Madweight and application to ttH

1st mini-workshop on "Theoretical advances in the Matrix Element Methods"

27 May 2013

Pierre Artoisenet
NIKHEF

PART I

MADWEIGHT

P.A., V. Lemaitre, F. Maltoni, O. Mattelaer

From a phase-space generator to a dynamical framework for the MEM analyses

Automation of the matrix element reweighting method

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Weights in the MEM

see Florencia Canelli's talk

$$P(\boldsymbol{x}_i, \alpha) = \frac{1}{\sigma^{obs}} \frac{1}{N} \sum_{\text{jet perm.}} \int d\phi_{\boldsymbol{y}} |M|^2(\boldsymbol{y}) W(\boldsymbol{x}_i, \boldsymbol{y})$$

integration on the parton-level phase-space

tree-level matrix element

transfer function

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integration on the parton-level phase-space

tree-level matrix element

transfer function

- Monte Carlo integration ?

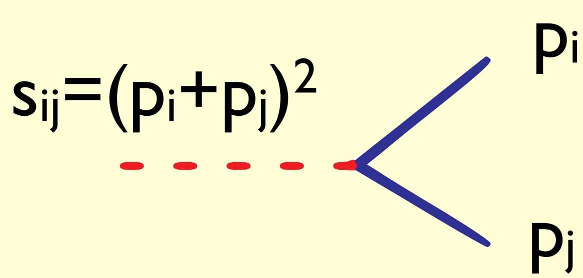
✓ available in mg5 for a very large set of processes

✓ can be extracted from Monte Carlo similations

Practical Evaluation of the weights

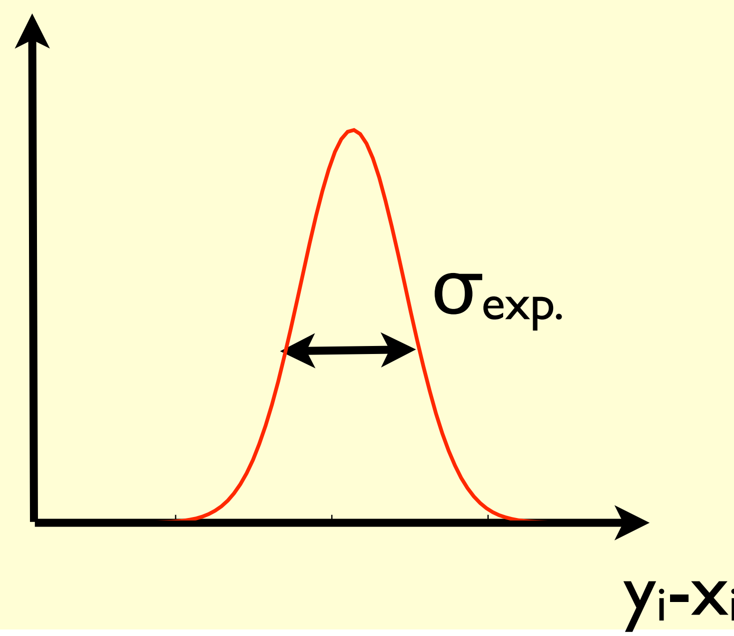
$$P(x,\alpha) \propto \int d\phi_{\boldsymbol{y}} \, |M|^2(\boldsymbol{y}) \, W(\boldsymbol{x},\boldsymbol{y})$$

highly non-uniform, especially in the presence of resonances



Breit-Wigner distr. in s_{ij}

highly non-uniform, especially when the resolution associated with a reconstructed quantity x_i is high:



when the dimension of the phase-space is large, this structure in "peaks" complicates the numerical evaluation of the weights

➡ need for an algorithm that is sufficiently fast (large number of weights must be evaluated)

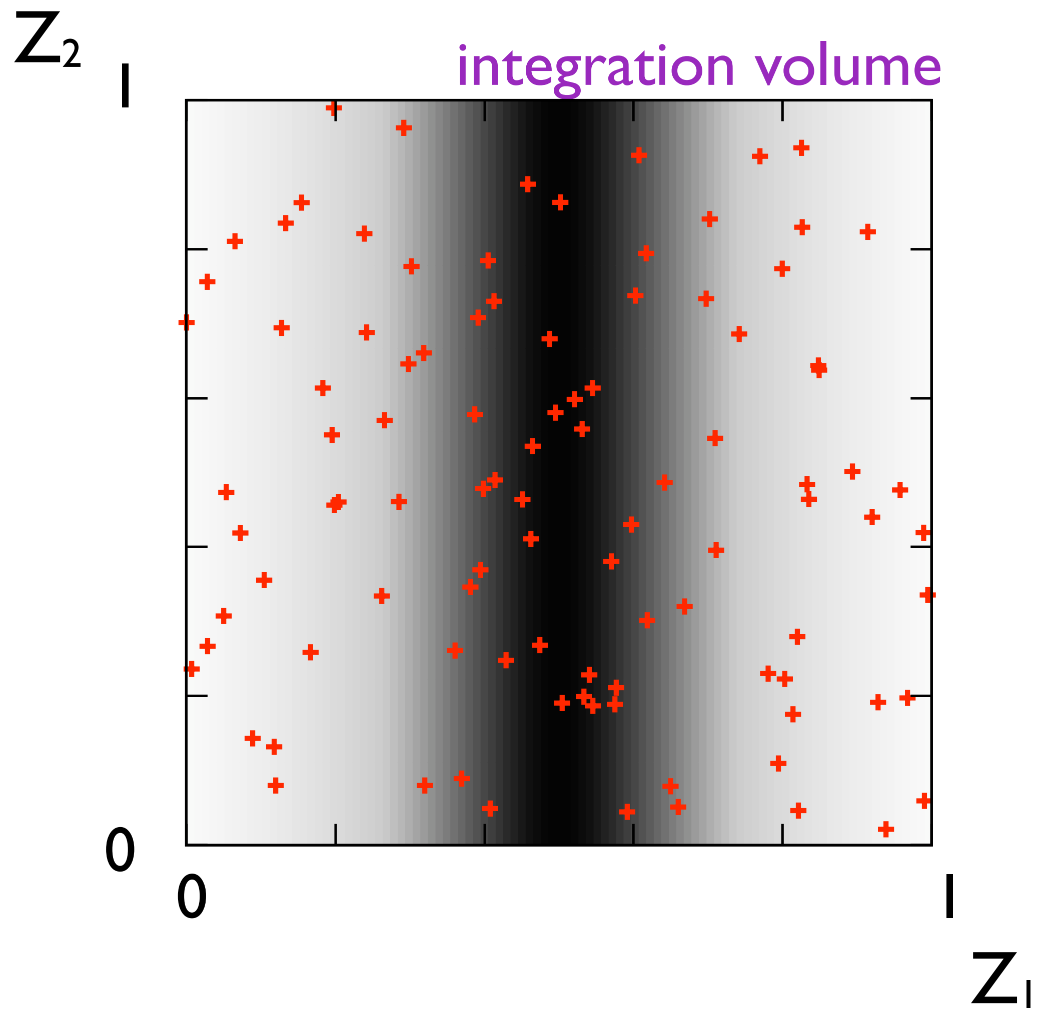
Monte Carlo integration

1. basic idea: $I = \int_V dz\, f(\boldsymbol{z})$ is estimated by sampling the volume V=[0,1]^d with N uniformly distributed random points: $E = \frac{1}{N}\sum_{n=1}^{N} f(\boldsymbol{z}_n)$

Std deviation: $\sigma_I \approx \frac{S}{\sqrt{N}}$

$$S^2 = \mathrm{var}(f) = \frac{1}{N-1}\sum_{n=1}^{N}\left[f(\boldsymbol{z}_n) - E\right]^2$$

S large ⇒ poor convergence

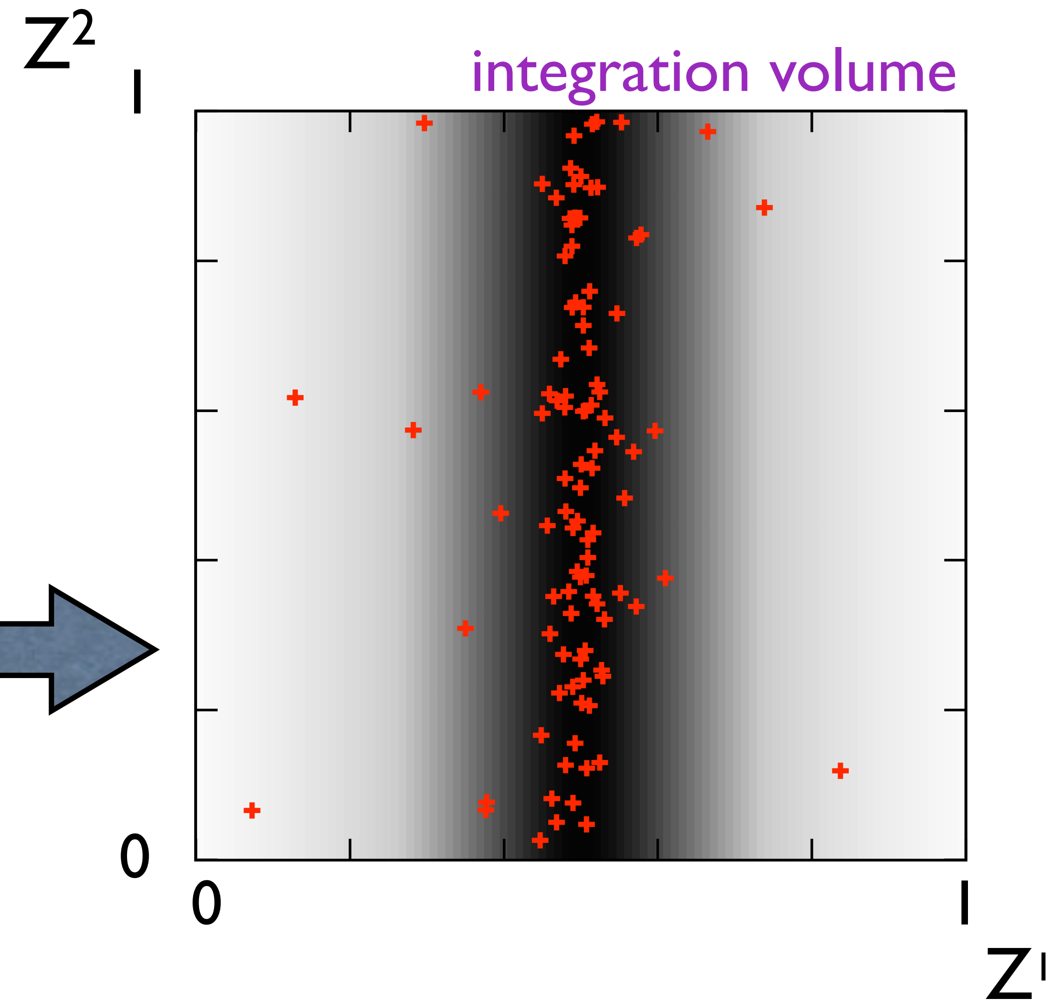


Monte Carlo integration

II. adaptive MC integration: probe the phase-space volume according to a probability density function $p(\boldsymbol{z}) = p_1(z^1)p_2(z^2)\dots p_d(z^d)$ (grid) that is adapted iteration after iteration

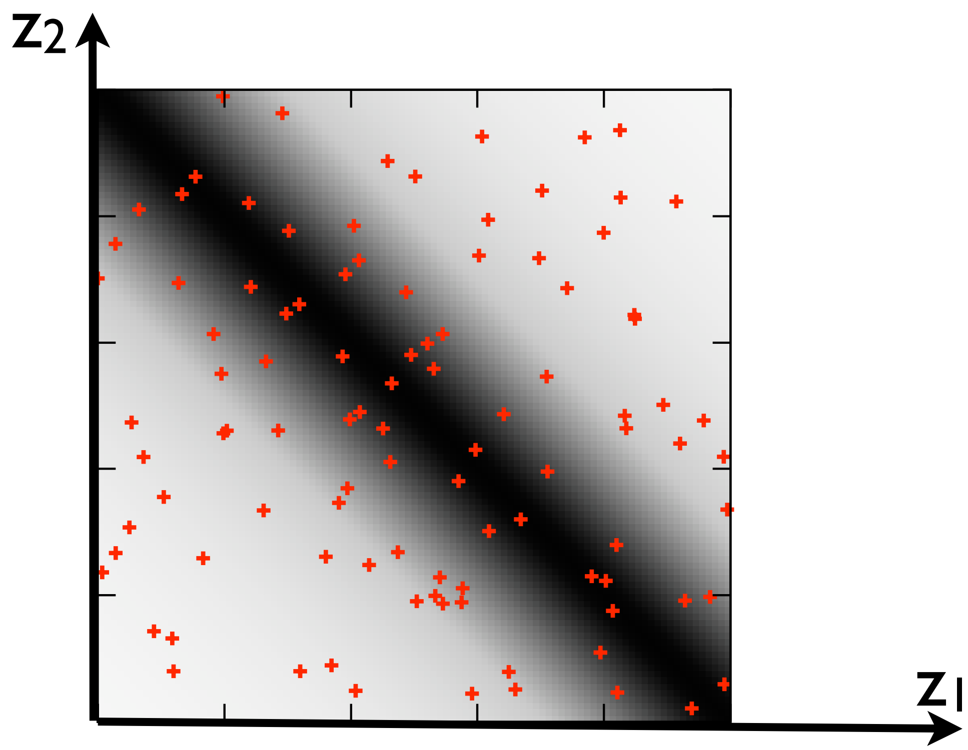
The grid has a factorized dependence in the integration variables

Here: adapt the expected density of points along the direction Z^1 to resolve the "peak"



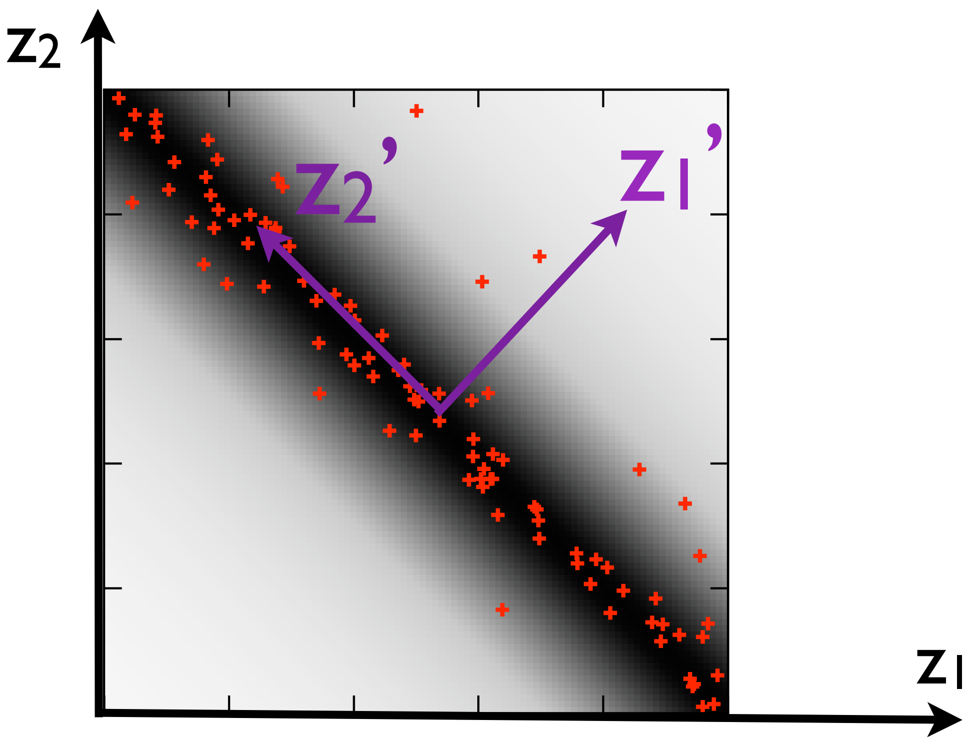
Adaptive Monte Carlo integration

the efficiency of the adaptive MC integration depends on the choice of variables of integrations



variables z_1, z_2:

the grid cannot be adjusted efficiently to the shape of the integrand because the strength of the "peak" in the integrand is not controlled by a single variable of integration

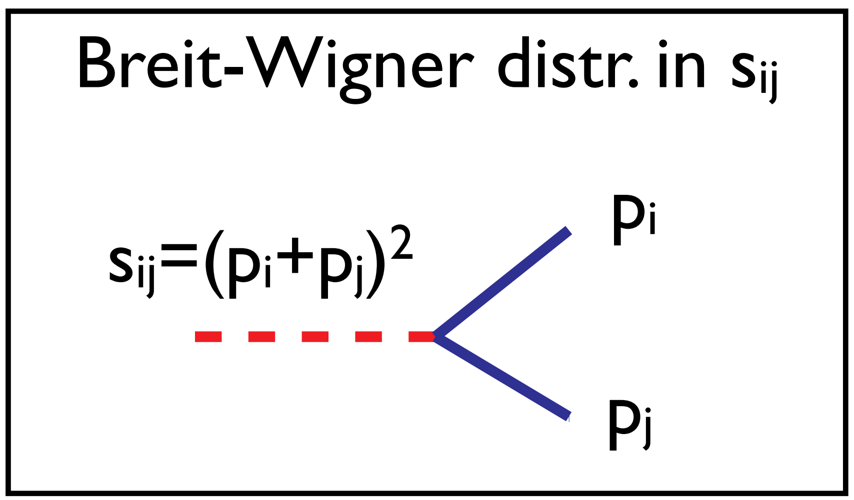


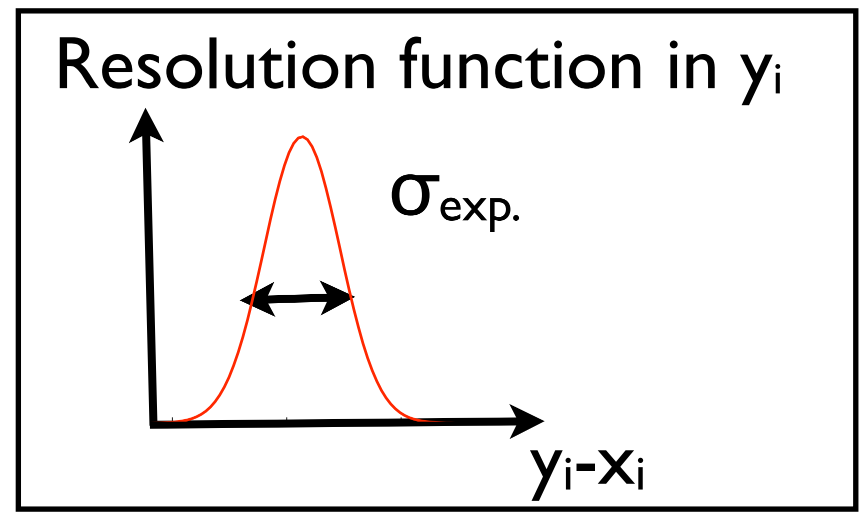
variables z_1', z_2':

the probability density along z_1' (= variable that controls the strength of the "peak") can be adapted to probe the integration region where the integrand is the largest

New phase-space mappings

- adaptive MC integration can be used for the computation of the weights, as we know where the "peaks" lie:



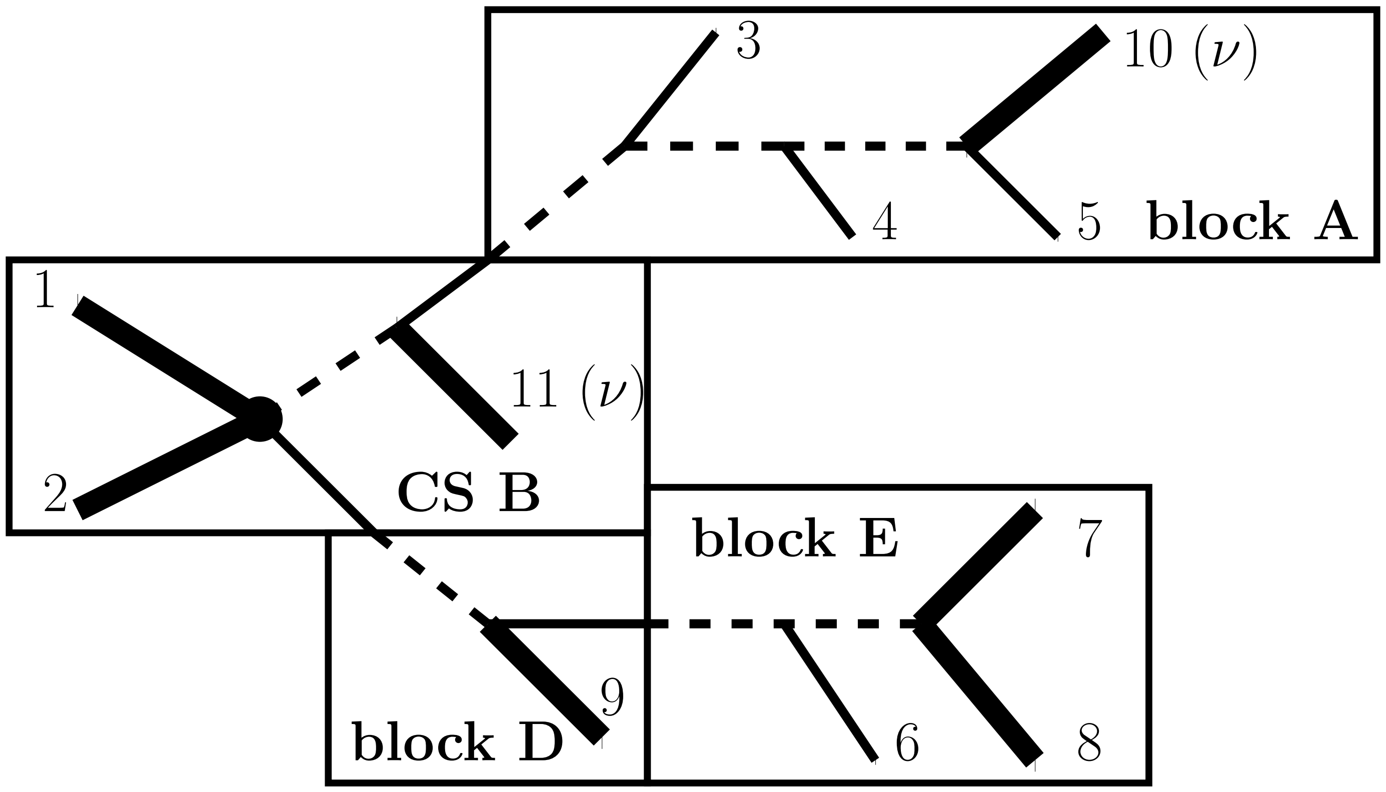


- for a given decay chain and a given transfer function, one needs to construct a new parametrization of the phase-space measure

- in the MEM analyses at the Tevatron, this problem was solved on a case-by-case basis

MadWeight

= generator of optimized phase-space mappings $d\phi_y$ for the evaluation of the weights in the Matrix Element Method



- The phase-space measure is decomposed into "blocks"
- The phase-space measure associated with each block is optimized to map the ME + TF enhancements
- momenta are generated backward (from the end of the decay chain to the interaction point)

- 12 blocks are defined in MadWeight ➪ infinite set of phase-space mappings
- the optimal phase-space mappings are generated automatically and combined in a multichannel approach

MadWeight history

- 2009 implementation in MGv4
    - multichannel integrator as described in (see paper)
- 2011 implementation in mg5 (‘madweight’ branch)
    - access to much lager set of matrix elements
    - effective treatment for ISR
    - subprocesses grouping
    - NWA
- 2013 release in mg5 v2   see Olivier’s talk
    - improved submission of jobs
    - NWA (cont’)
    - MC over parton-jet assignments
    - pre-training of the grid

Implementation in mg5

framework for MEM that is reliable, user-friendly, reproducible, fast

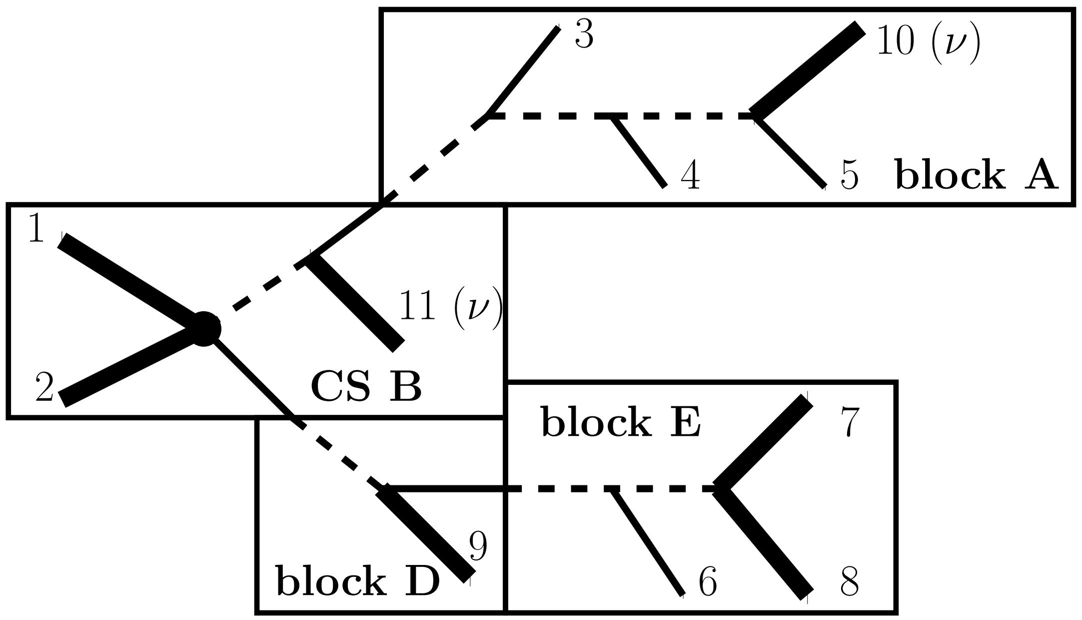
Implementation in mg5

framework for MEM that is reliable, user-friendly, reproducible, fast

EXACT phase-space measure:

reproduction of the phase-space volume for a large class of PS parametrizations $d\phi_y$

l	blocks	integrated volume
3	MB A	6.30×10^{-5}
3	MB B	6.30×10^{-5}
3	MB C	6.30×10^{-5}
6	MB D	694 GeV^6
4	MB E	0.0166 GeV^2
4	MB F	0.0166 GeV^2
5	MB B + SB A	3.89 GeV^4
4	MB B + SB B	0.0166 GeV^2
3	MB B + SB C	6.30×10^{-5}
3	MB B + SB D	6.30×10^{-5}
4	MB B + SB E	0.0166 GeV^2



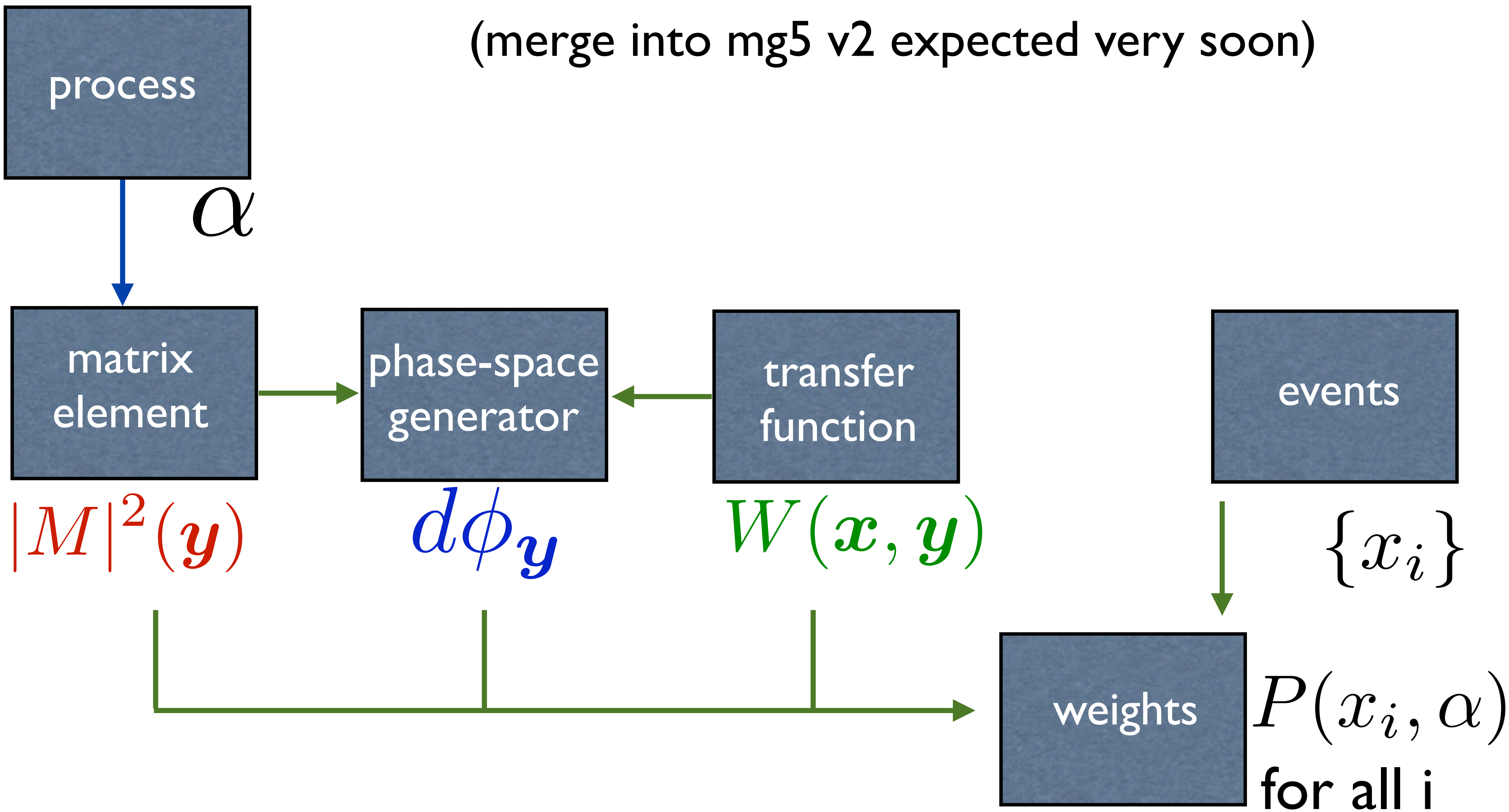
Implementation in mg5

framework for MEM that is reliable, user-friendly, reproducible, fast

➪ load madweight implementation in madgraph 5:

```
bzr branch lp:~maddevelopers/madgraph5/madweight
```

(merge into mg5 v2 expected very soon)



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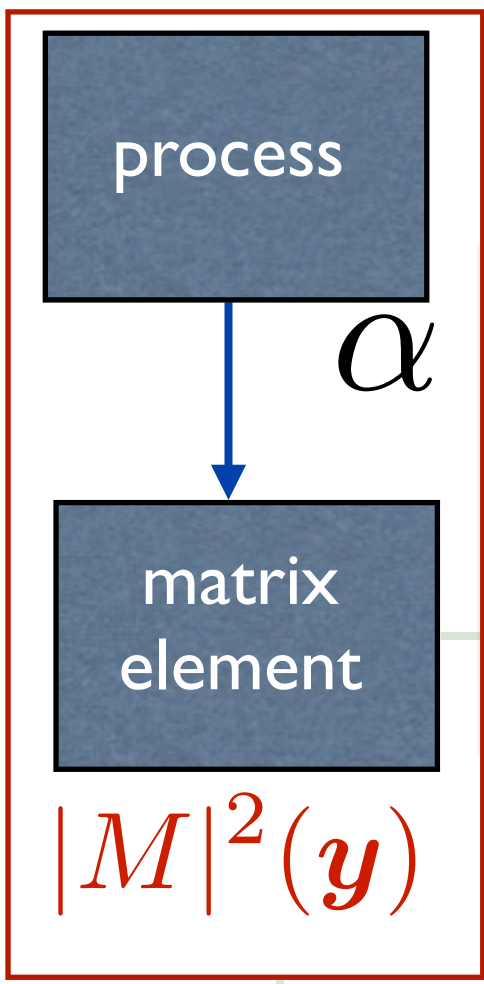


input : proc_card_mg5.dat

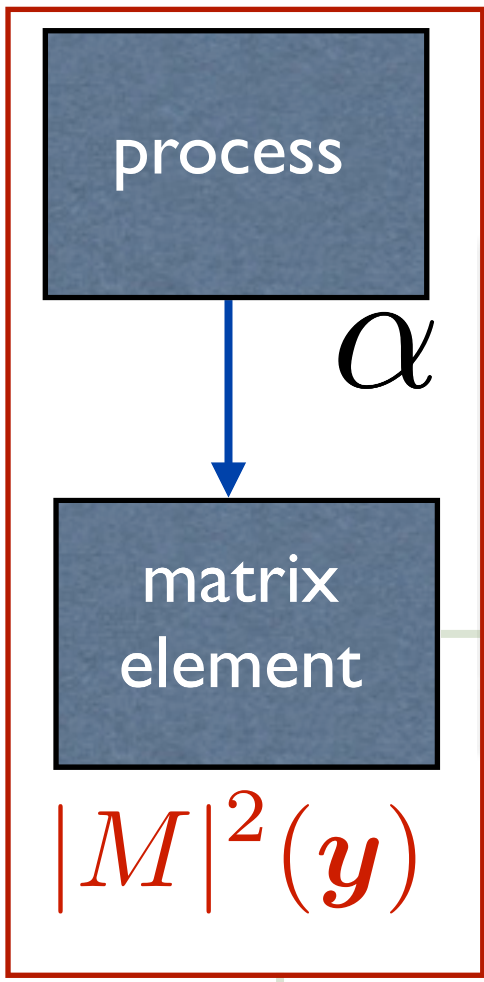
```
import model sm
generate p p > Z H , Z > mu+ mu- , H > b b~
output madweight HZ_hypo
```

output :

code for the evaluation of the weights in directory HZ_hypo

Implementation in mg5

framework for MEM that is reliable, user-friendly, reproducible, fast



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output :

code for the evaluation of the weights in directory HZ_hypo

type ‘launch’ for the evaluation of the weights

and follow the instructions

Implementation in mg5

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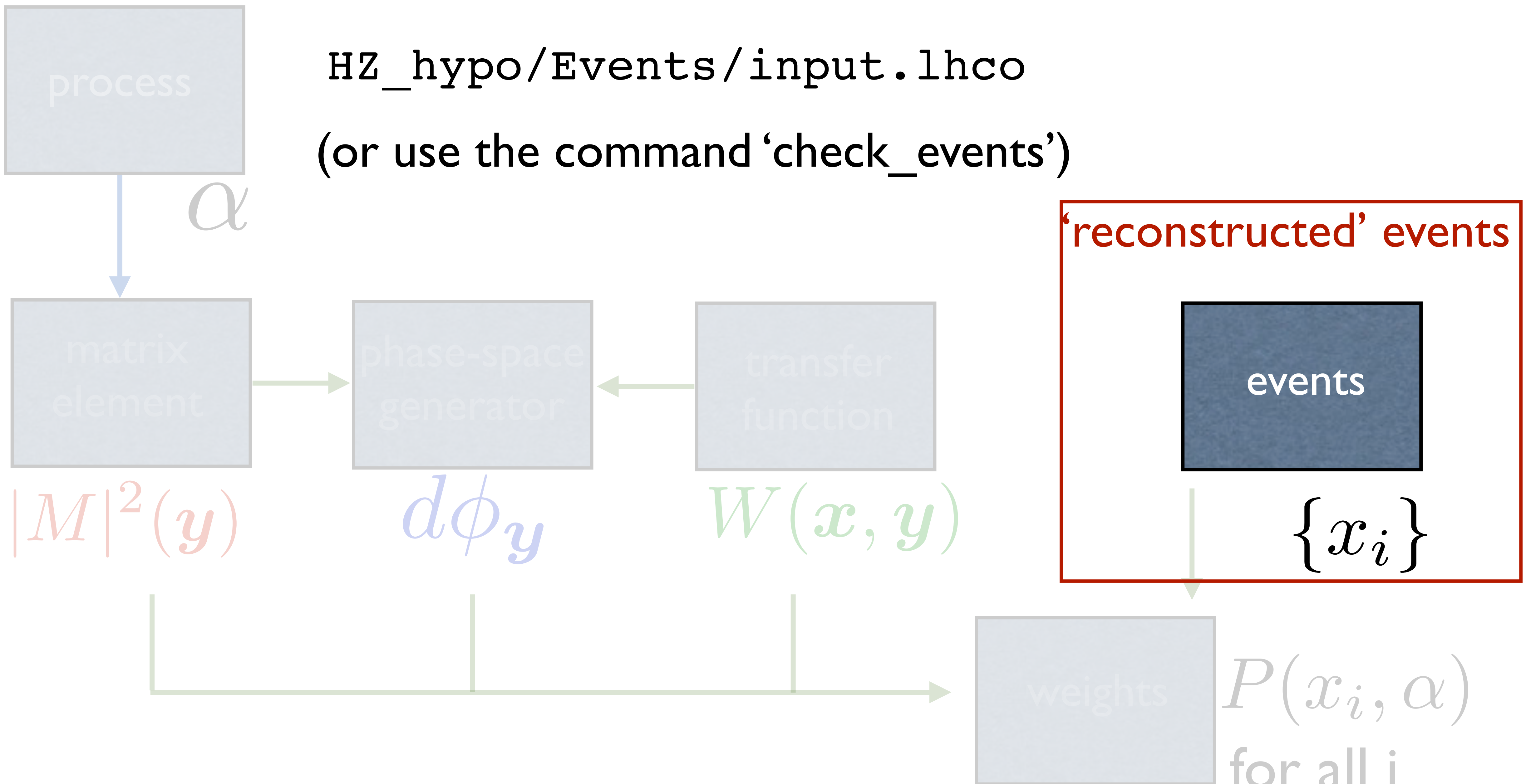
lhco event file must be copied at

`HZ_hypo/Events/input.lhco`

(or use the command ‘check_events’)



Implementation in mg5

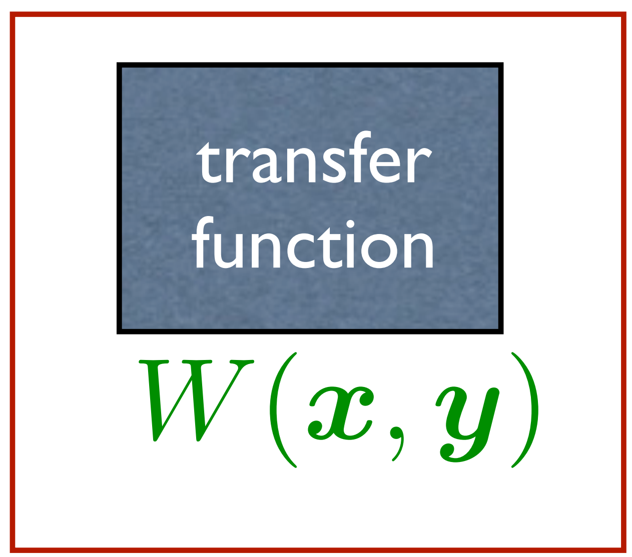
framework for MEM that is reliable, user-friendly, reproducible, fast

define your own TF parametrization

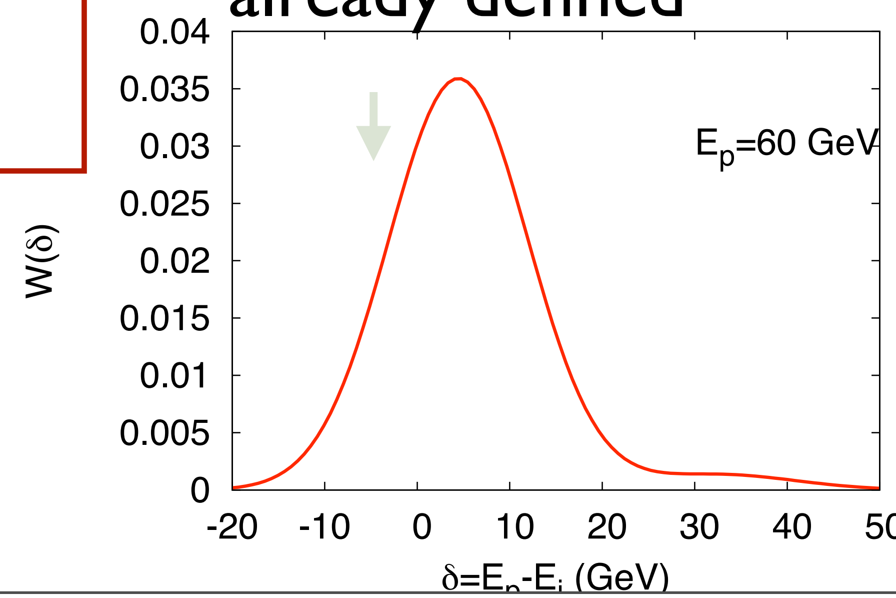
Source/MadWeight/transfer_function/data/TF_my_tf.dat

load TF: type ‘change_tf.py ’

```
Please choose your transfer_function
 0 / all_delta
 1 / dbl_gauss_pt_jet
 2 / gauss_on_leptons
 3 / single_gaussian
 4 / uniform
 5 / user
```



several parametrizations already defined



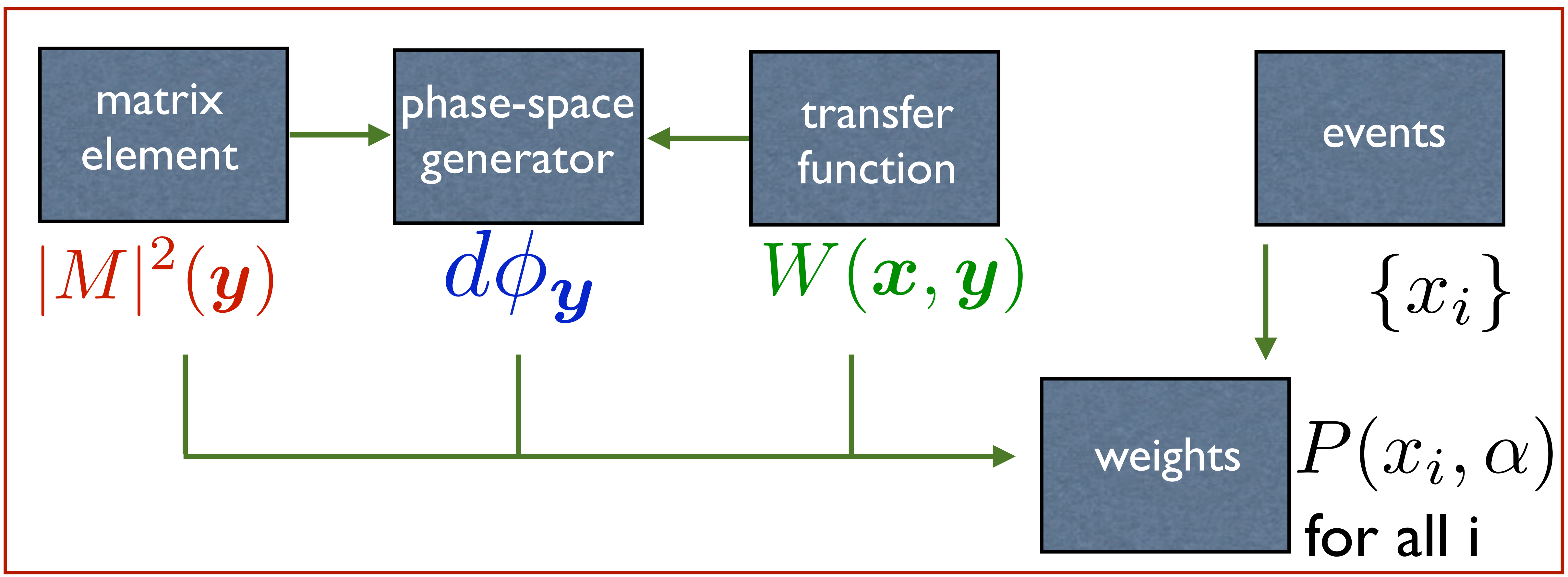
Implementation in mg5

framework for MEM that is reliable, user-friendly, reproducible, fast

input cards:

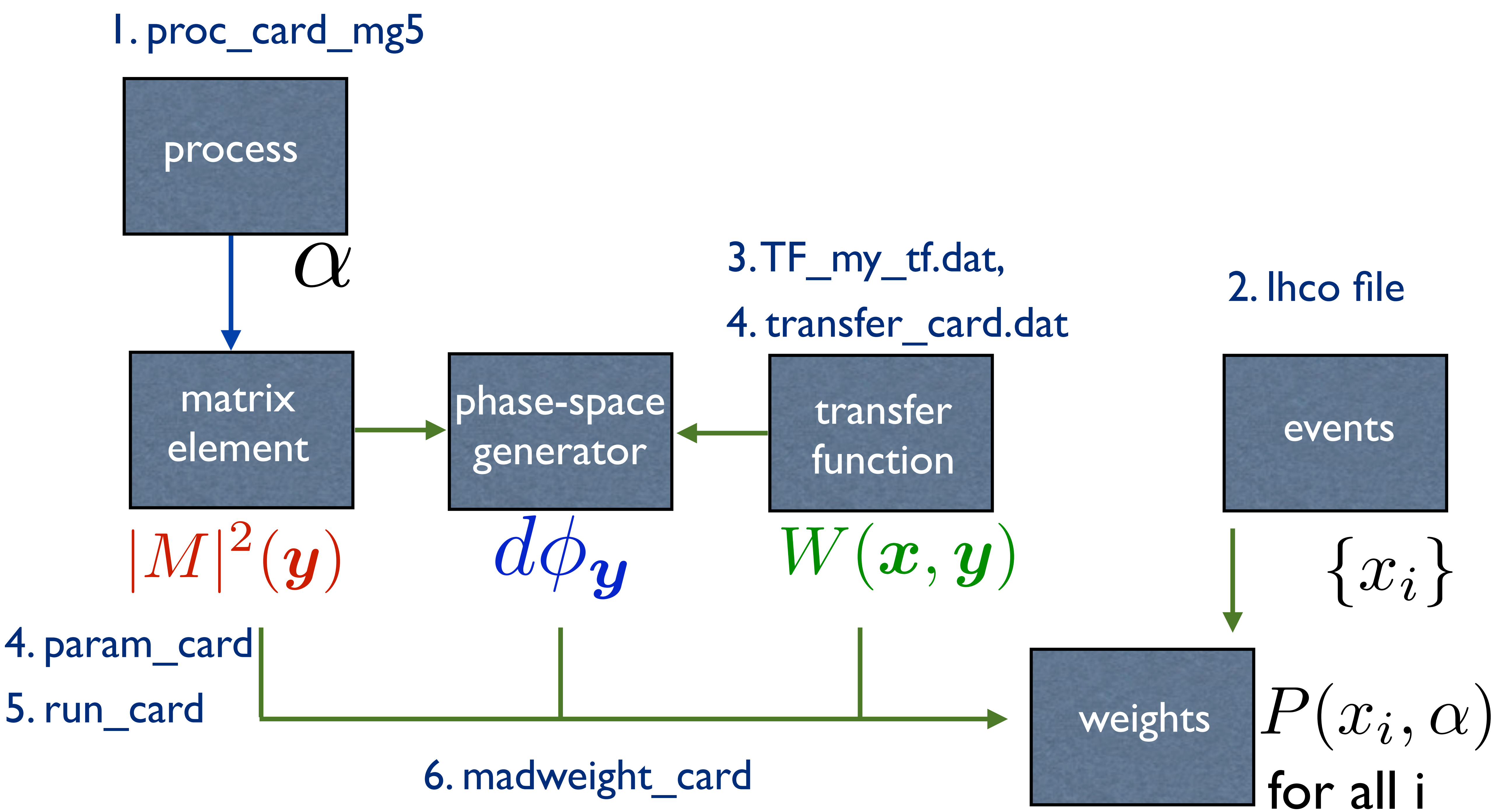
```
Do you want to edit one card (press enter to bypass editing)?
  1 / param       : param_card.dat
  2 / run         : run_card.dat
  3 / madweight   : madweight_card.dat
  4 / transfer    : transfer_card.dat
```

the code will load phase-space generator, evaluate the weights, collect the results



Implementation in mg5

framework for MEM that is reliable, user-friendly, reproducible, fast



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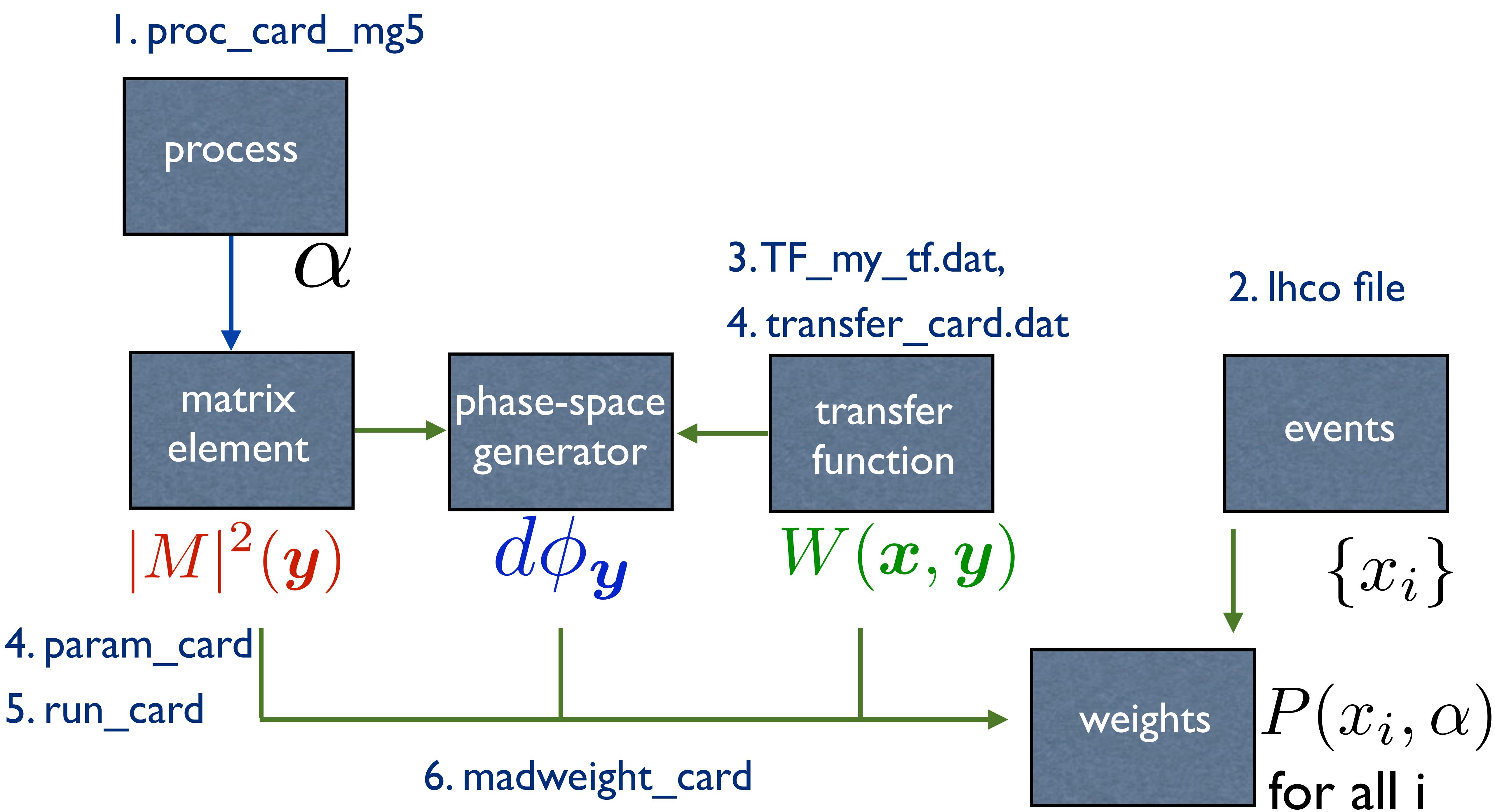
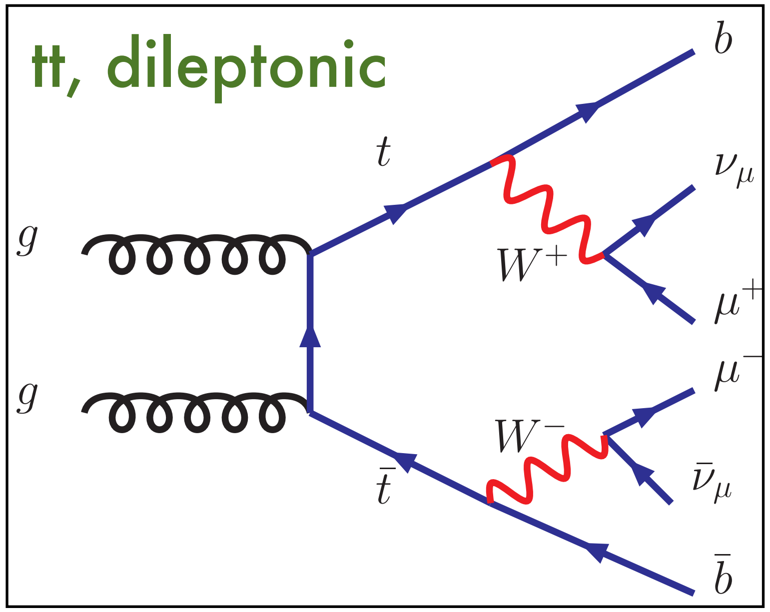


Implementation in mg5

framework for MEM that is reliable, user-friendly, reproducible, fast ?

the time spent on the evaluation of a specific matrix element weight is process-dependent

- an easy case:



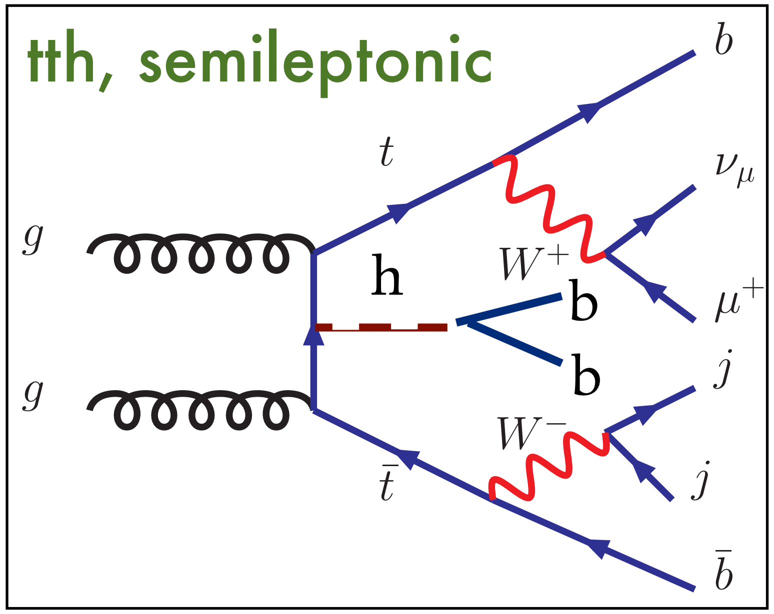
- exactly constrained system, need to consider one phase-space channel
- 2 parton-jet assignements
- less than 1min

Implementation in mg5

framework for MEM that is reliable, user-friendly, reproducible, fast ?

the time spent on the evaluation of a specific matrix element weight is process-dependent

- a difficult case:



- 8 final-state particles
- overconstrained system,
- 720 parton-jet assignements

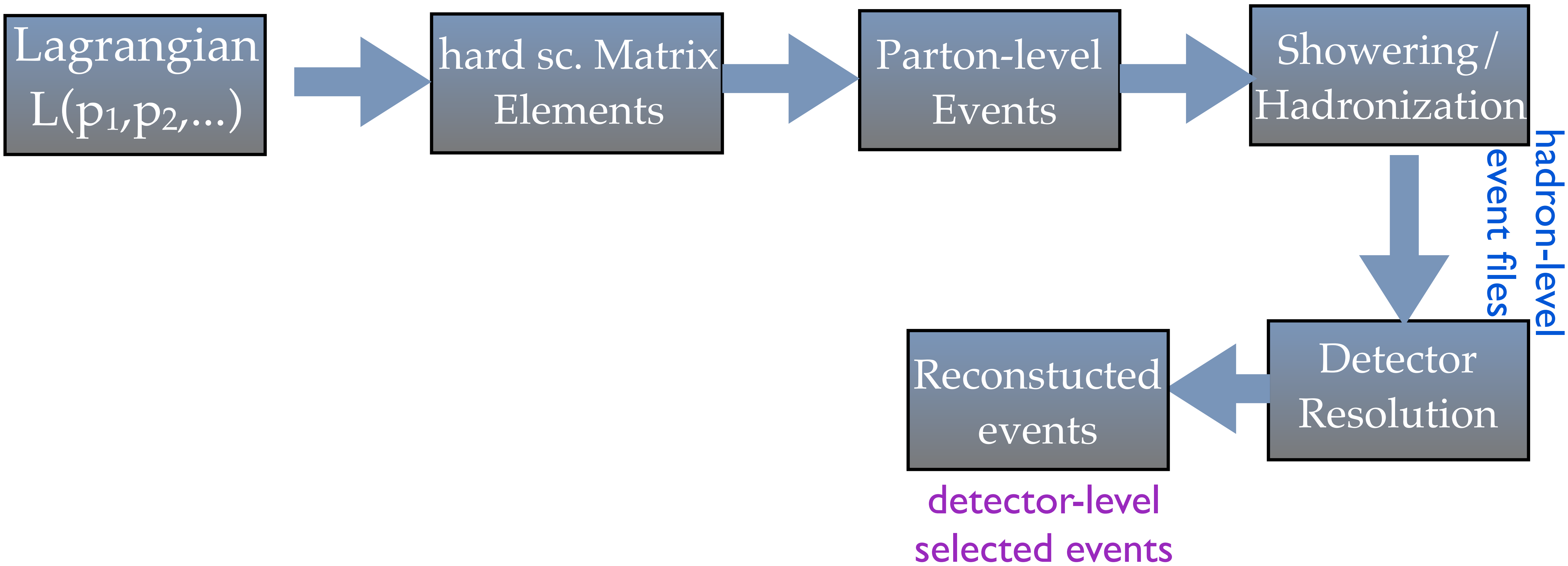
Integration strategy:

- multichannel techniques
- Monte Carlo over the different parton-jet assignments
- pre-training of the TF

see Olivier's talk

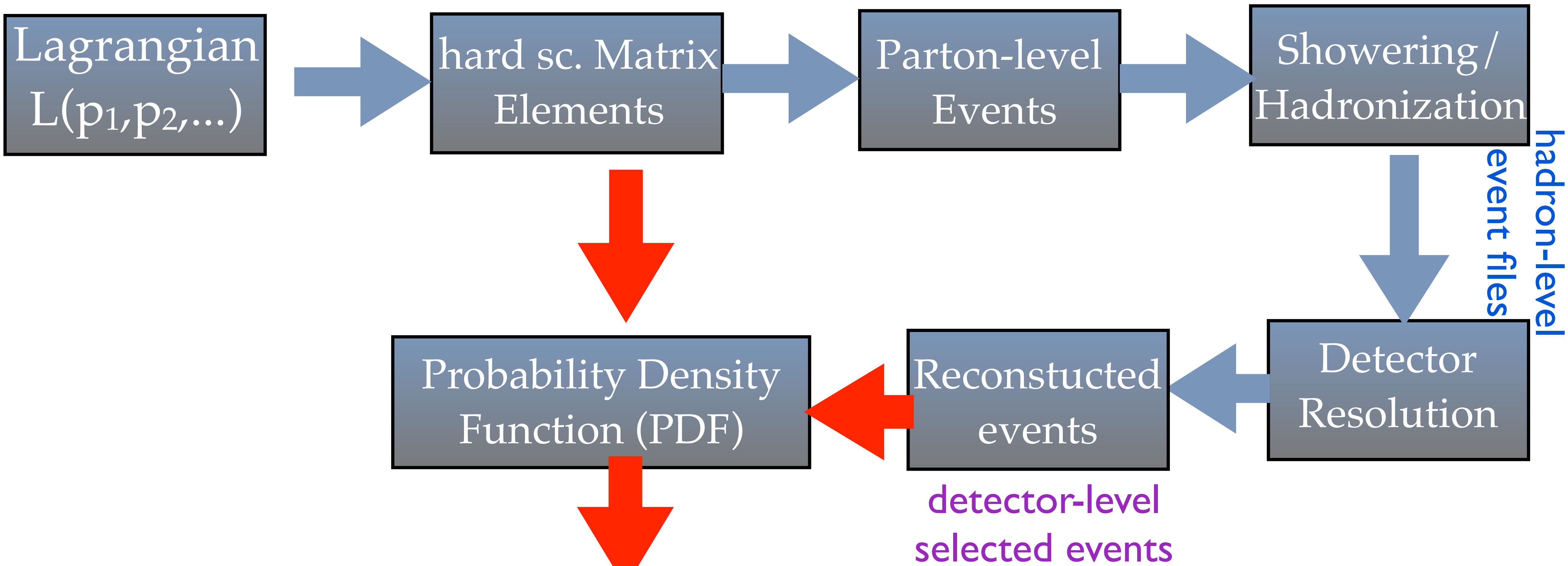
MadWeight philosophy

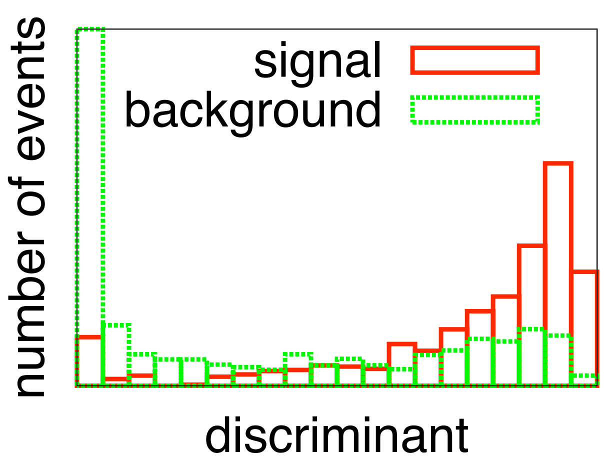
Nowadays Monte Carlo generators have reached a high level of automation and reliability



MadWeight philosophy

In the same spirit, MadWeight is aimed at providing a reliable and automated framework for Matrix Element Methods





MadWeight philosophy

'Automated' does NOT mean that it can be used as a 'black box'.
For most analyses, dedicated studies are required:

1. definitition of the MEM weights

- ad-hoc treatment of ISR ?
- matrix element with higher-order radiation ?
- extraction of the transfer function ?
- normalization of the transfer function ?
- ...

→ need to adjust the input card parameters and/or update the framework

many discussions resulting from MEM activities in CP3

MadWeight philosophy

'Automated' does NOT mean that it can be used as a 'black box'.
For most analyses, dedicated studies are required:

2. CPU time / MC convergence issues:

- sum over ALL parton-jet assignments ?
- select only specific channel of integrations ?
- assume infinite energy resolution for some particle species ?
- narrow width approximation ?
- specific subprocesses only ?
- submission of the jobs ?
- ...

→ need to adjust the input card parameters and/or update the framework

MadWeight philosophy

1. definitition of the MEM weights
2. CPU time / MC convergence issues

gives ideas to improve 1. and 2.

dynamical framework for MEM studies ← → specific pheno/ exp. analyses

gives a practical access to all previous analyses in the 'MadWeight' framework

see e.g. talks by
Arnaud Pin
Alexandre Mertens
Michele Selvaggi
Petra van Mulders

A. proc_card_mg5.dat
B. run_card.dat, param_card.dat
C. pythia_card.dat
D. delphes_card.dat, delphes_trigger.dat
E. selection.cpp

event generations

A. proc_card_mg5.dat
B. TF_my_tf.dat, transfer_card.dat
C. madweight_card.dat
D. run_card.dat, param_card.dat

weight evaluation

MadWeight philosophy

1. definitition of the MEM weights
2. CPU time / MC convergence issues

gives ideas to improve 1. and 2.

dynamical framework for MEM studies ← → specific pheno/ exp. analyses

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Perspectives

- more efficient treatment of the systematics (see Kyle Cranmer's talk)
- LDS generator (see Oleg Brandt's talk) ...

PART II

ttH with MadWeight*

P. Artoisenet, P. de Aquino, F. Maltoni, O. Mattelaer

- search for ttH at the LHC using the the Matrix Element Method (LHC@14 TeV)
- compare the significance in the dilepton and single lepton channels

*some slides taken from Priscila's talk

Unravelling $t\bar{t}h$ via the matrix element method

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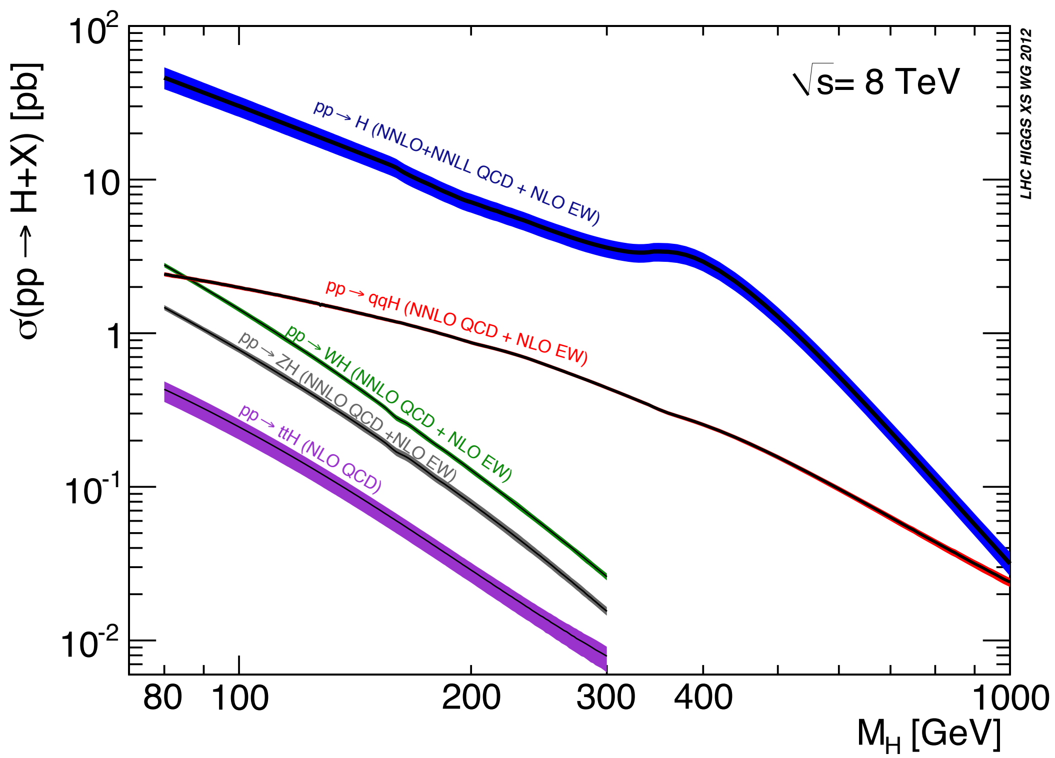
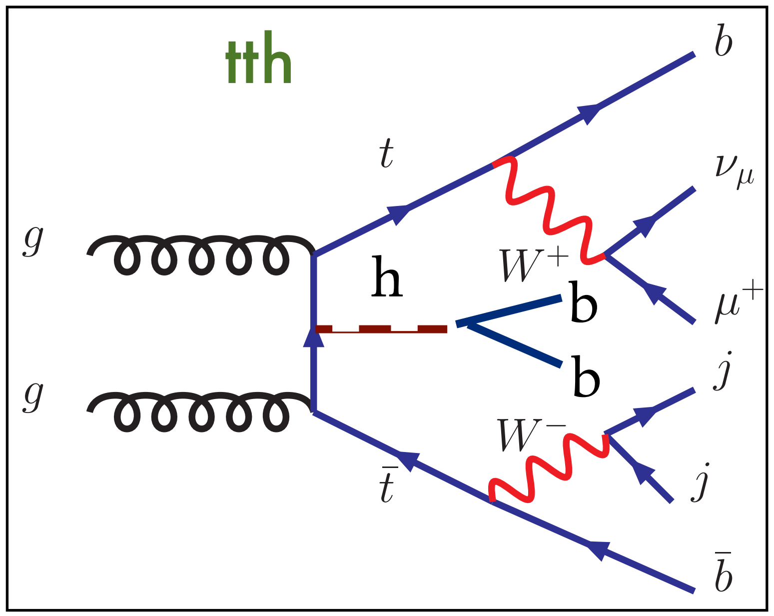
[c] *Centre for Cosmology, Particle Physics and Phenomenology (CP3), Université catholique de Louvain, Chemin du Cyclotron 2, B-1348 Louvain-la-Neuve, Belgium*
[d] *Department of Physics, University of Illinois at Urbana-Champaign, 1110 West Green Street, Urbana, IL 61801*

The challenge of observing ttH





$W^+ W^- b \bar{b} b \bar{b}$ final state

1) the production rate is small

NLO prediction @ LHC:

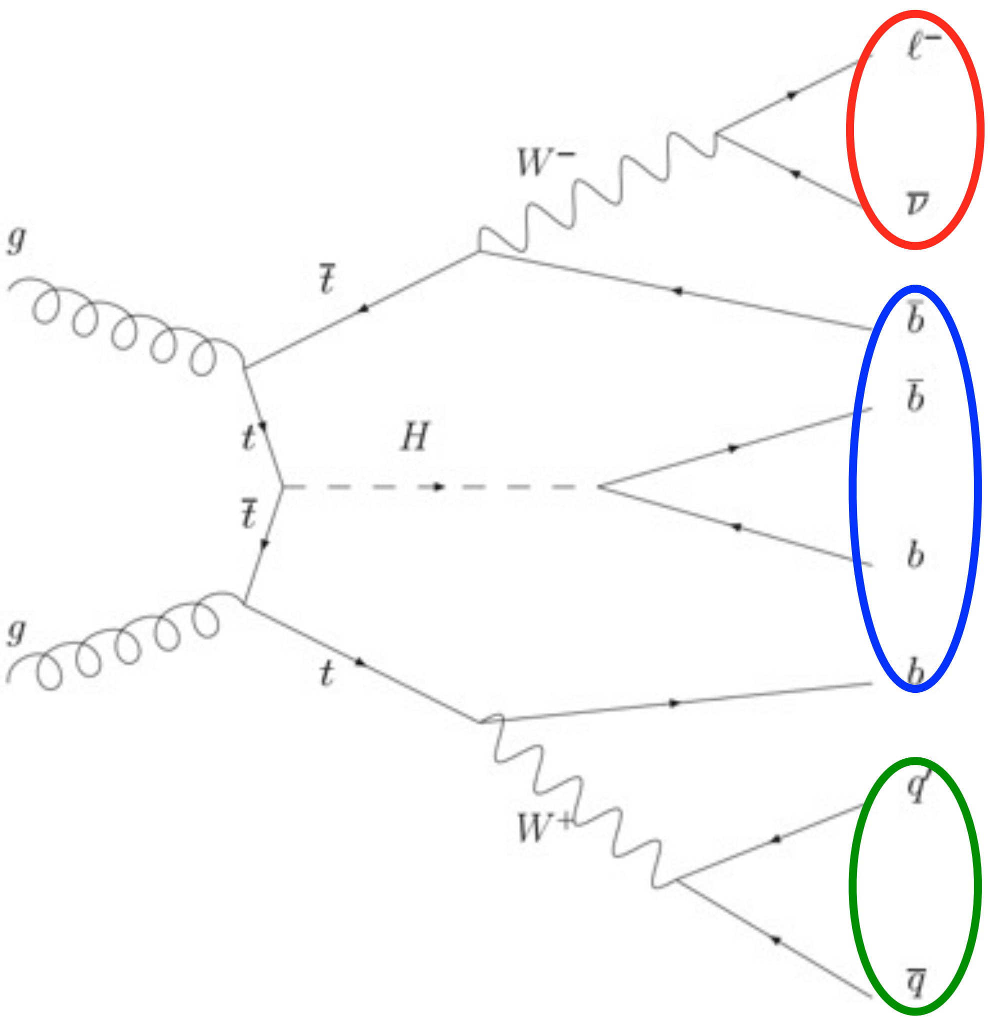
8 TeV	14 TeV
0.137 pb	0.632 pb

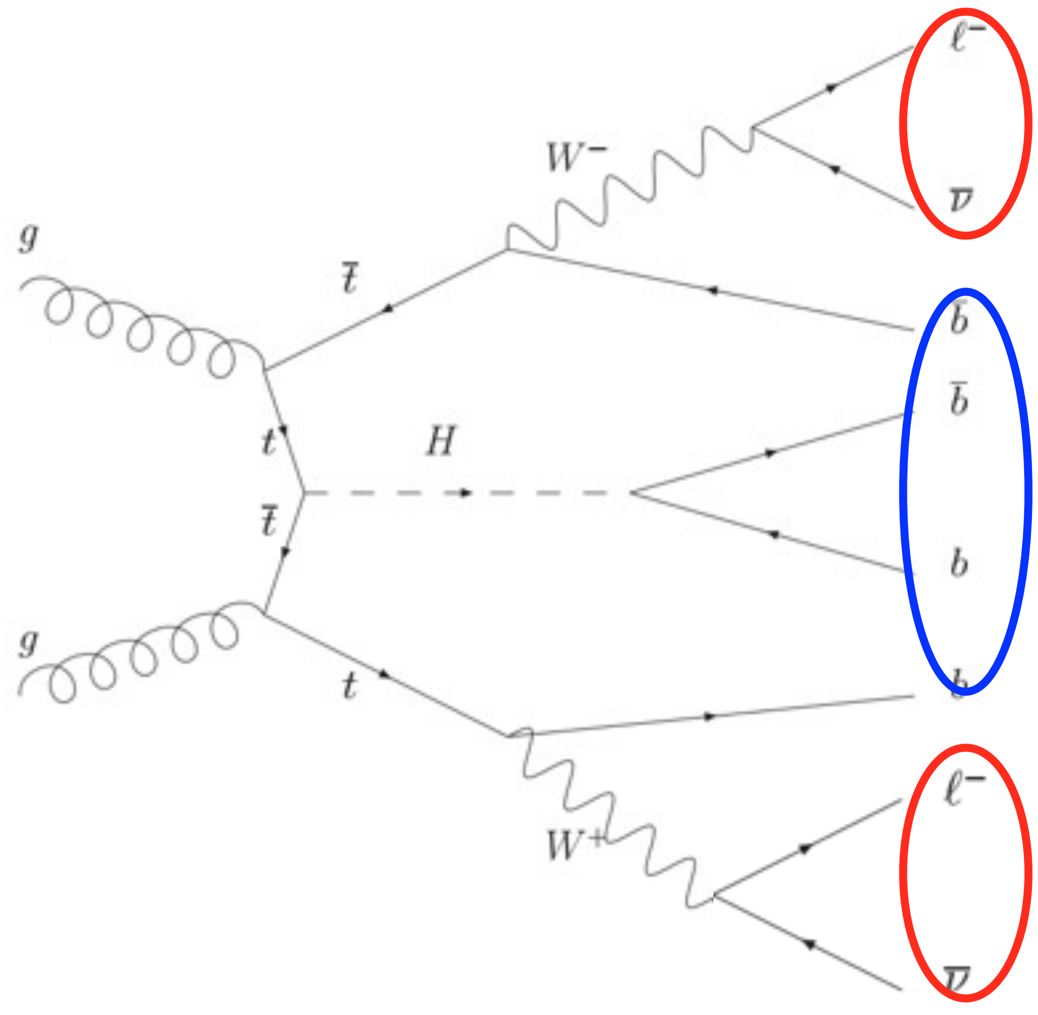
2) Challenging backgrounds:

- $t \bar{t}$ + jets
- combinatorial background (identification of the b-jets coming from the Higgs)

Q1: can the MEM be used to increase the significance in discriminating S+B and B-only hypotheses ?

Decay channels



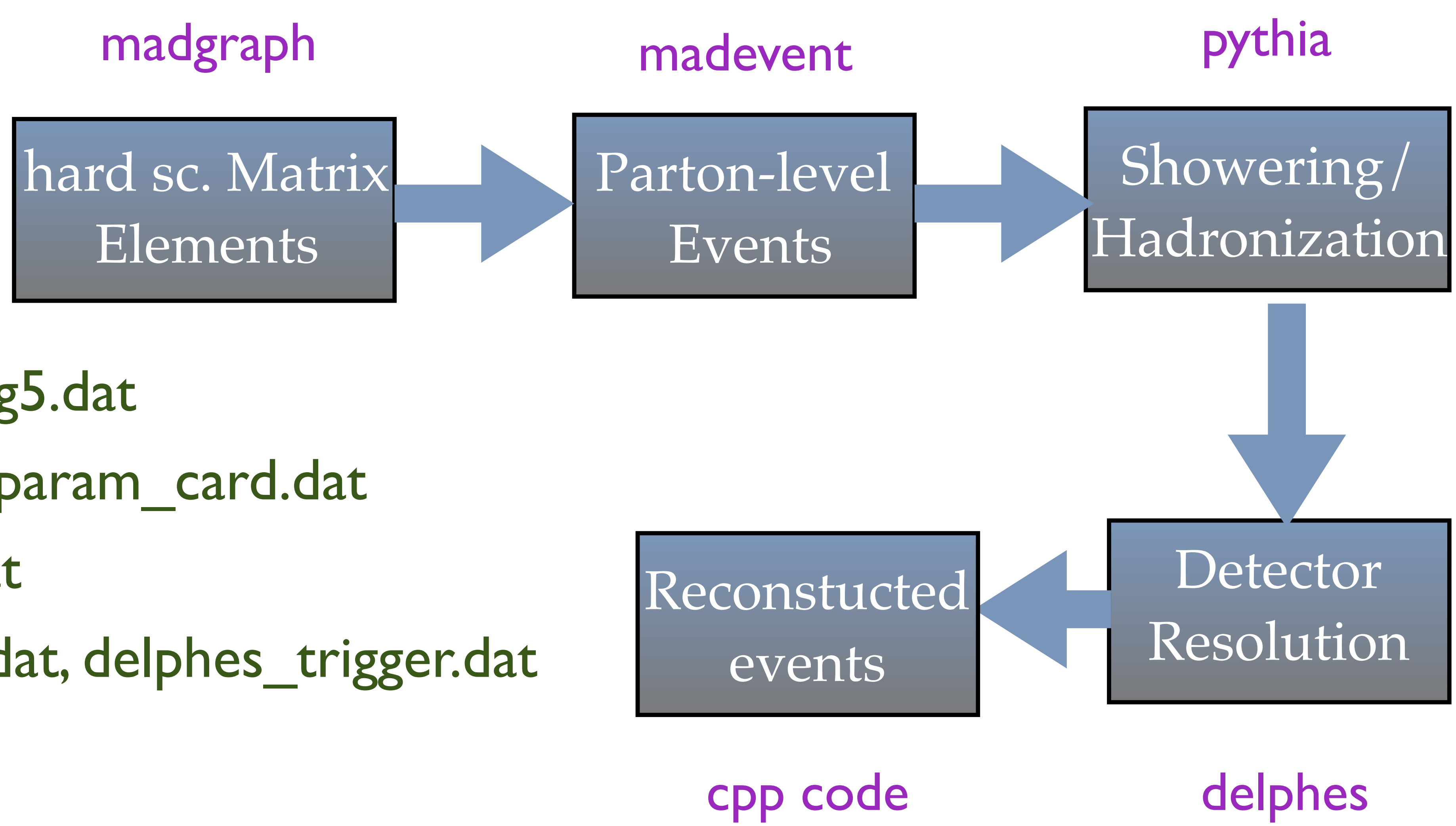


single-lepton final state

di-lepton final state

Q2: is the discriminating power in the di-lepton channel higher or less than the one in the semi-lepton channel ?

Event generation



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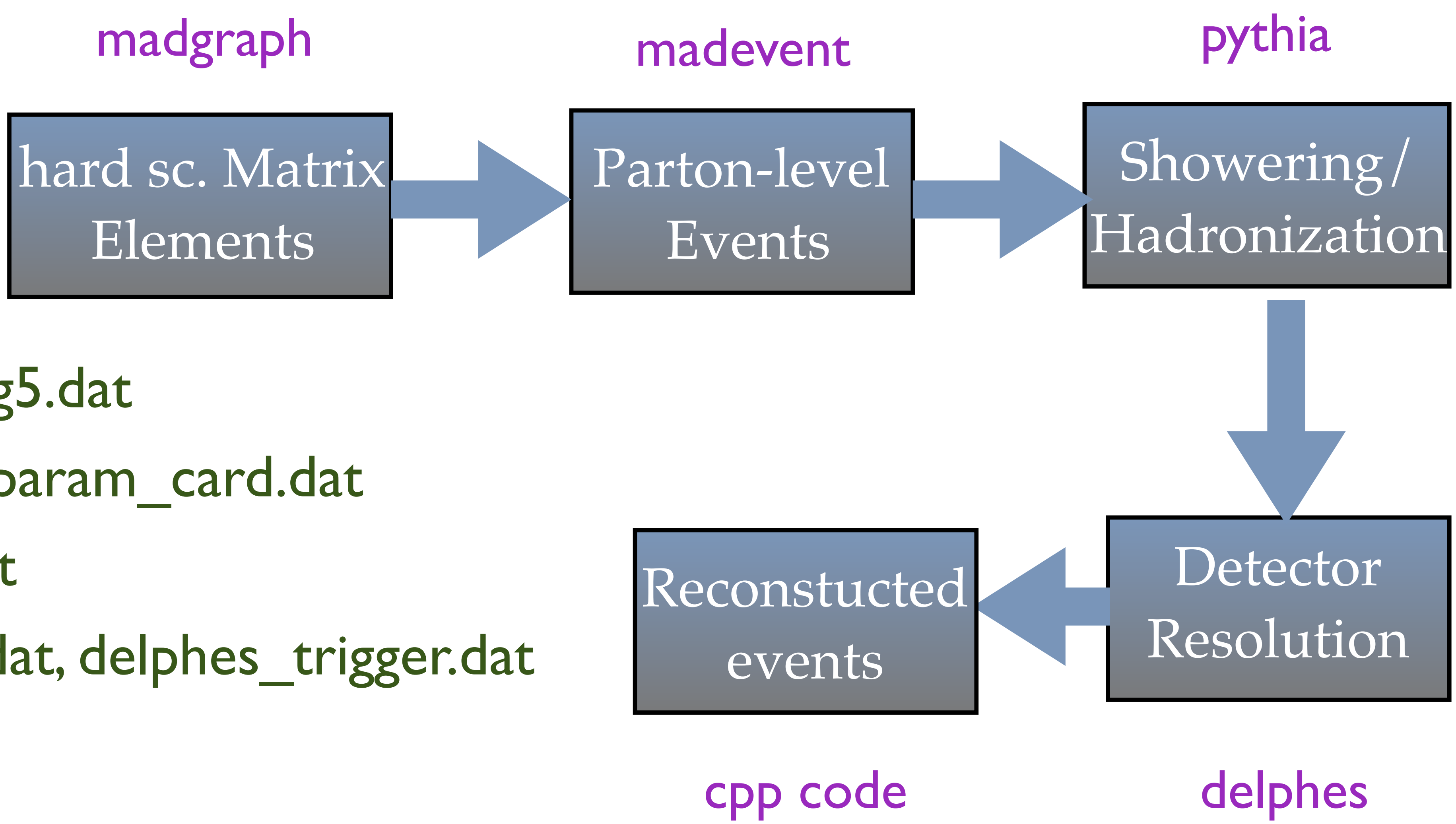
reliable, user-friendly, reproducible

Event generation

generation with ME+PS matching, detector response simulated by delphes
reasonably close to genuine experimental condition



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reliable, user-friendly, reproducible

Event generation

- Event selection: (CMS measurement for tt cross section, di-lept. channel)
  - Leptons: P_T > 20 GeV and $|\eta|$ < 2.4
  - Jets: anti-k_T with R=0.5 , P_T > 30 GeV and $|\eta|$ < 2.5
  - At least 4 b-jets required

    ↳ lower the risk of selecting the 'wrong' jets for the signal

process	incl. σ	efficiency	σ^{rec}
$t\bar{t}h$, single-lepton	111 fb	0.0485	5.37 fb
$t\bar{t}h$, di-lepton	17.7 fb	0.0359	0.634 fb
$t\bar{t}$+jets, single-lepton	256 pb	0.463×10^{-3}	119 fb
$t\bar{t}$+jets, di-lepton	40.9 pb	0.168×10^{-3}	6.89 fb

Event generation

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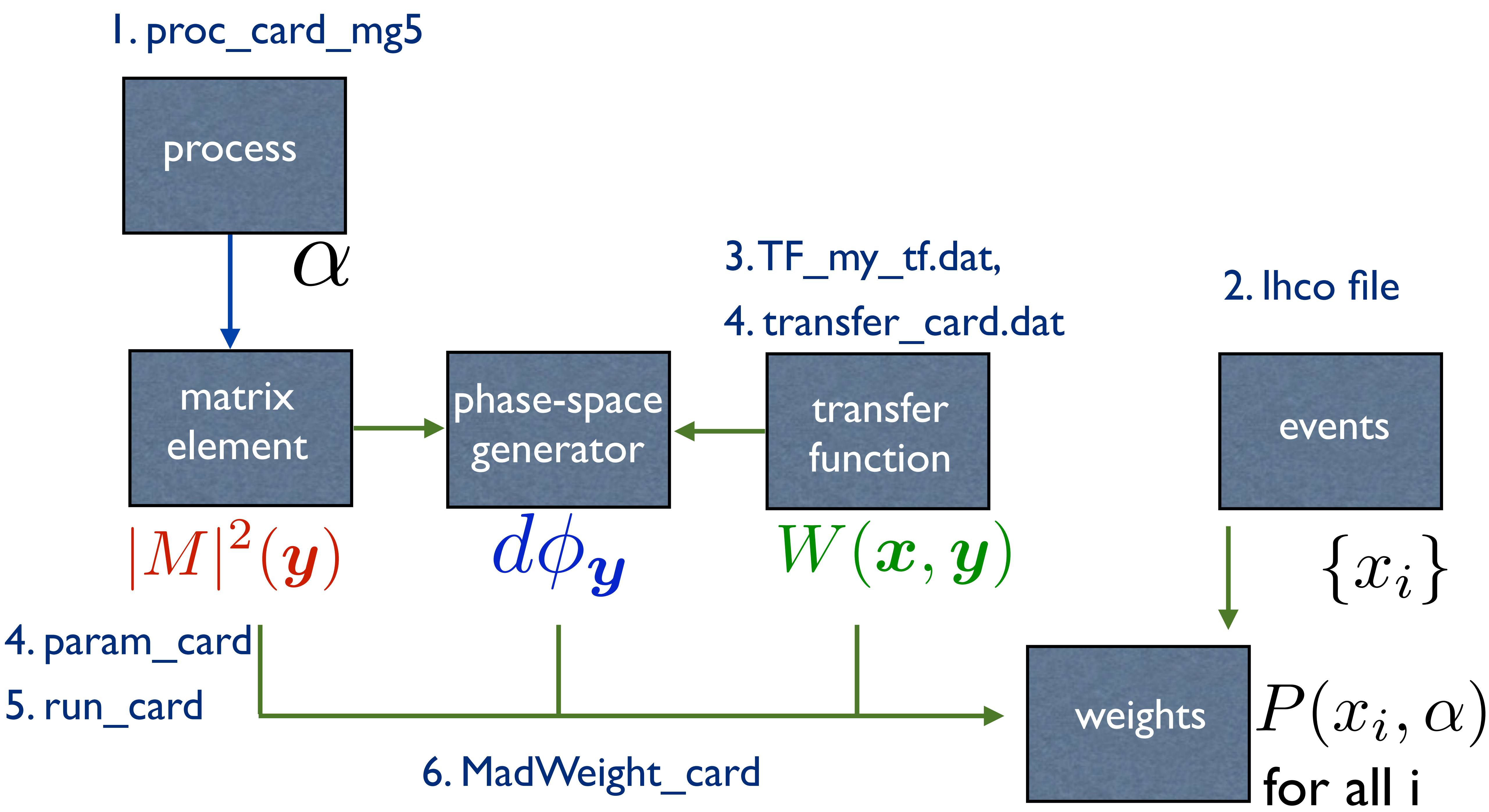
$t\bar{t}$+jets, di-lepton	40.9 pb	0.168×10^{-3}	6.89 fb

single-lepton: S/B ~ 1/22

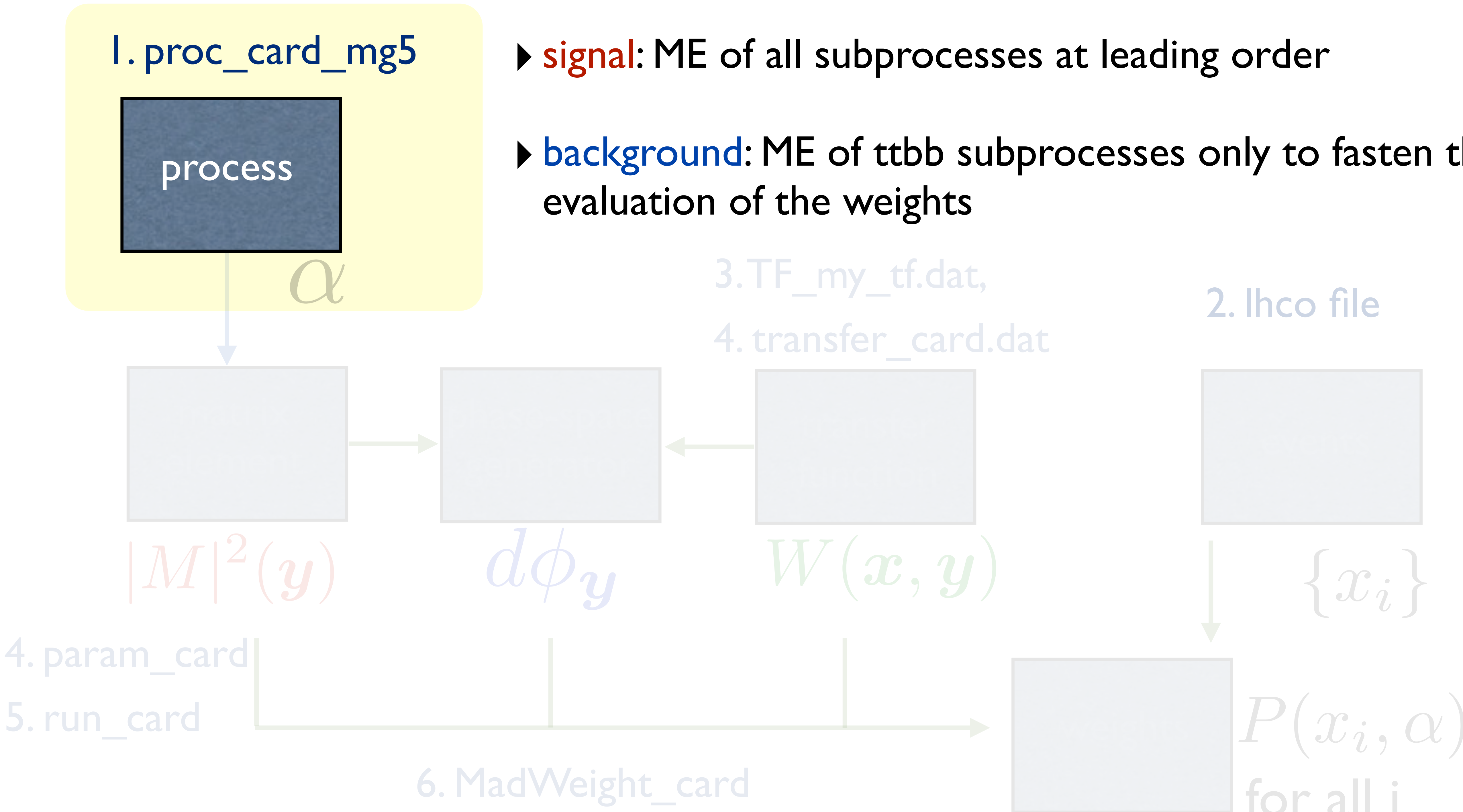
di-lepton: S/B ~ 1/11

Calculation of the weights



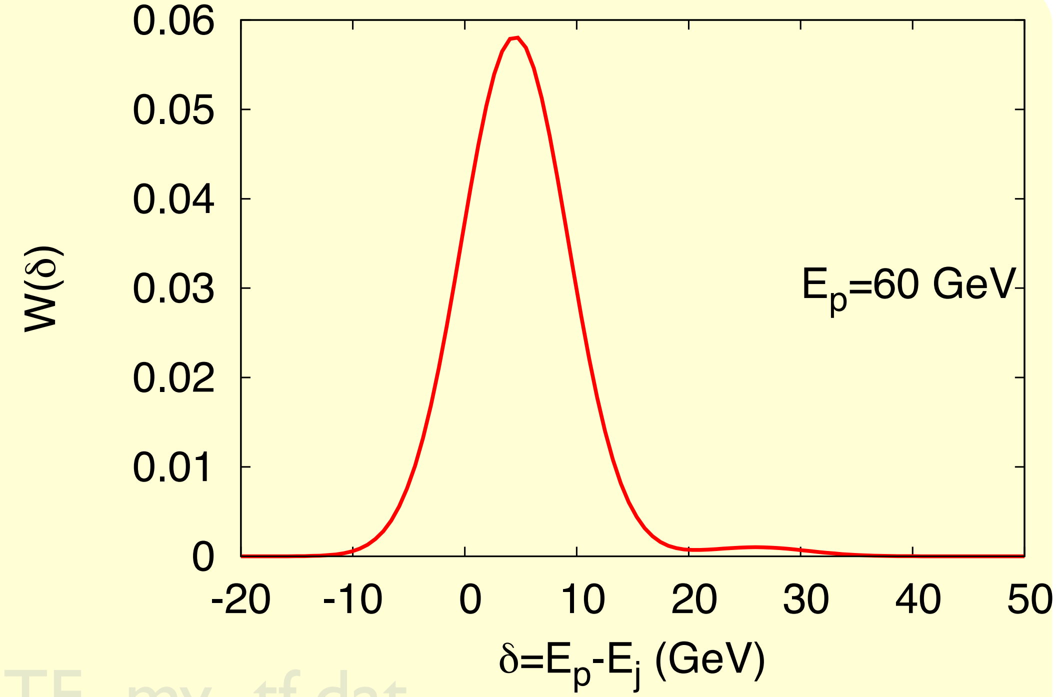
Calculation of the weights

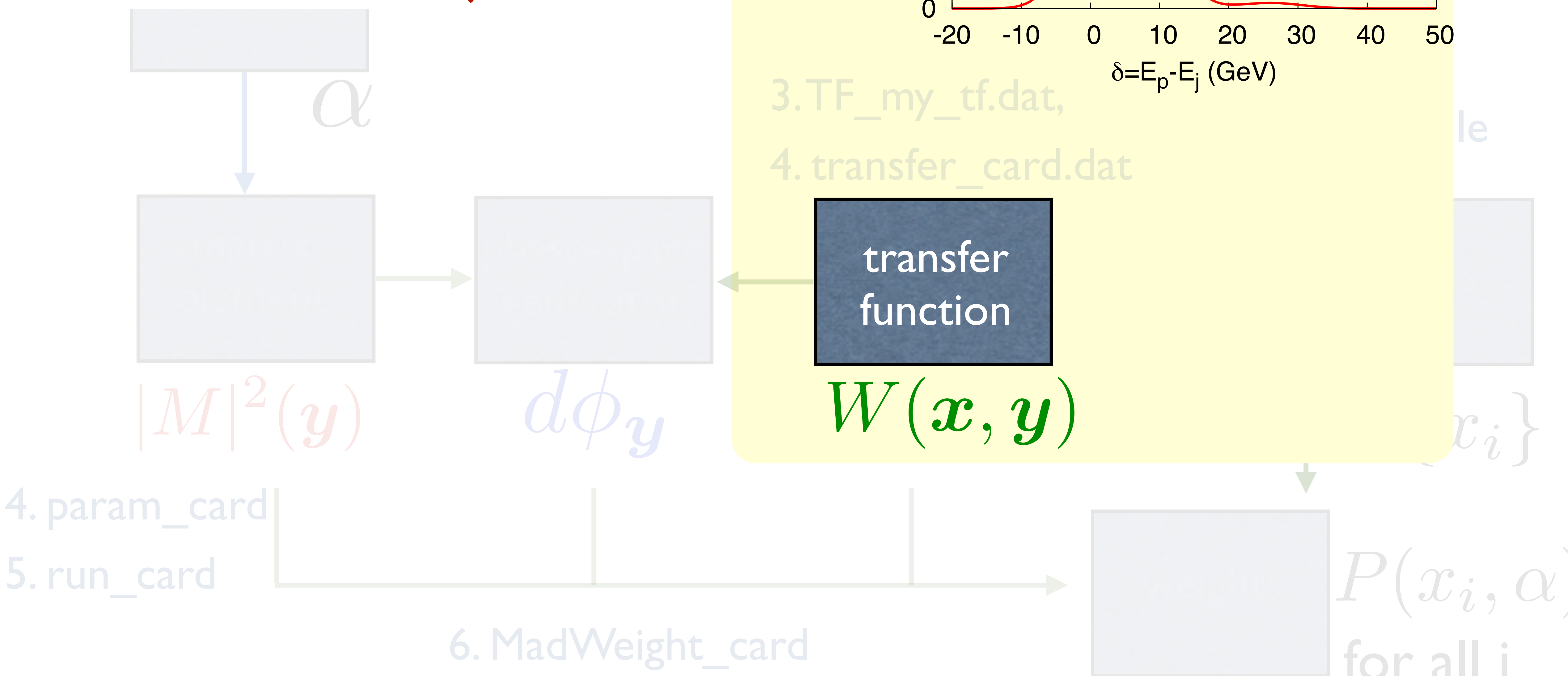
- signal: ME of all subprocesses at leading order
- background: ME of ttbb subprocesses only to fasten the evaluation of the weights



Calculation of the weights

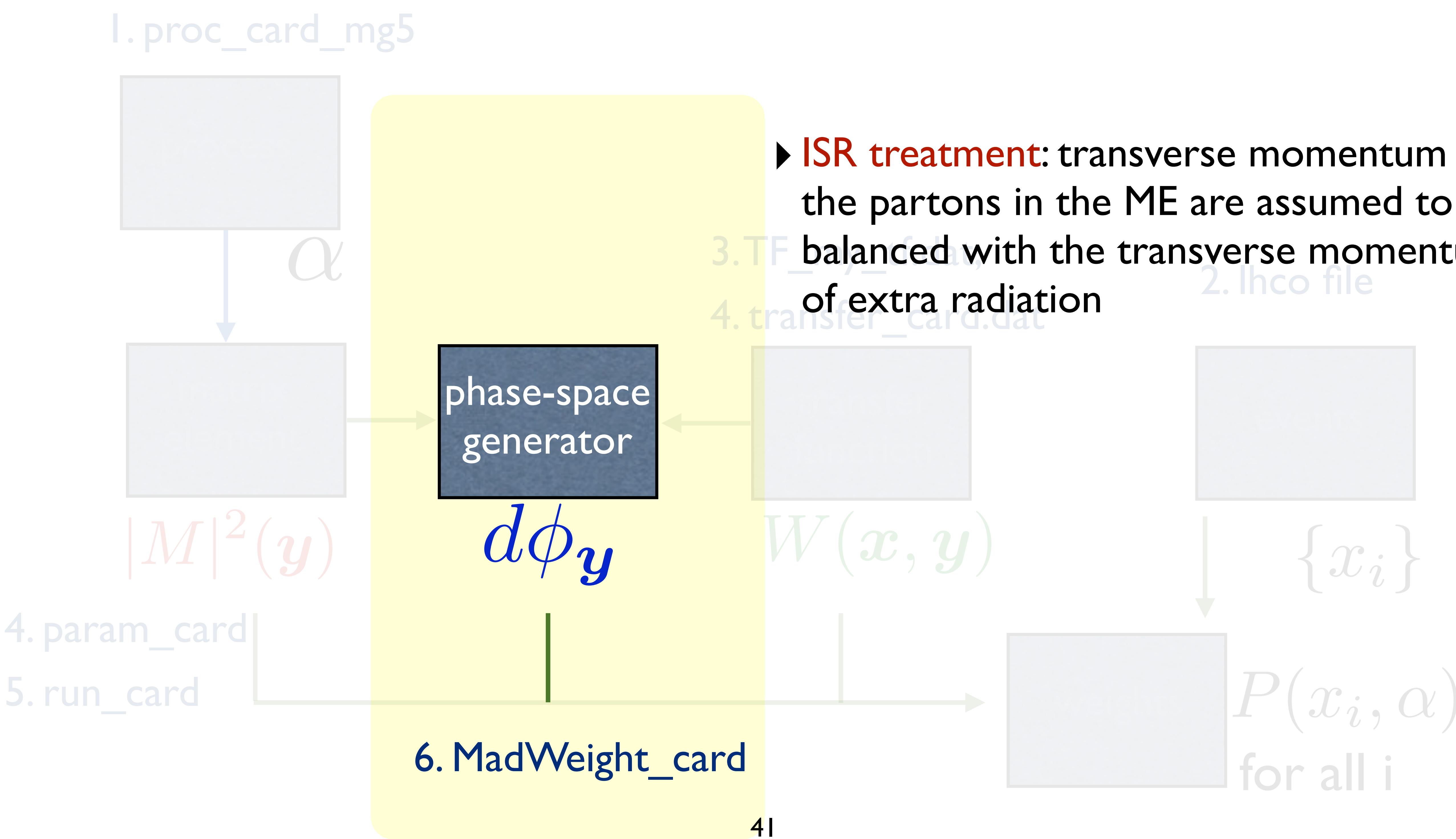
- infinite resolution on leptons
- double Gaussian TF on jet energies extracted from tt event samples
- infinite resolution on jet directions



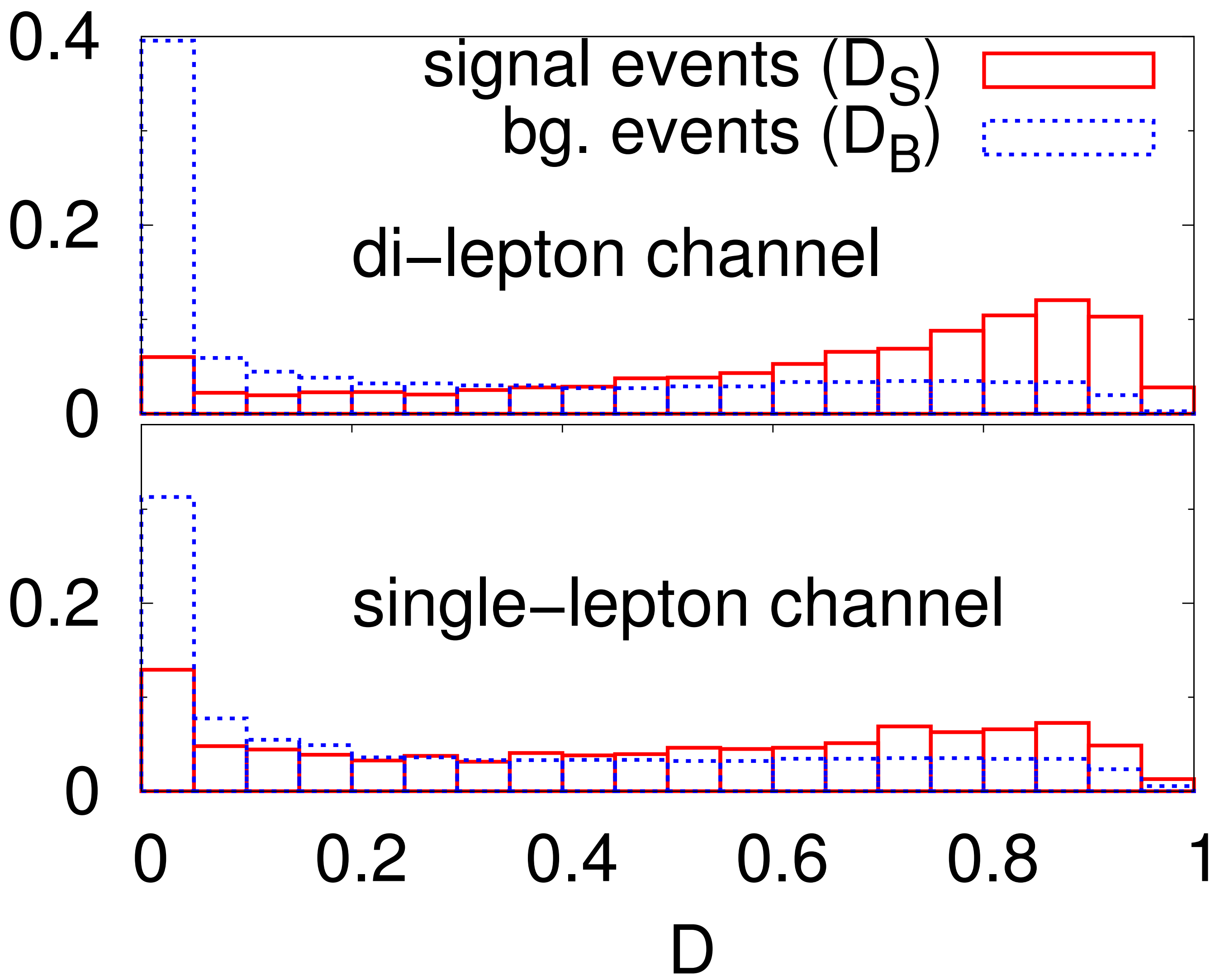


Calculation of the weights

- ISR treatment: transverse momentum of the partons in the ME are assumed to be balanced with the transverse momentum of extra radiation



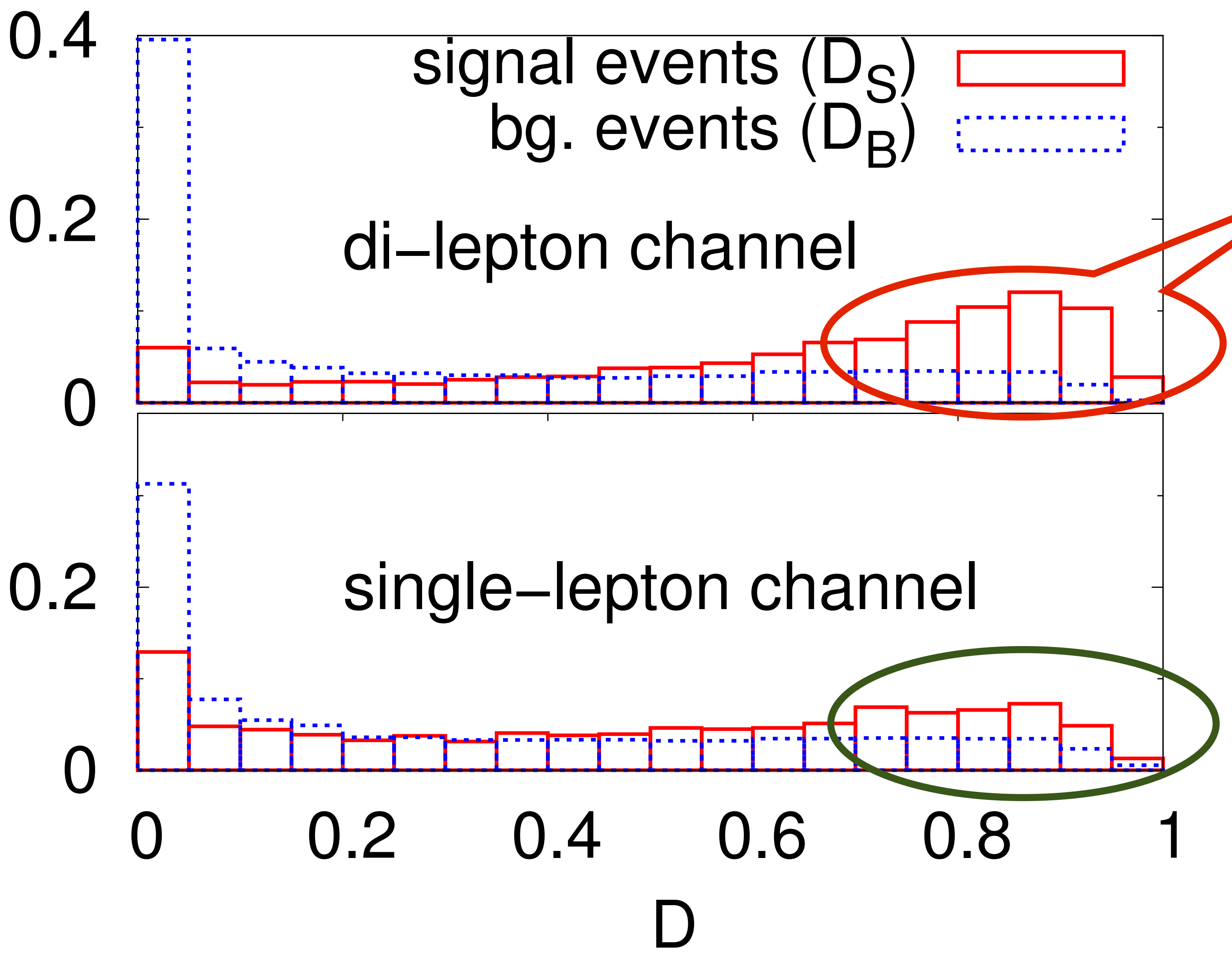
Discriminant plot



For event i with kinematics x_i:

$$D_i = \frac{P(x_i|S)}{P(x_i|S) + P(x_i|B)}$$

Discriminant plot



Higher discriminative power:

Cleaner, with only b-jets in the final state (lower probability of wrongly include QCD radiation), and better combinatorial background

For event i with kinematics x_i:

$$D_i = \frac{P(x_i|S)}{P(x_i|S) + P(x_i|B)}$$

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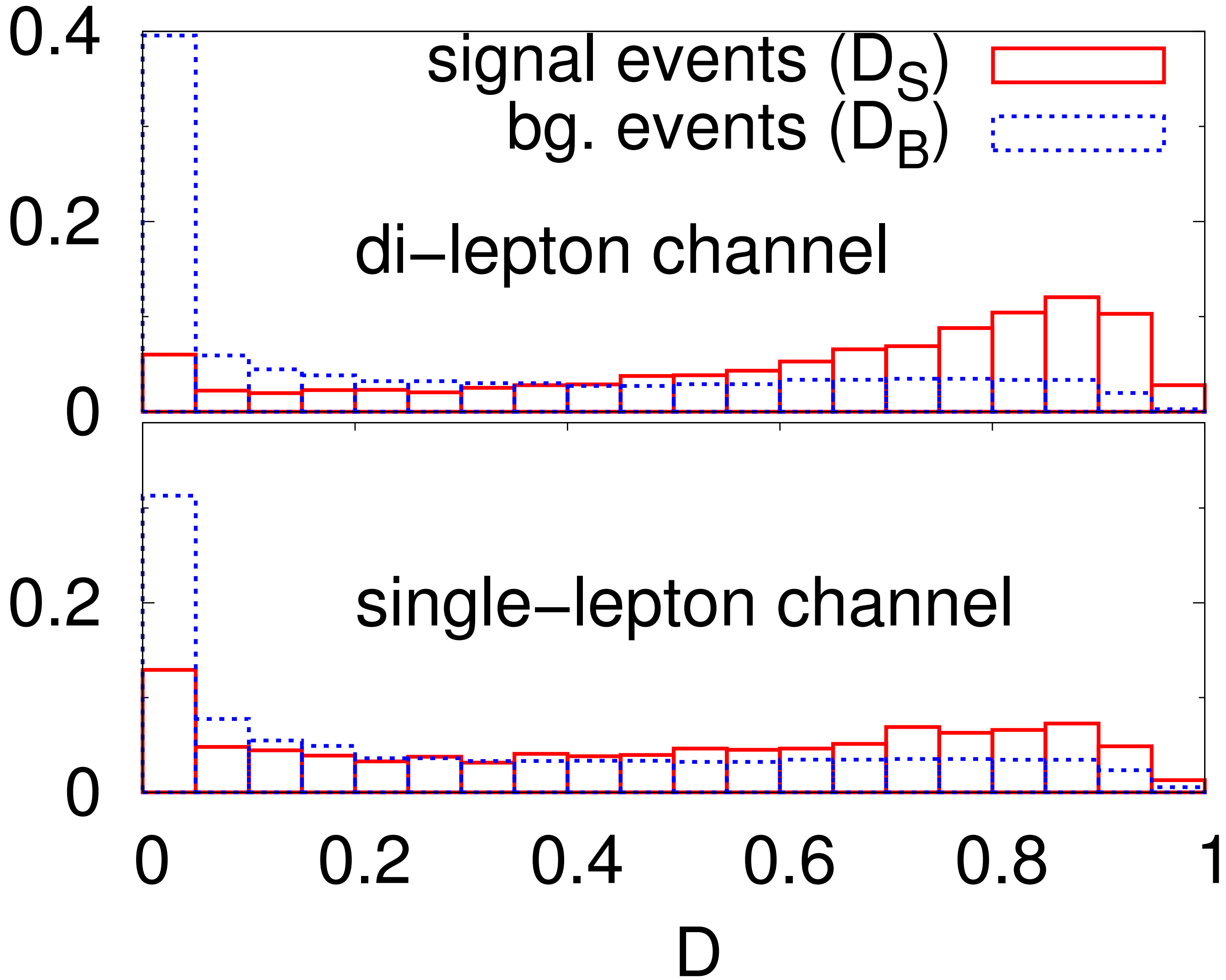
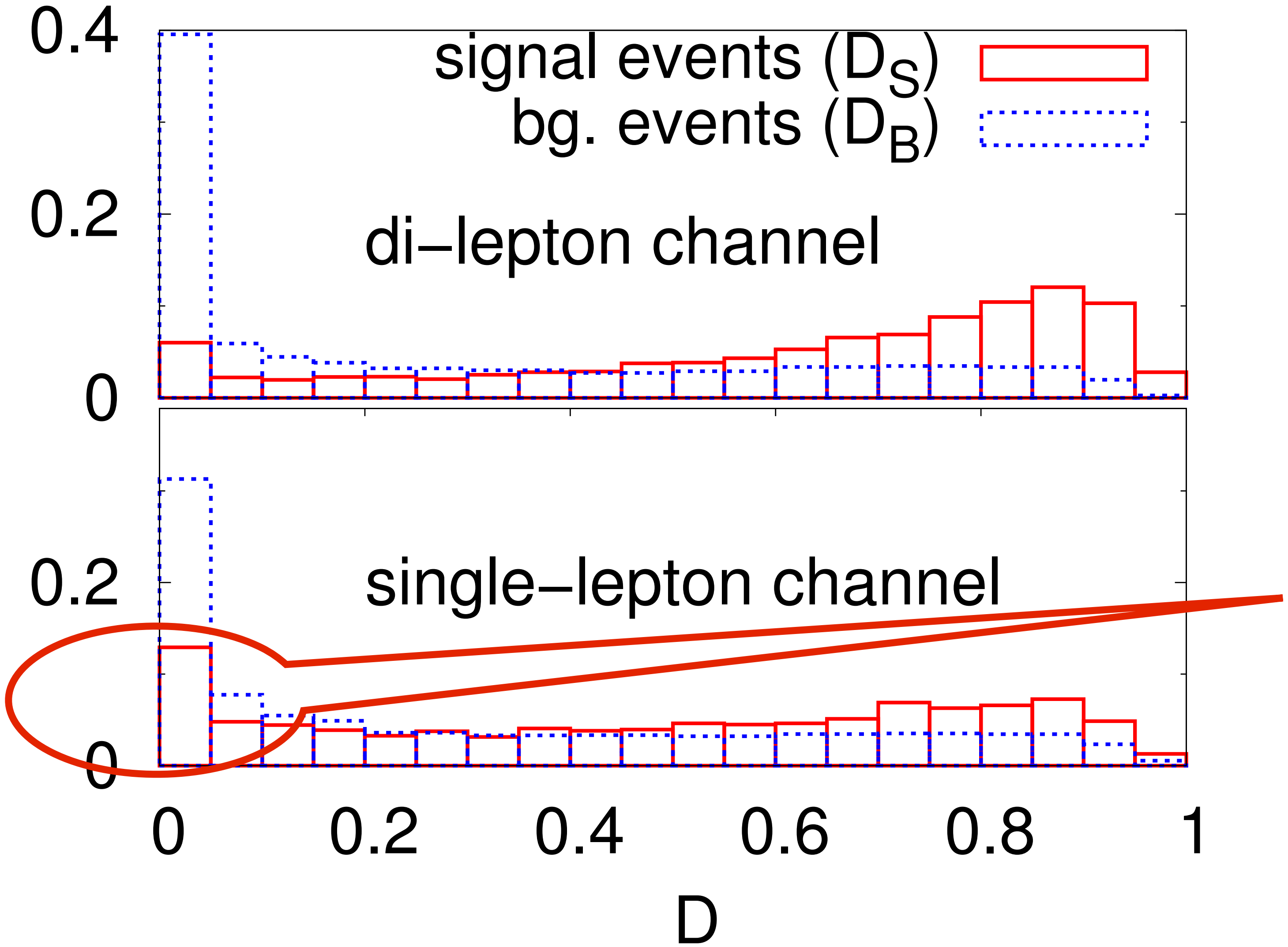
Discriminant plot



For event i with kinematics x_i:

$$D_i = \frac{P(x_i|S)}{P(x_i|S) + P(x_i|B)}$$

Discriminant plot



Higher probability, of including QCD radiation the selection process

For event i with kinematics x_i:

$$D_i = \frac{P(x_i|S)}{P(x_i|S) + P(x_i|B)}$$

Significance

- To access the significance that can be achieved at the LHC 14 TeV for a given luminosity, we consider a large number of pseudo-experiments

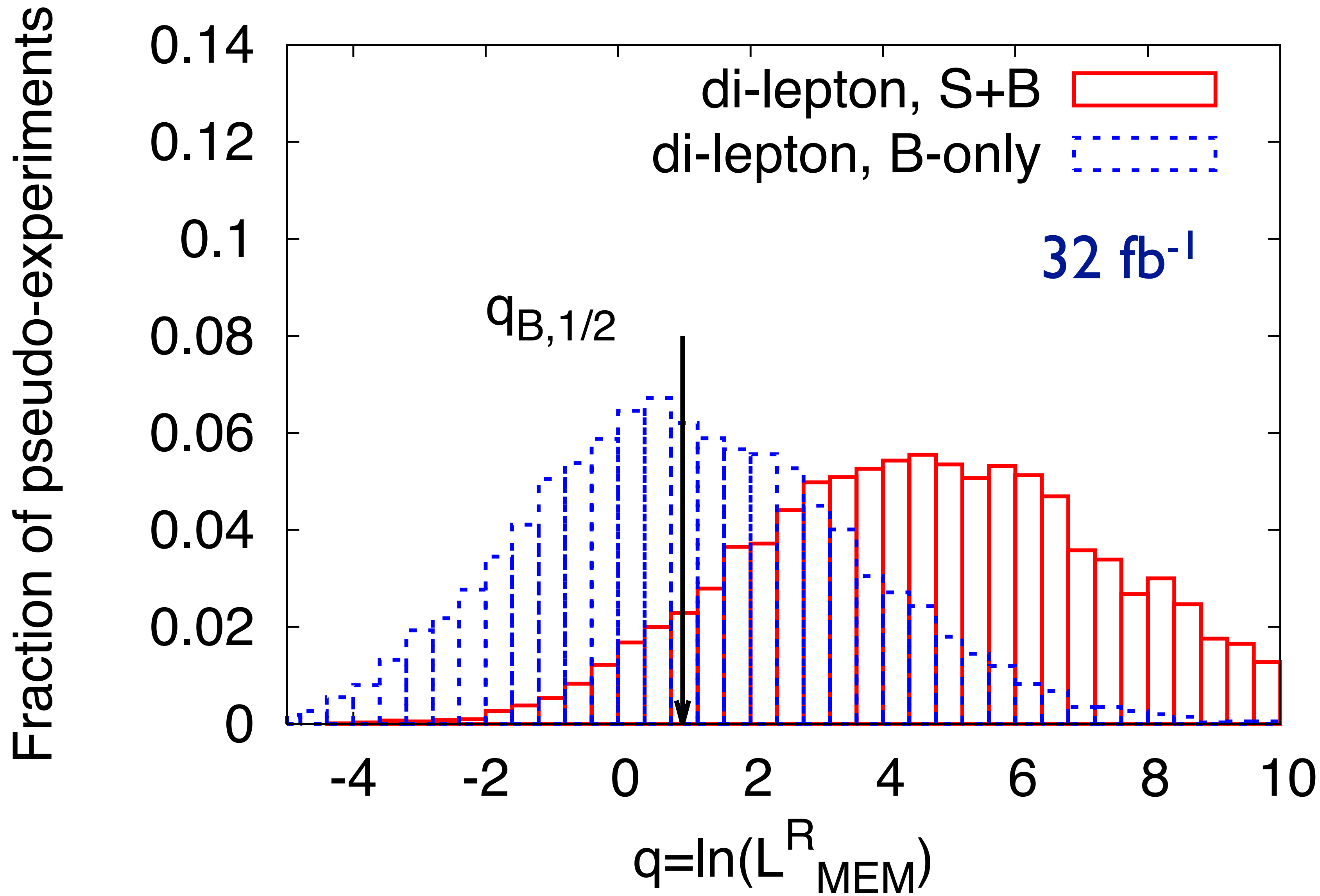
- For each pseudo-experiment, the likelihood ratio is calculated:

$$L^R_{MEM} = \prod_i^N \frac{r_0 P(x_i|S) + (1-r_0) P(x_i|B)}{P(x_i|B)} \qquad r_0 = \frac{s_0}{s_0 + b_0}$$

- For a given luminosity, we generate 10^4 ps-ex under the two hypotheses:
  - B-only hypothesis
  - S+B hypothesis

  ... and obtain the distributions of the ps-ex with respect to ln L^R_{MEM}

Significance

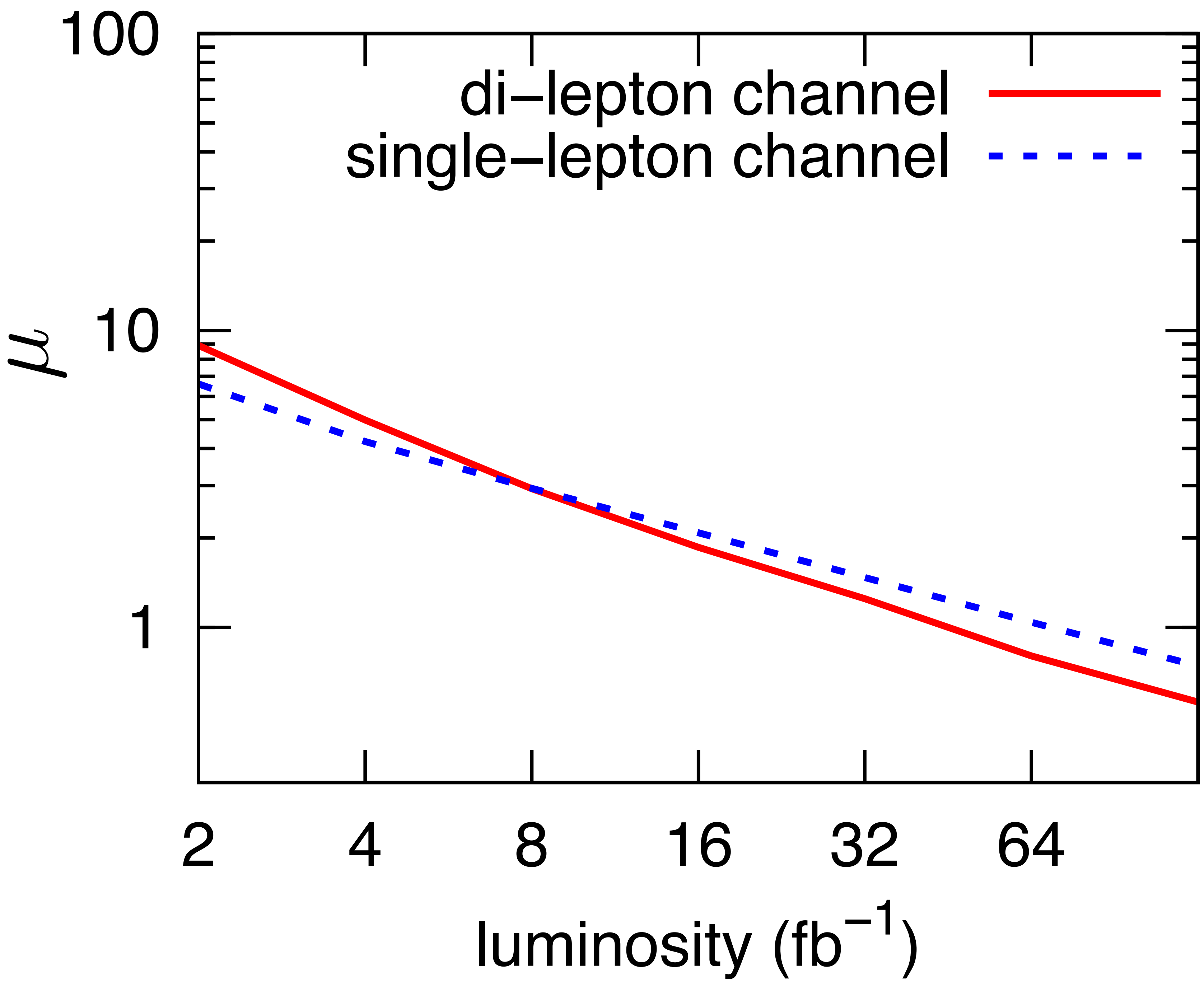


test: confidence level in rejecting S+B hypothesis if B-only hypothesis is realized

- compute $q_{B,1/2}$ = median of the B-only distribution
- estimate the p-value as the faction of events in the S+B distr.ibution satisfying $q < q_{B,1/2}$
- C.L. = 1-p

Significance

- rescale the ttH cross section by a factor μ such that S+B is excluded at 95% C.L



Conclusion

- MadWeight = generic and dynamical framework for Matrix element methods
- I presented one application: ttH at the LHC, 14 TeV
    - tt+jets + combinatorial backgrounds can be overcome with the MEM
    - the dilepton channel provides (at least) as much discriminant power as the single-lepton channel