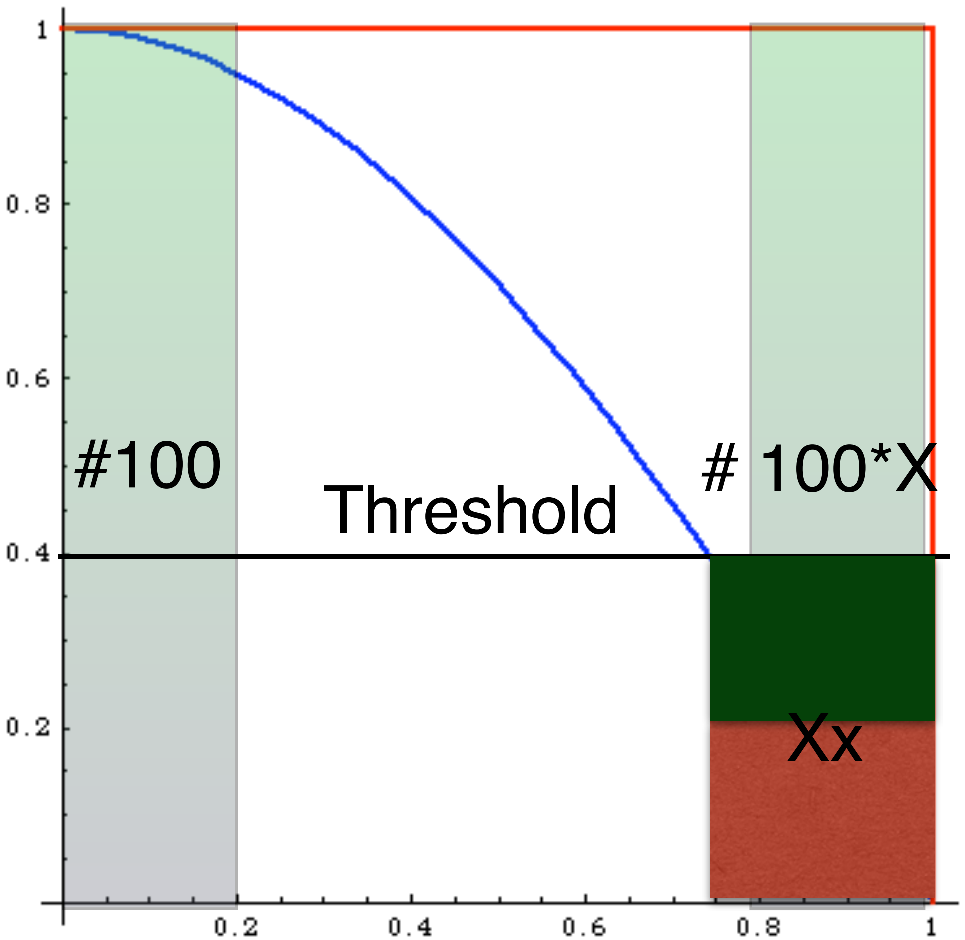


- Let's put a threshold
  - But keep X*100% of the events below
  - Multiply the weight of each event by 1/X (preserve cross-section)

- Let's improve
  - We could reject more event (change X) where the function is small

Do we need to keep small weight?



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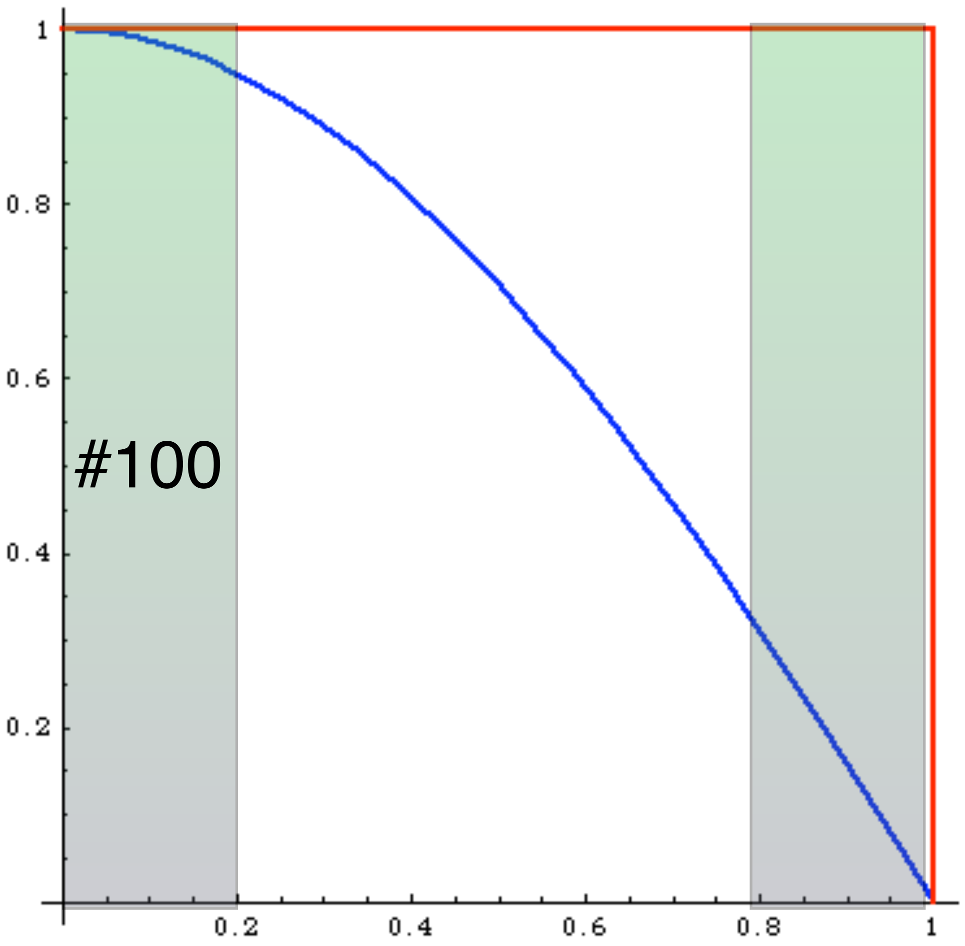

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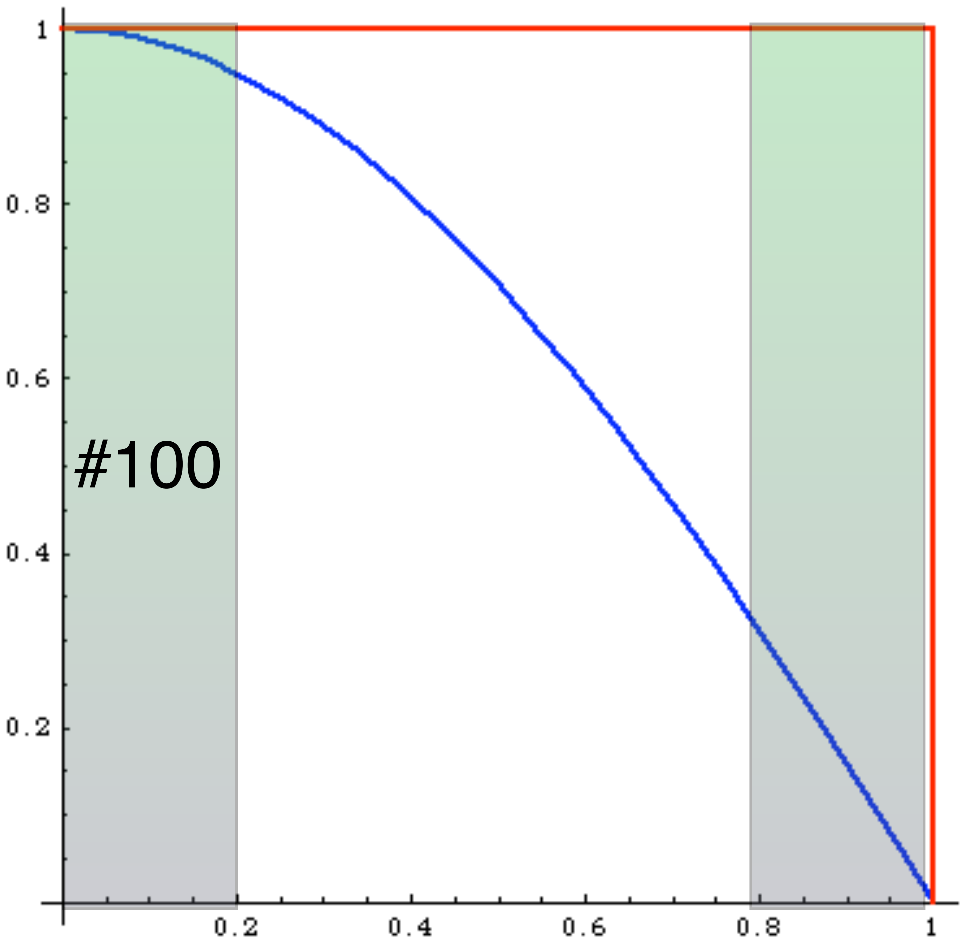
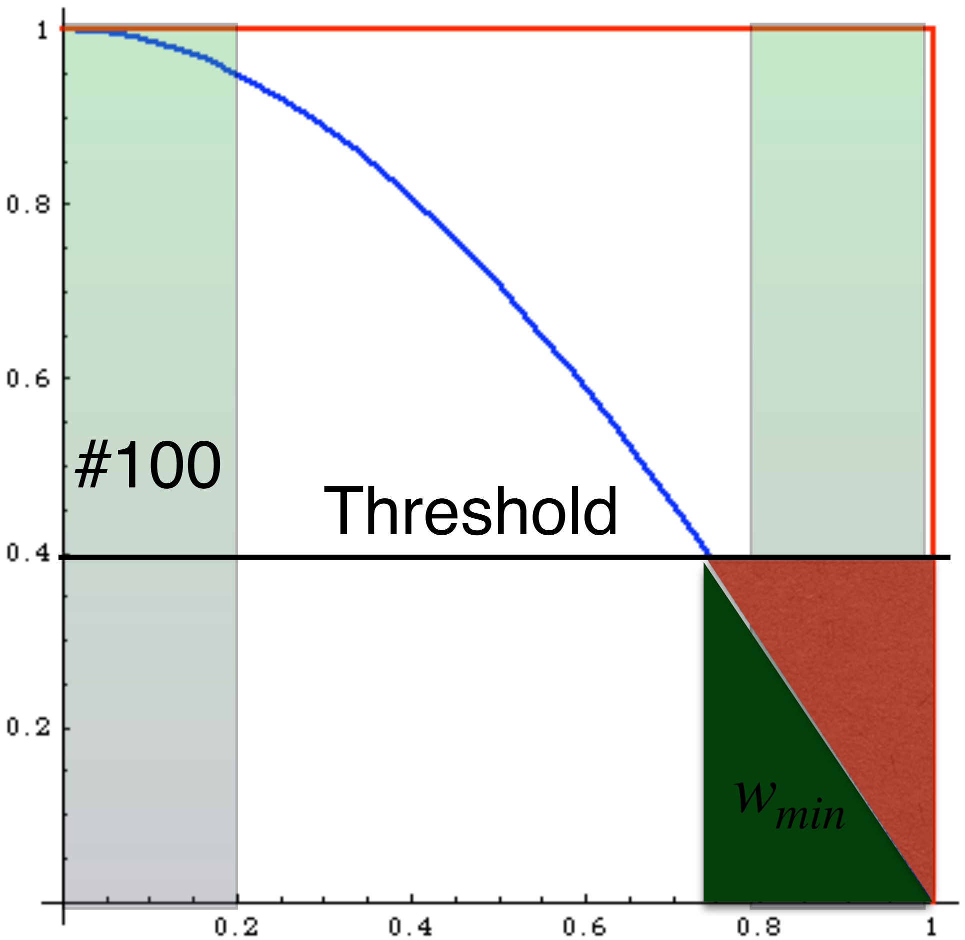


- Let’s put a threshold
  - But keep X*100% of the events below
  - Multiply the weight of each event by 1/X (preserve cross-section)

- Let’s improve
  - Let’s make the threshold proportional to the weight

Do we need to keep small weight?



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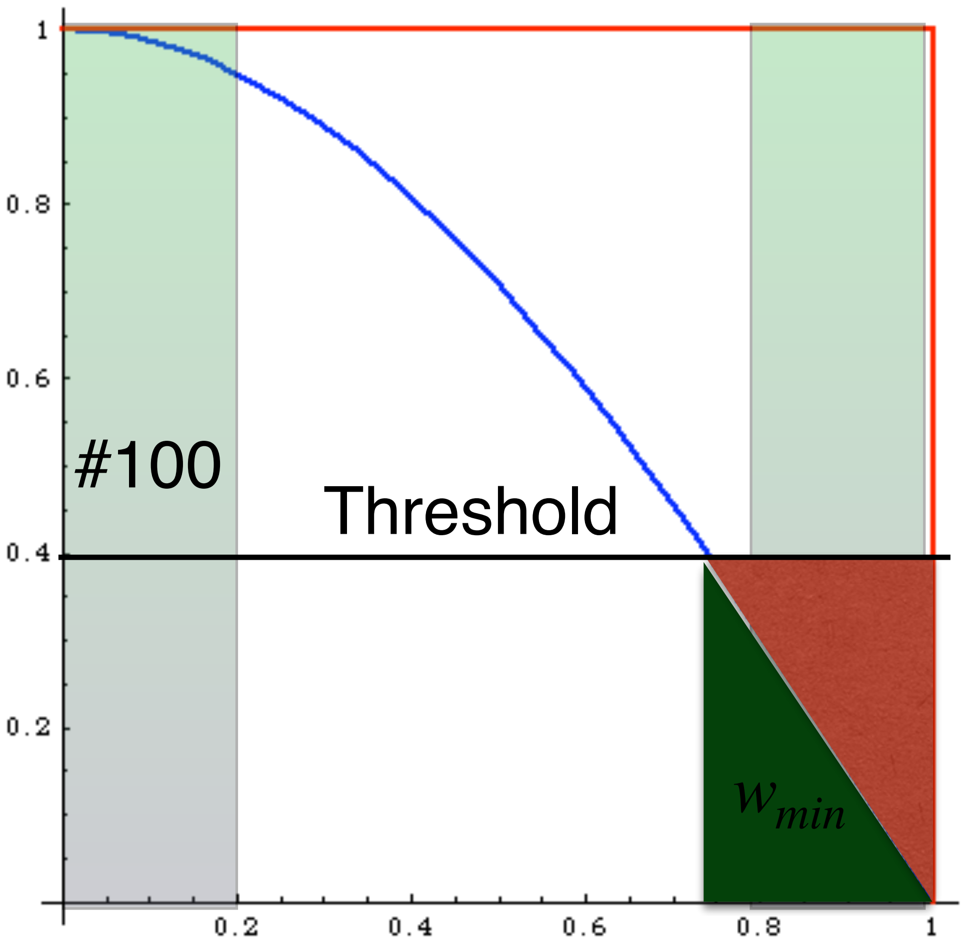

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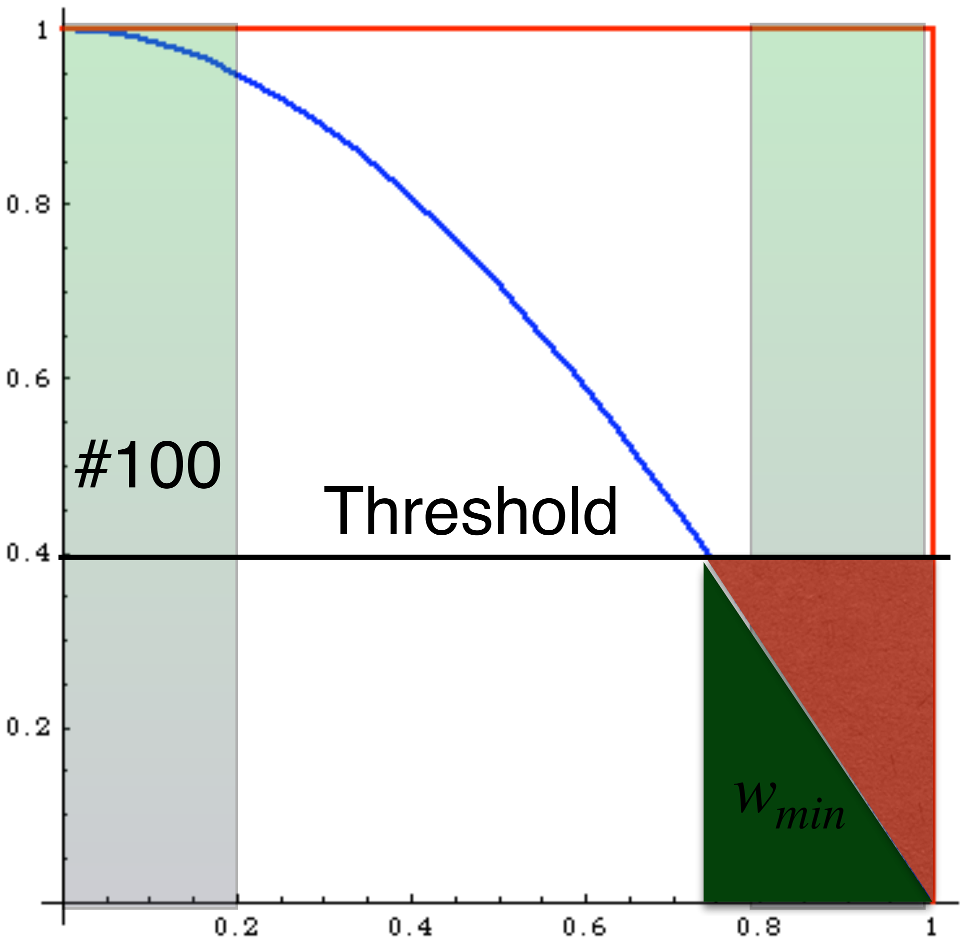
- Let's improve
  - Let's make the threshold proportional to the weight
  - Keep each event with $\frac{100w}{w_{thres}}\%$ probability

Do we need to keep small weight?



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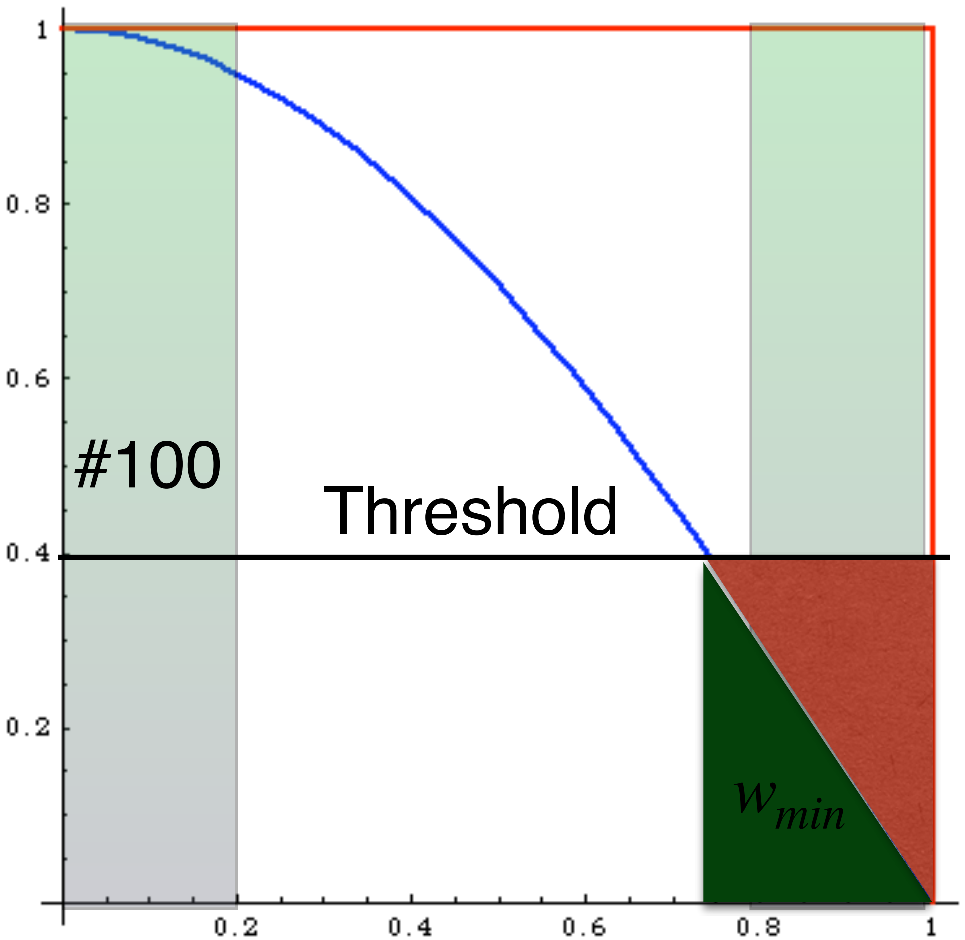
- Let's improve
  - Let's make the threshold proportional to the weight
  - Keep each event with $\frac{100w}{w_{thres}}\%$ probability
  - If kept multiply his weight by $\frac{w_{thres}}{w}$

Do we need to keep small weight?



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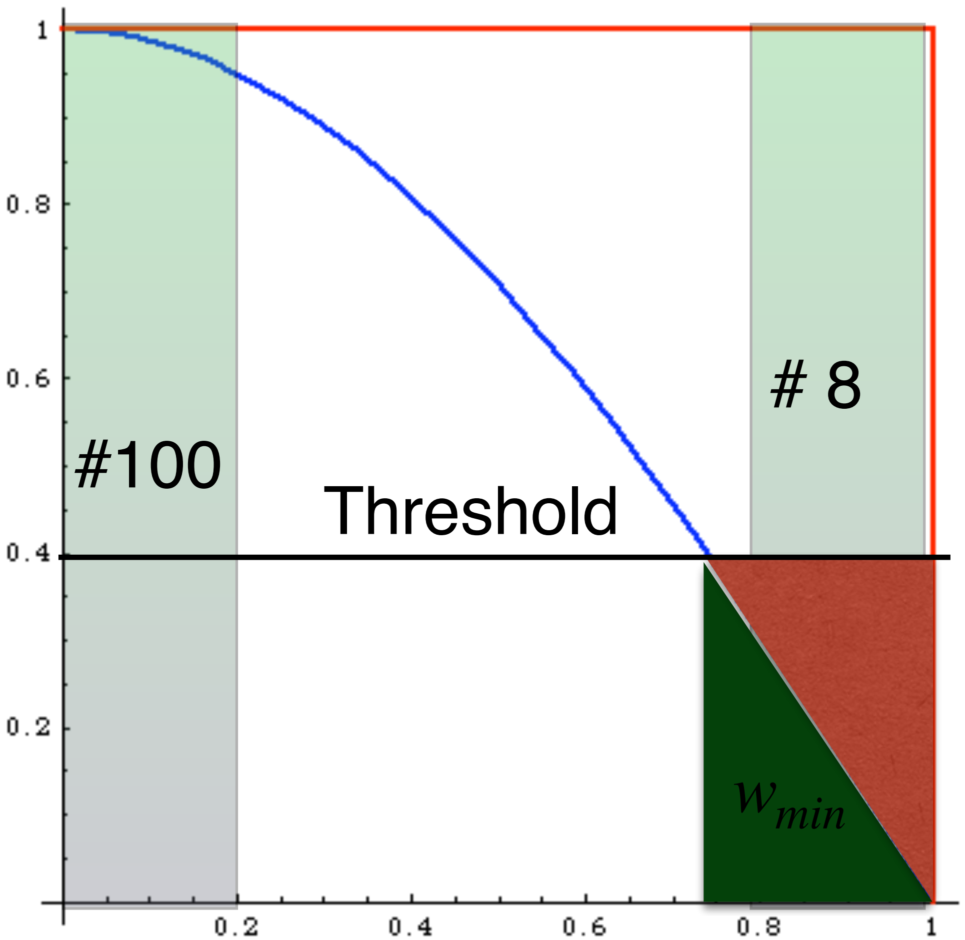
  - If kept multiply his weight by $\frac{w_{thres}}{w}$
  - So the new weight is w_{thres}

Do we need to keep small weight?



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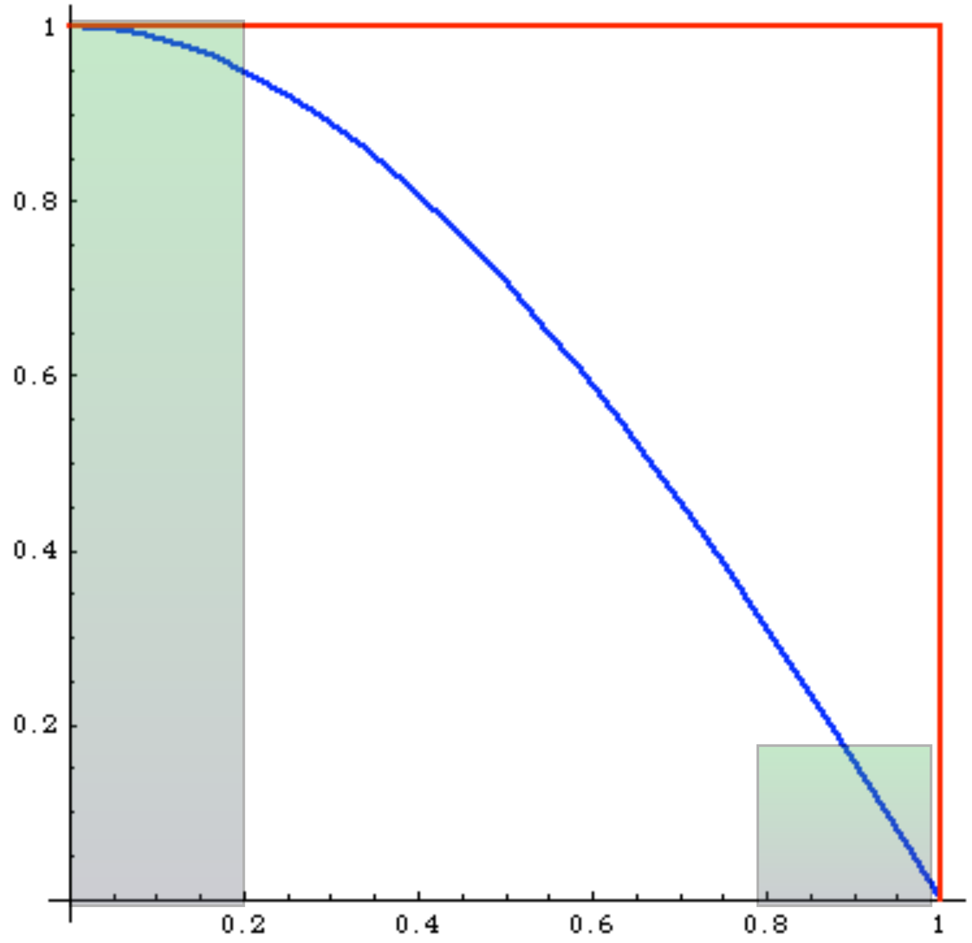
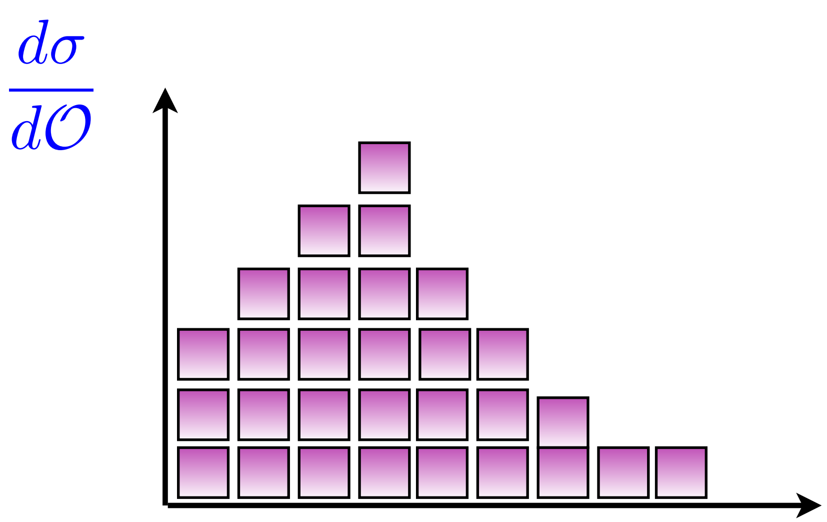
Unweighted events

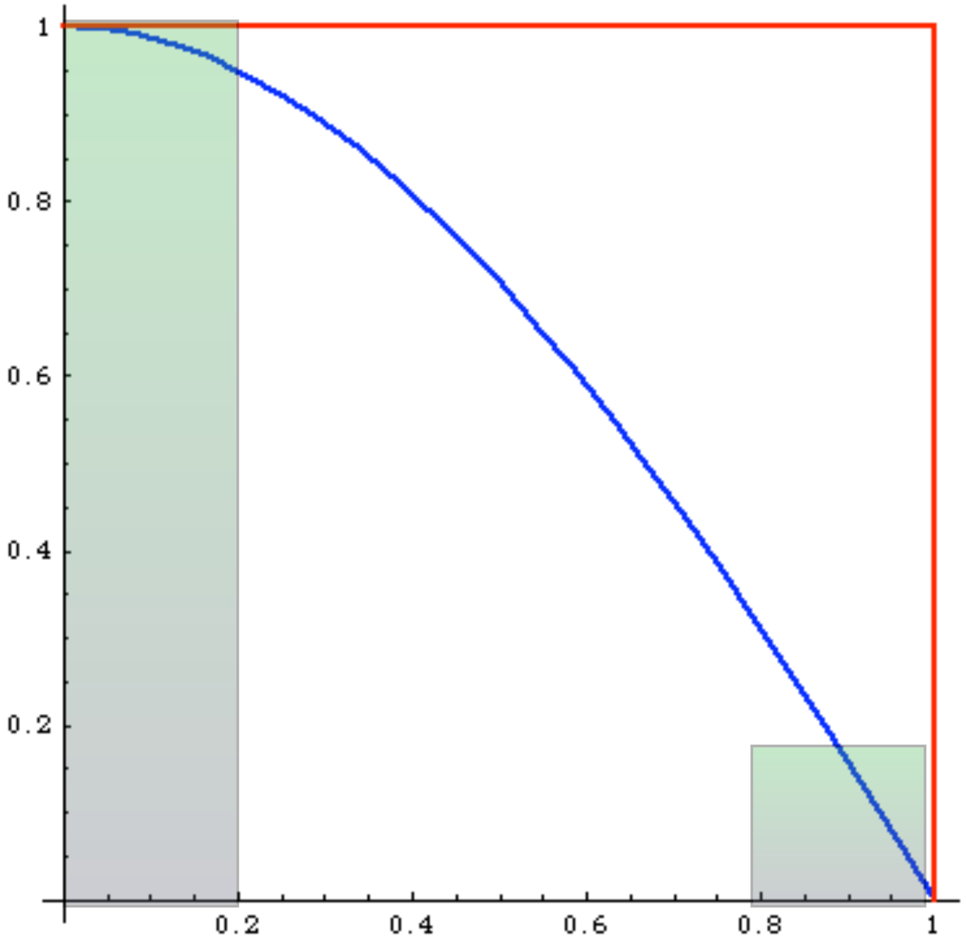
Events distributed as in nature

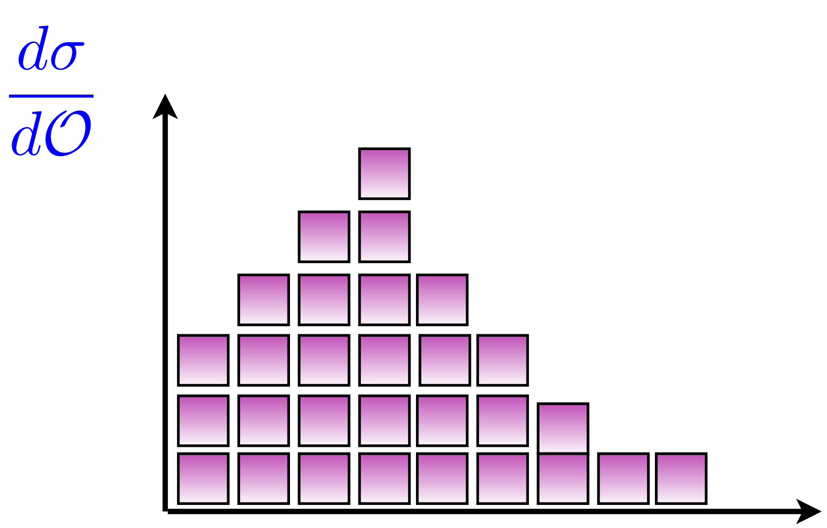




Unweighted events

Events distributed as in nature

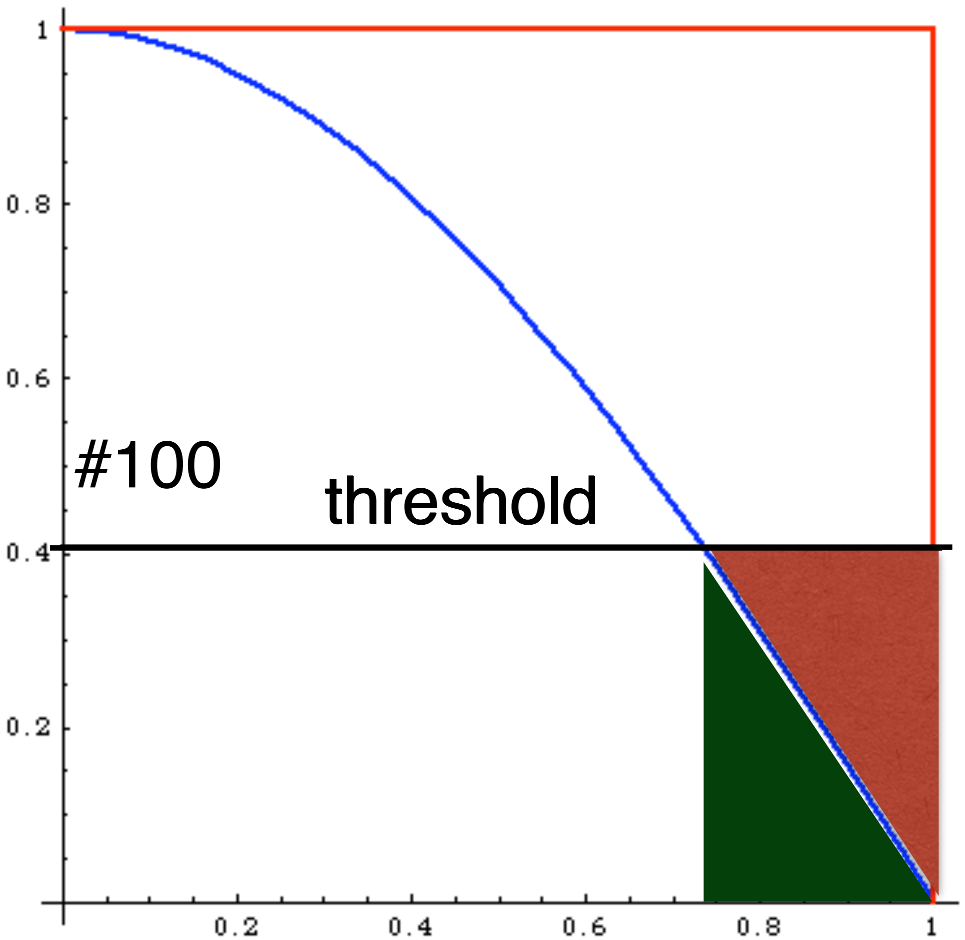




- All bins should event event proportional to their cross-section (Up to Poisson distribution)
- All events should have the same weight

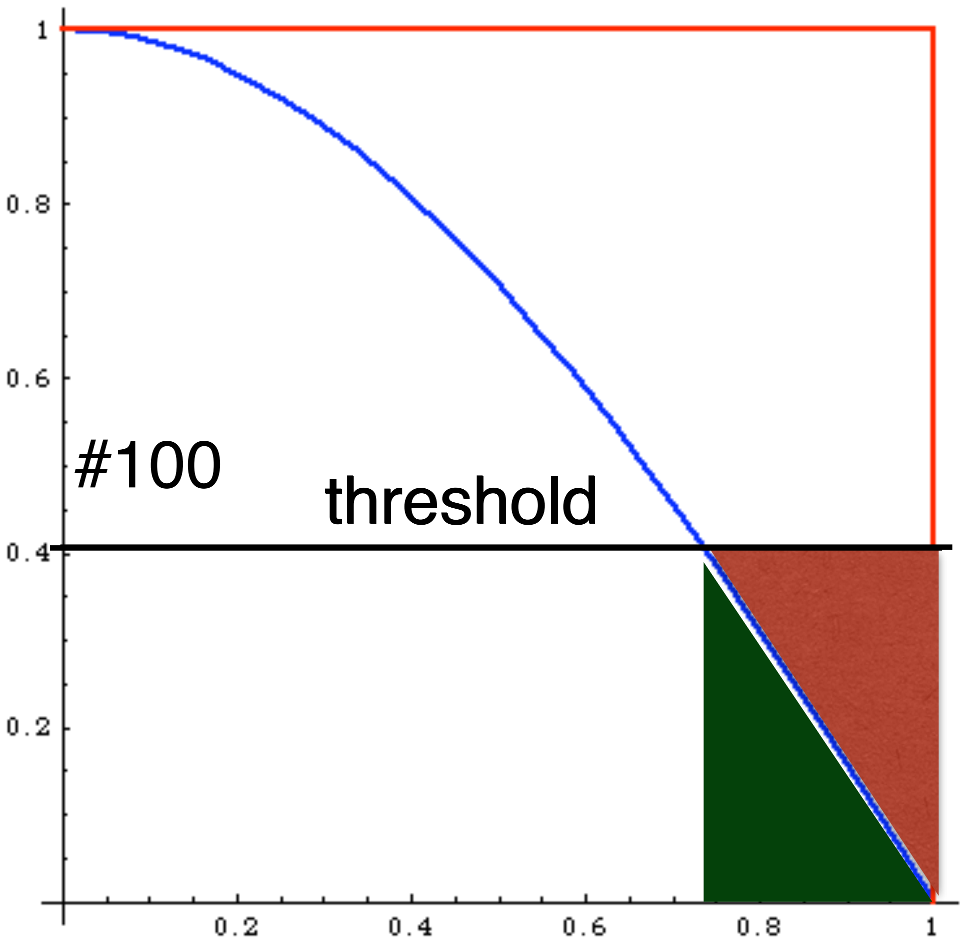
- This correspond to the smallest file size or maximum compression

Do we need to keep small weight?



- Let’s improve
  - Let’s make the threshold proportional to the weight
  - So the new weight is w_{thres}

Do we need to keep small weight?



- Let's improve
  - Let's make the threshold proportional to the weight
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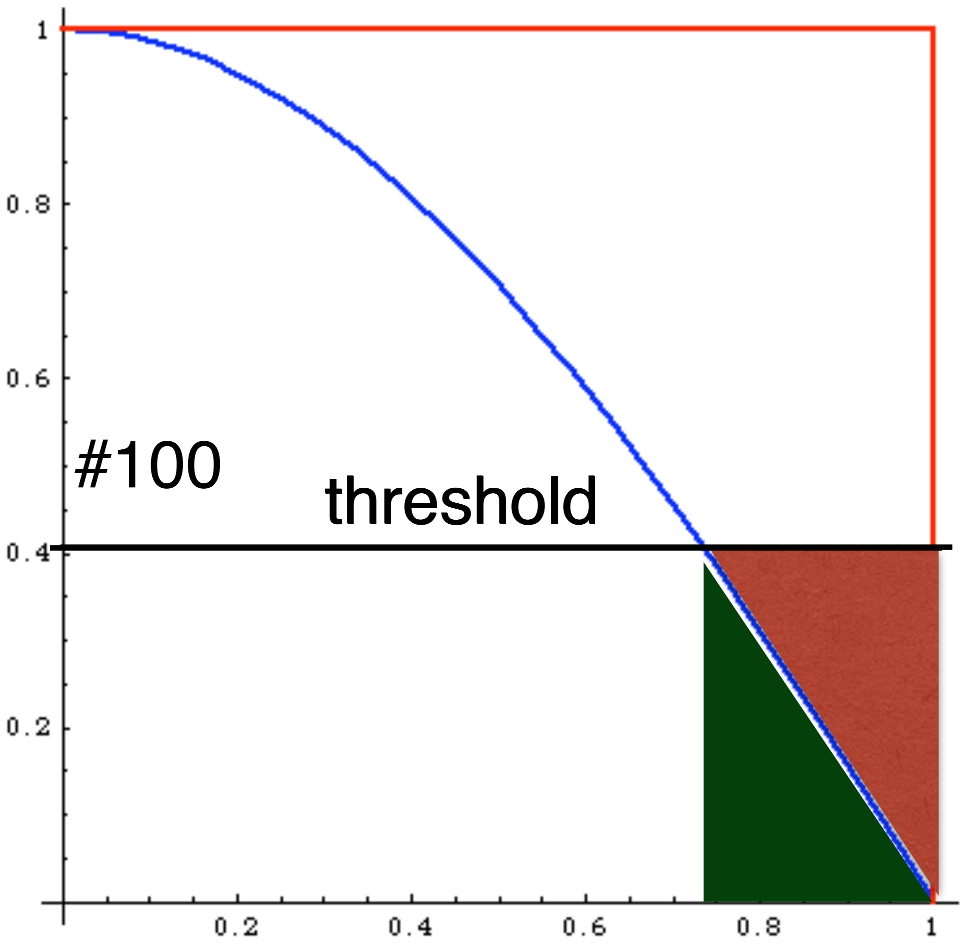
- Let's all event have the same weight

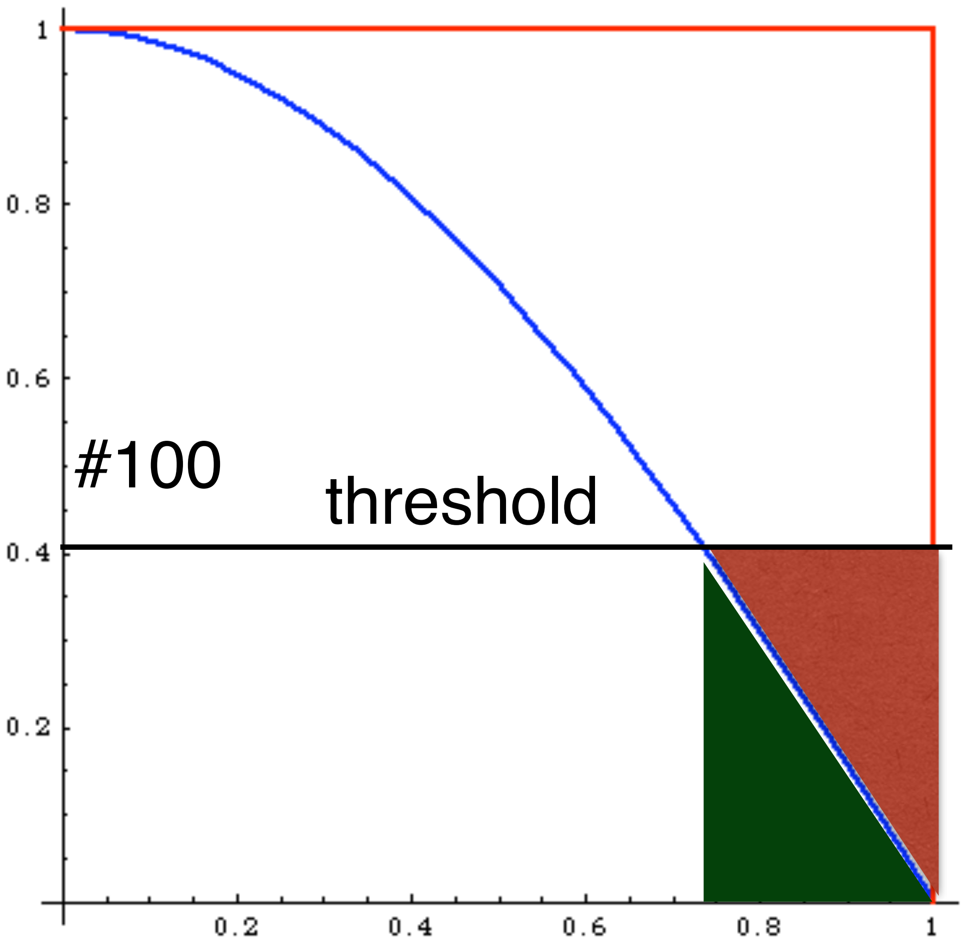
Do we need to keep small weight?



- Let’s improve
  - Let’s make the threshold proportional to the weight
  - So the new weight is w_{thres}

- Let’s all event have the same weight
  - So set $w_{thres} > \max(w)$

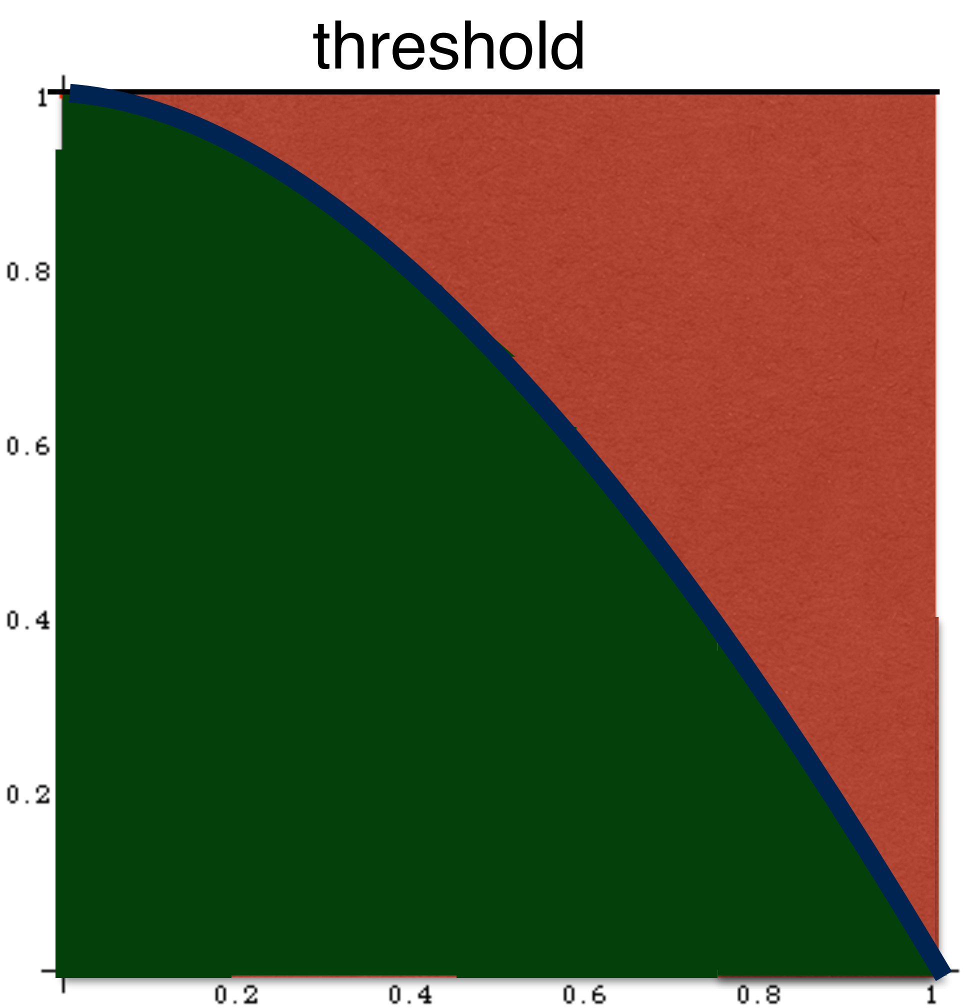
Do we need to keep small weight?



- Let's improve
  - Let's make the threshold proportional to the weight
  - So the new weight is w_{thres}

- Let's all event have the same weight
  - So set $w_{thres} > \max(w)$
- Maximal compression

Do we need to keep small weight?

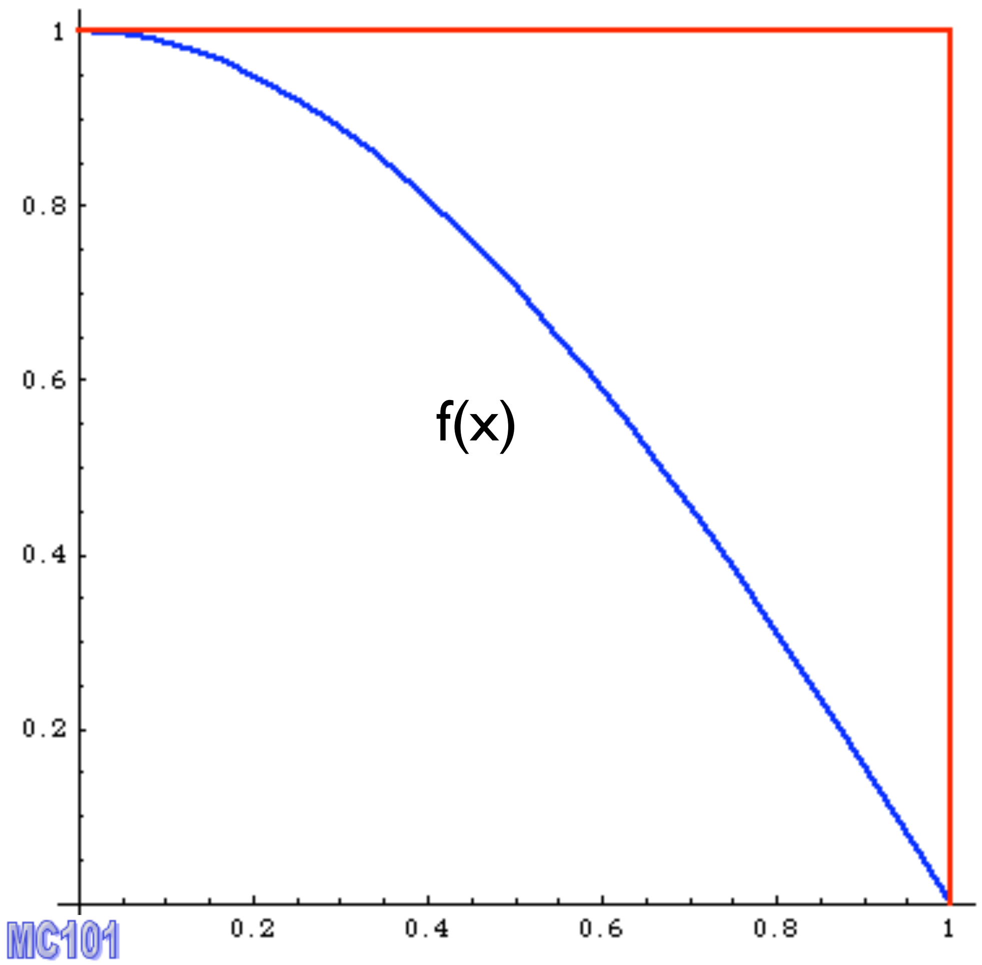


- Let’s improve
  - Let’s make the threshold proportional to the weight
  - So the new weight is w_{thres}

- Let’s all event have the same weight
  - So set $w_{thres} > \max(w)$
- Maximal compression

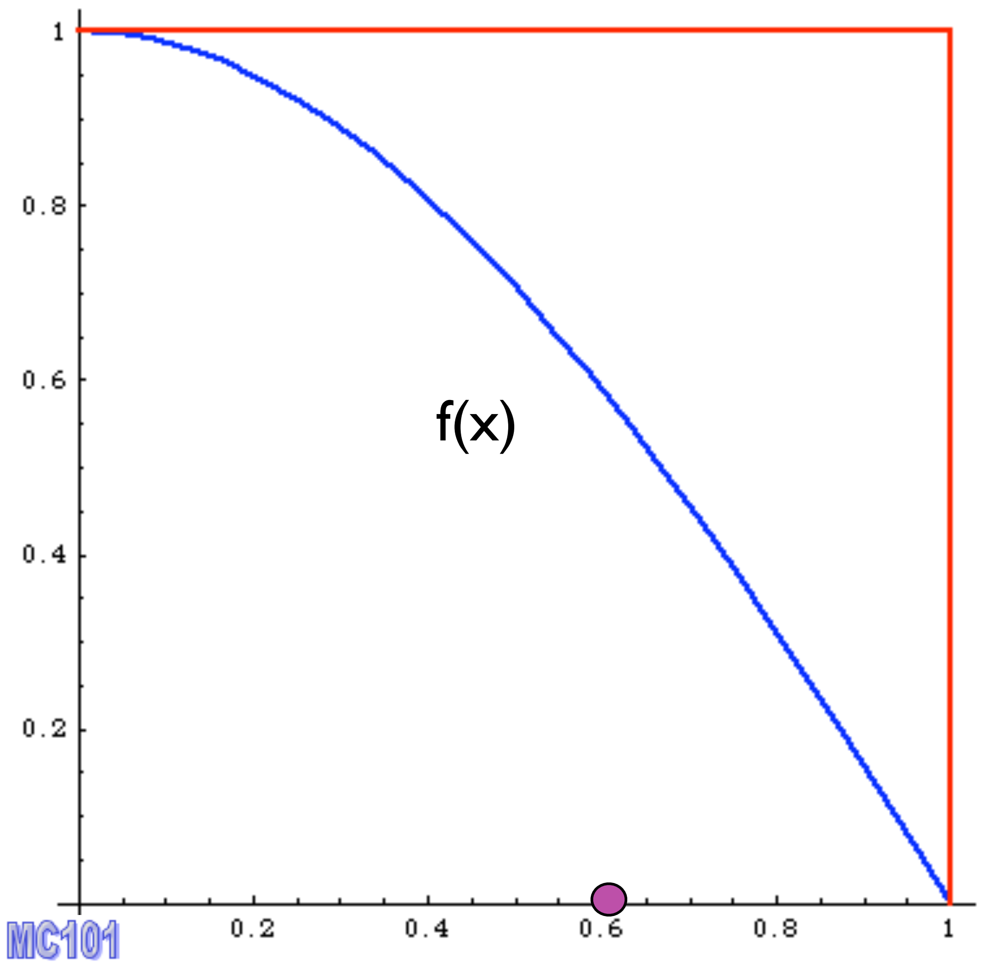
Event generation

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



Event generation

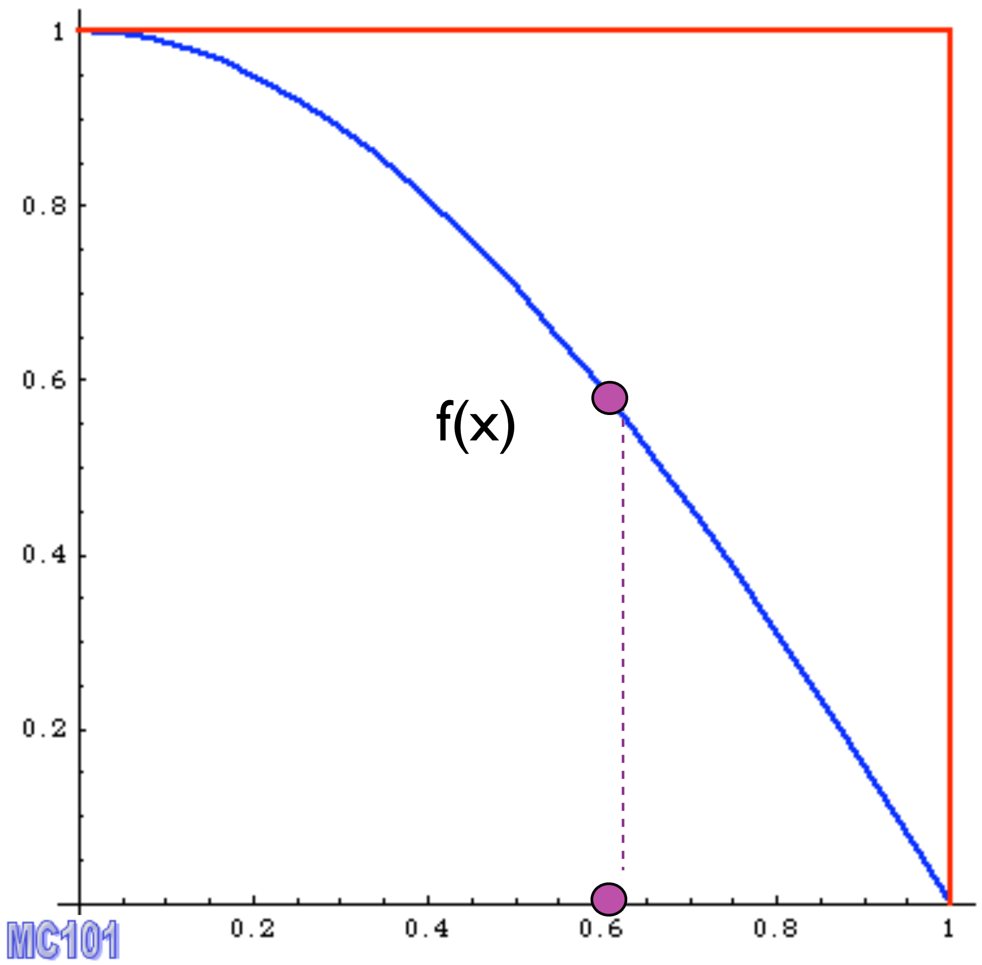
$$\int f(x)dx = \frac{1}{N}\sum_{i=1}^{N} f(x_i) = \frac{1}{N}\sum_{i=1}^{N} \frac{f(x_i)}{w_{thres}} w_{thres}$$



1. pick x_i

Event generation

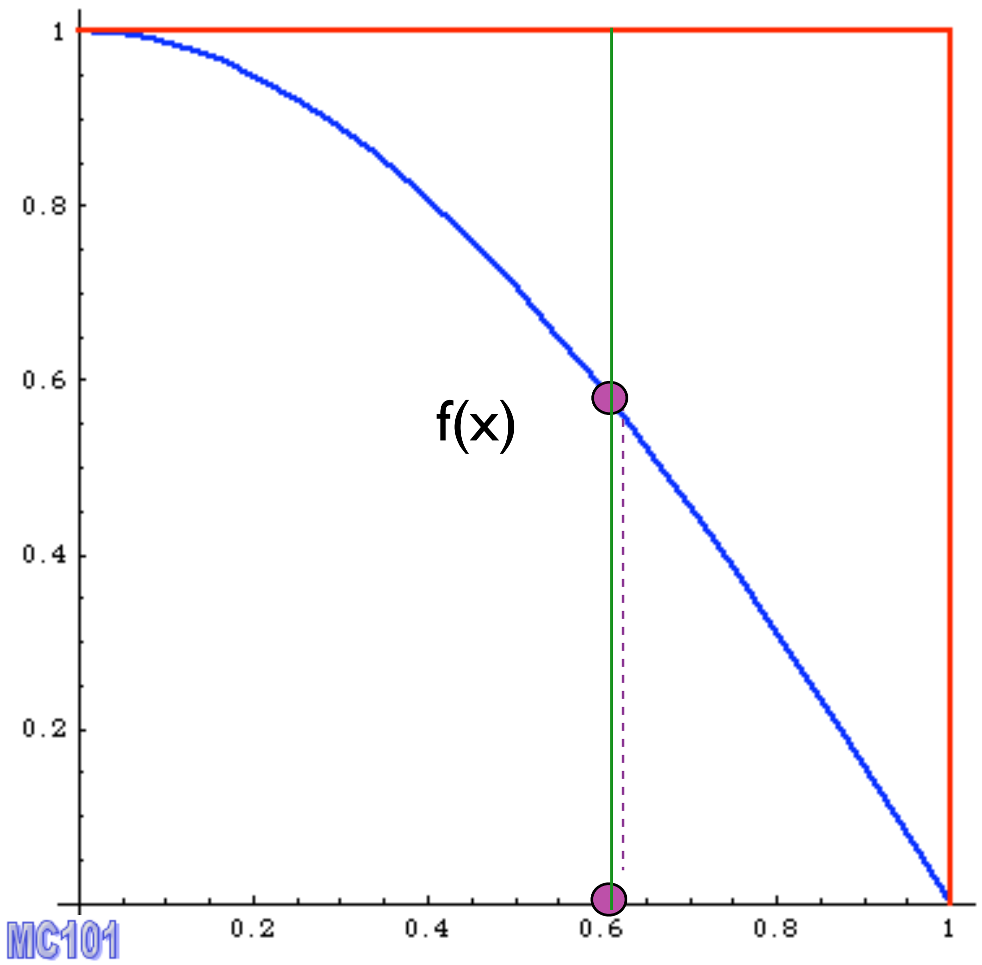
$$\int f(x)dx = \frac{1}{N}\sum_{i=1}^{N} f(x_i) = \frac{1}{N}\sum_{i=1}^{N} \frac{f(x_i)}{w_{thres}} w_{thres}$$



1. pick x_i
2. calculate $f(x_i)$

Event generation

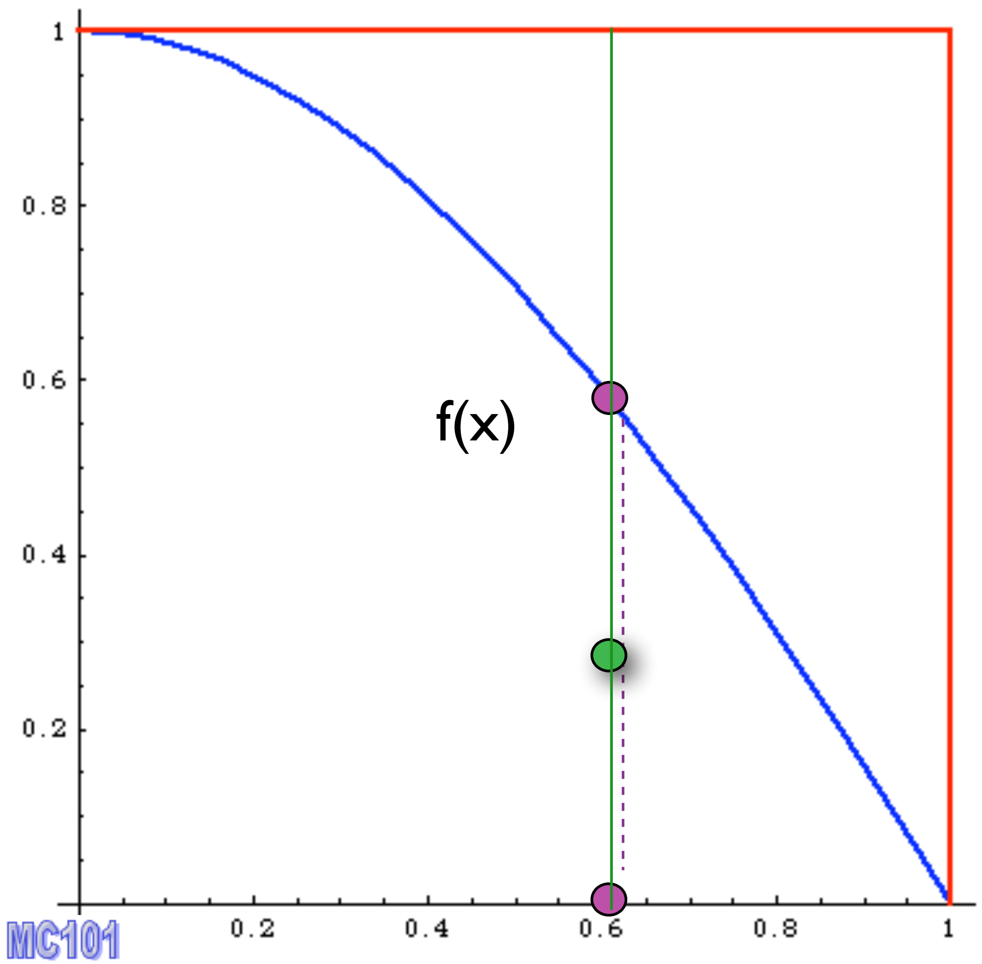
$$\int f(x)dx = \frac{1}{N}\sum_{i=1}^{N} f(x_i) = \frac{1}{N}\sum_{i=1}^{N} \frac{f(x_i)}{w_{thres}} w_{thres}$$



1. pick x_i
2. calculate $f(x_i)$
3. pick $y \in [0, max(f)]$

Event generation

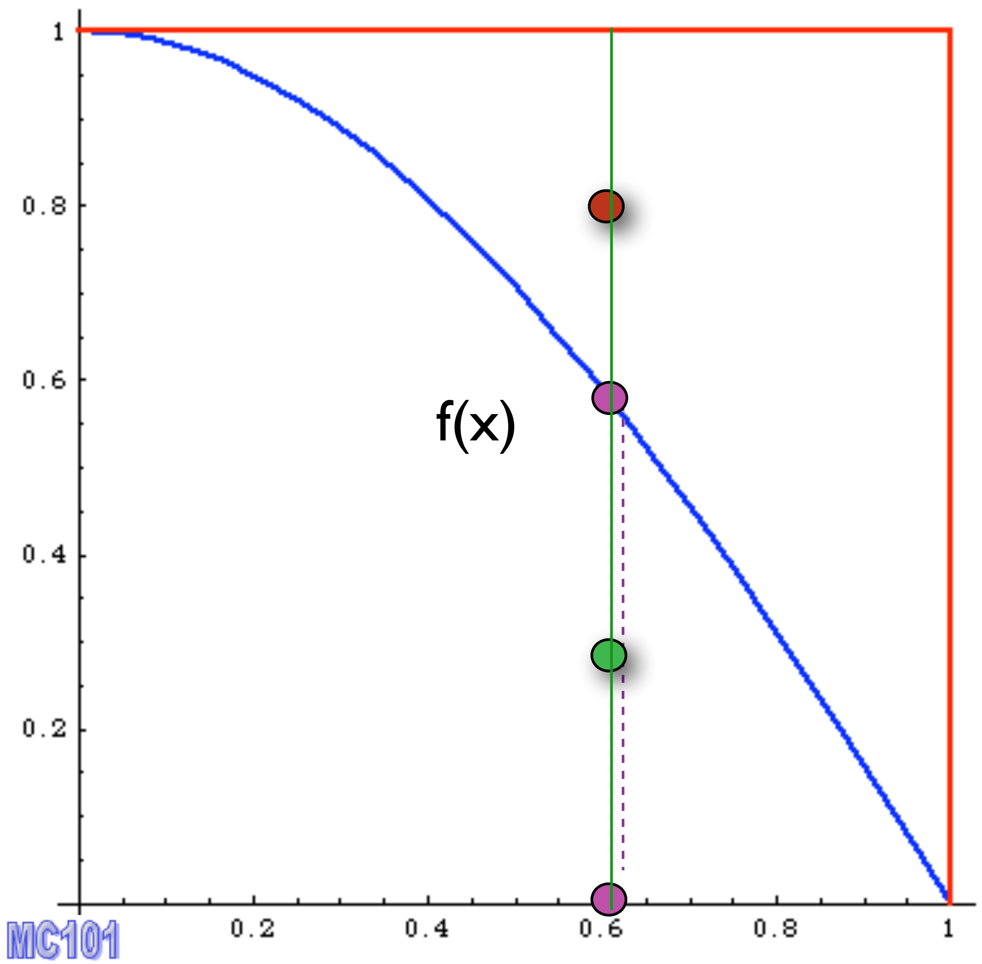
$$\int f(x)dx = \frac{1}{N}\sum_{i=1}^{N} f(x_i) = \frac{1}{N}\sum_{i=1}^{N} \frac{f(x_i)}{w_{thres}} w_{thres}$$



1. pick x_i
2. calculate $f(x_i)$
3. pick $y \in [0, max(f)]$
4. Compare:
   if $y < f(x_i)$ accept event,

Event generation

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

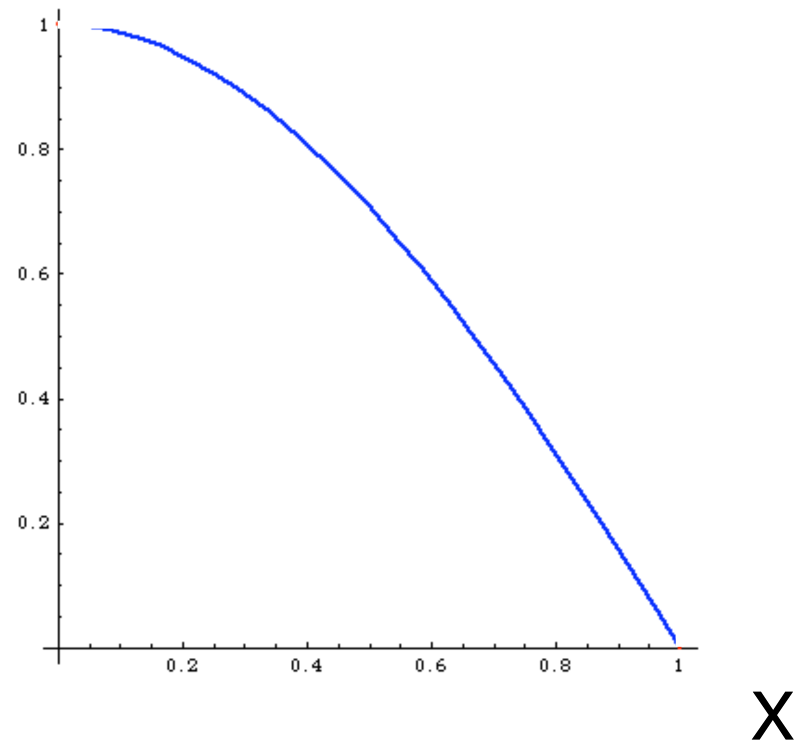


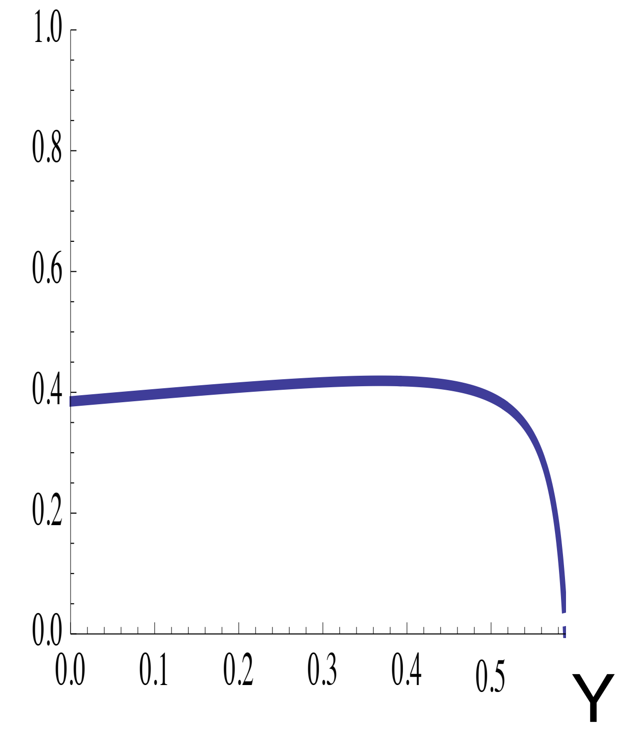
1. pick x_i
2. calculate $f(x_i)$
3. pick $y \in [0, max(f)]$
4. Compare:
   if $y < f(x_i)$ accept event,

   else reject it.

Event generation

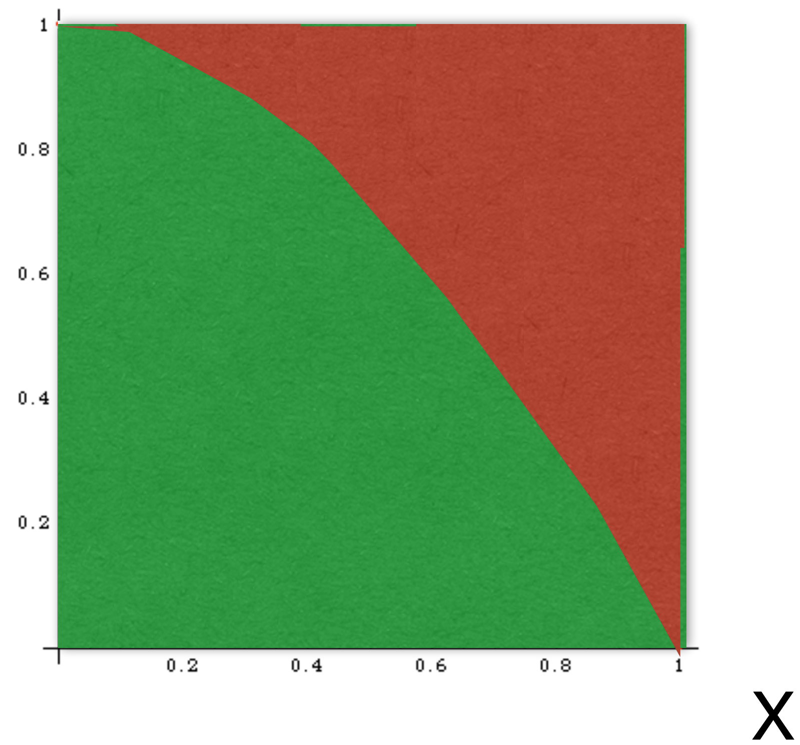
$$\int f(x)dx = \int dy \frac{f(y)}{p(y)} = \frac{1}{N}\sum_{i=1}^{N}\frac{f(y_i)}{p(y_i)} = \frac{1}{N}\sum_{i=1}^{N}\frac{f(y_i)}{p(y_i)\ w_{thres}} w_{thres}$$

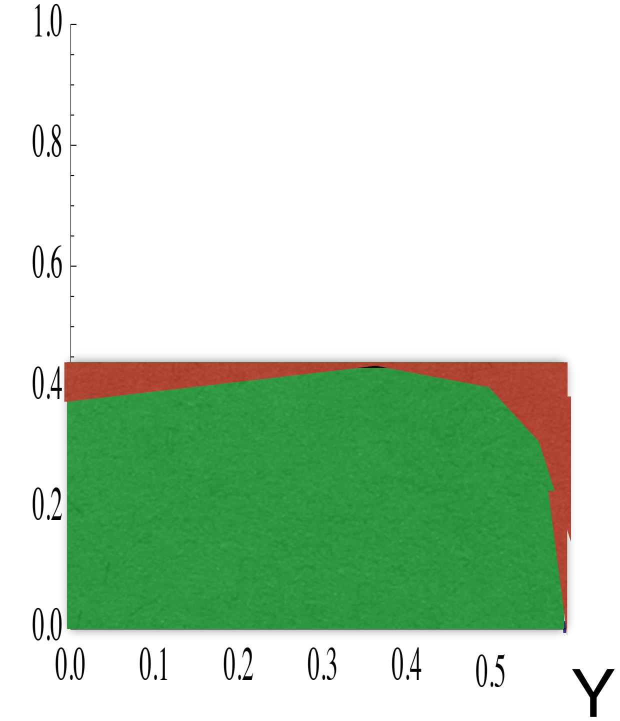




Event generation

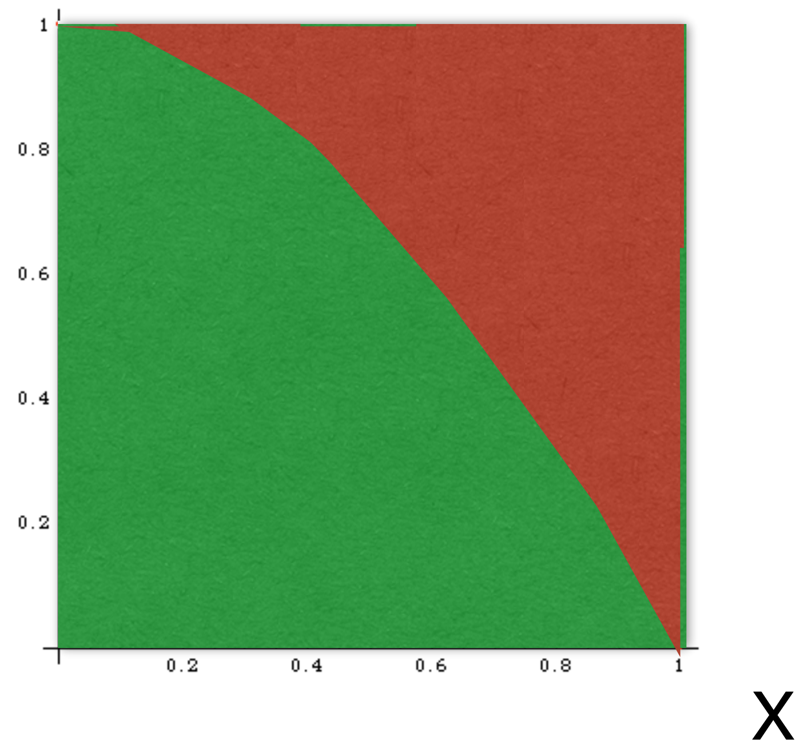
$$\int f(x)dx = \int dy \frac{f(y)}{p(y)} = \frac{1}{N}\sum_{i=1}^{N}\frac{f(y_i)}{p(y_i)} = \frac{1}{N}\sum_{i=1}^{N}\frac{f(y_i)}{p(y_i)\ w_{thres}} w_{thres}$$

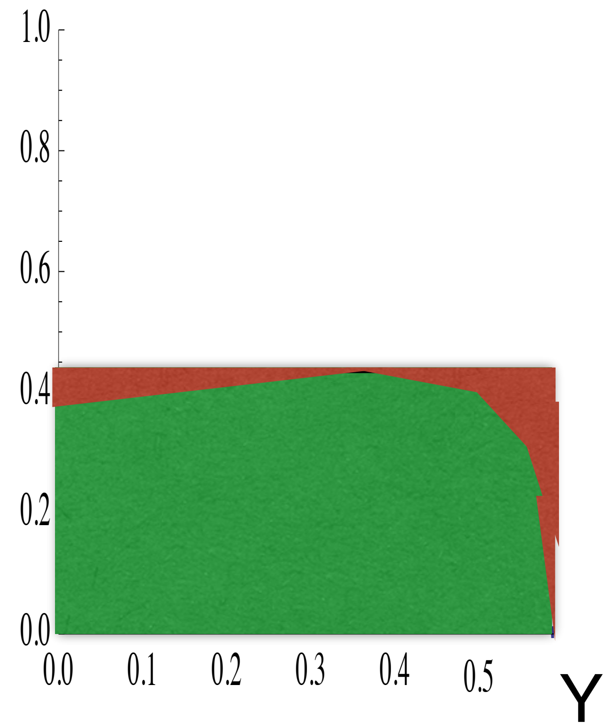




Event generation

$$\int f(x)dx = \int dy \frac{f(y)}{p(y)} = \frac{1}{N}\sum_{i=1}^{N}\frac{f(y_i)}{p(y_i)} = \frac{1}{N}\sum_{i=1}^{N}\frac{f(y_i)}{p(y_i)\ w_{thres}} w_{thres}$$





- Having smaller variance (flatter function) also allows to have $\frac{w}{w_{thres}}$ or $\frac{w}{max(w)}$ closer to one and therefore better unweighting efficiency (i.e. faster code)