Automatic event reweighing with matrix elements in MadGraph/MadEvent

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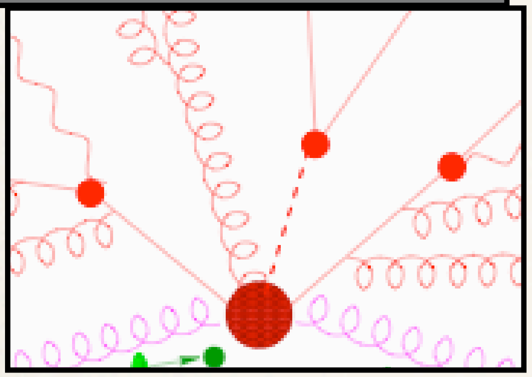
Outline

- Motivation
- Event reweighing based on matrix element techniques
- Automatic computation of the matrix element weights
- Conclusion and perspectives

Work done in collaboration with
Vincent Lemaitre, Fabio Maltoni and Olivier Mattelaer

From theory to data: MC road

Lagrangian $L(p_1,p_2,...)$ → Feynman rules → Matrix Elements → Events (Signal +Background) → Showering/ Hadronization → Detector Resolution → Data Analysis



Aim #1:

For a given signature, try to identify an excess of events over the expected number of background events

From data to theory:

Data Analysis → Lagrangian $L(p_1, p_2, \ldots)$

Aim #2:

Given an excess of events, try to identify the underlying theory and measure the properties of the new fields (mass, spin, coupling)

an "easy" example

$pp \to Z' \to e^+e^-$

properties of the Z′ can be studied by analyzing one observable at the time (mass$\longleftrightarrow m_{inv(e+,e-)}$, spin$\longleftrightarrow \Omega_e$)

a "tough" example

$pp \to \tilde{g}\tilde{g}, \tilde{g}\tilde{q}, \tilde{q}\tilde{q} \to$ jets + MET

measurement of the properties of the new fields has to proceed with more complex observables

From data to theory:

Data Analysis → Lagrangian $L(p_1,p_2,\ldots)$

Two different approaches have been investigated to handle the measurement of properties of decay chains with missing E_T at hadron colliders

Kinematics methods

- based on a restricted number of observables
- no use of strong theoretical assumptions
- relevant for the early stages of investigation

Model dependent analyses

- attempt to maximize the amount of experimental information
- strong theoretical assumptions
- relevant for precise measurements

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Kinematics methods

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ex: endpoint region, MT2,...

Model dependent analyses

- attempt to maximize the amount of experimental information
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- relevant for precise measurements

ex: matrix element method

investigated in this talk

The matrix element method

basic idea: likelihood analysis based on the whole information at hand [kondo, 88]

Given an experimental sample $S=\{x_i\}$ of N events distributed according to an expected probability law $P(x|\alpha)$ parametrized by α = a set of unknown theoretical parameters (can include mass, spin, bg normalization, ...), one needs to

1. evalutate the weight $P(x_i|\alpha)$ for each event x_i

2. extract the values of the theoretical parameters in the set α by maximizing the likelihood built upon the weights $P(x_i|\alpha)$ attached to each reconstructed event

$$L(\alpha) \propto \prod_{i=1}^{N} P(x_i|\alpha)$$

The matrix element method

The question is: how to define the weights $P(x_i|\alpha)$?

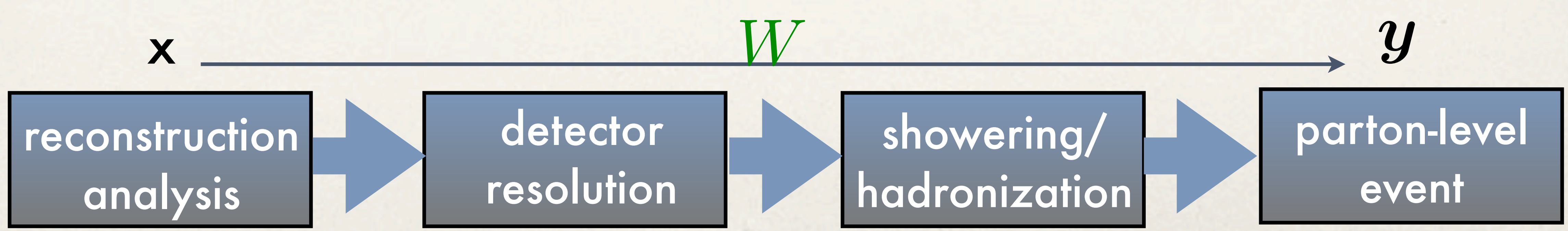
- If each final-state particle (including partons) was measured with a very good resolution, the weight $P(x_i|\alpha)$ would be simply given by the parton-level scattering amplitude $|M_\alpha(\boldsymbol{y})|^2$

- But some particles may escape from the detector without any interaction, and the partons themselves are not reconstructed in the detector

→ we need to marginalize over unconstrained information and to convolute with a resolution function W for the measured quantities

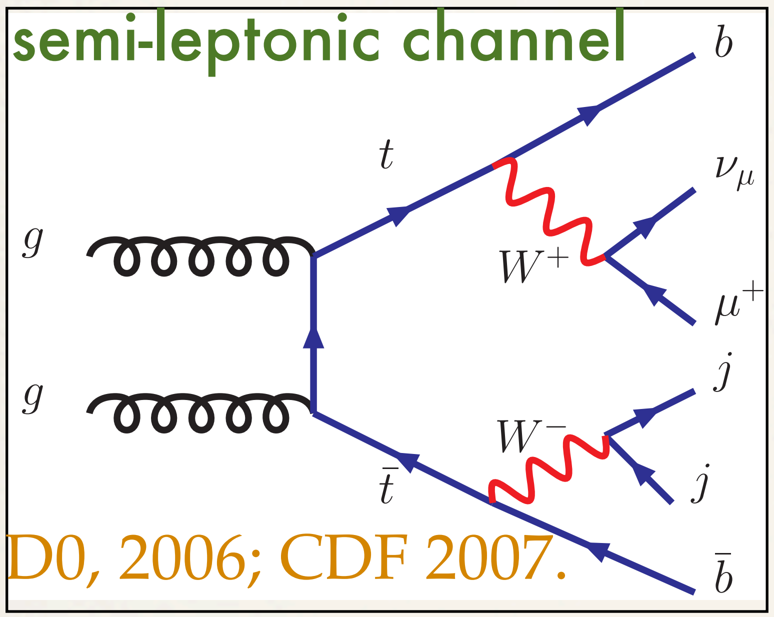
$$P(\boldsymbol{x}_i, \alpha) = \frac{1}{\sigma} \int d\phi_{\boldsymbol{y}} |M_\alpha|^2(\boldsymbol{y}) W(\boldsymbol{x}_i, \boldsymbol{y})$$

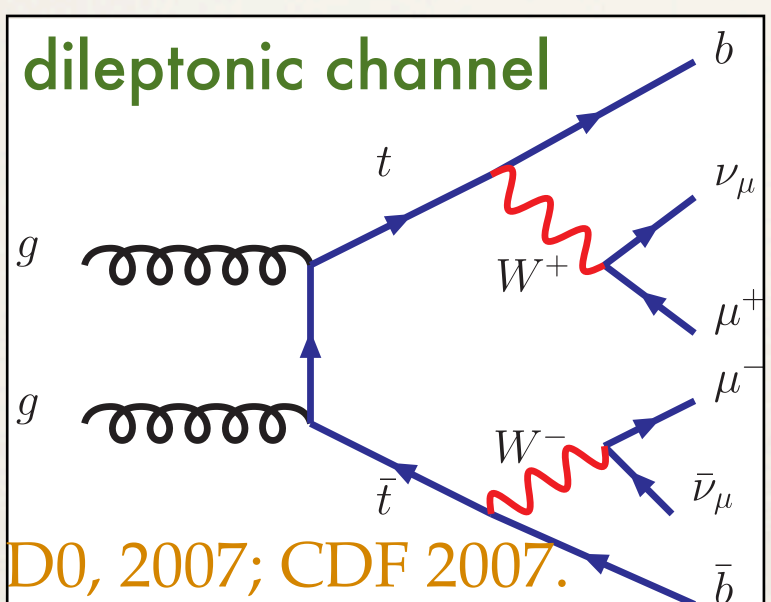
$W(x, y)$ is called the transfer function

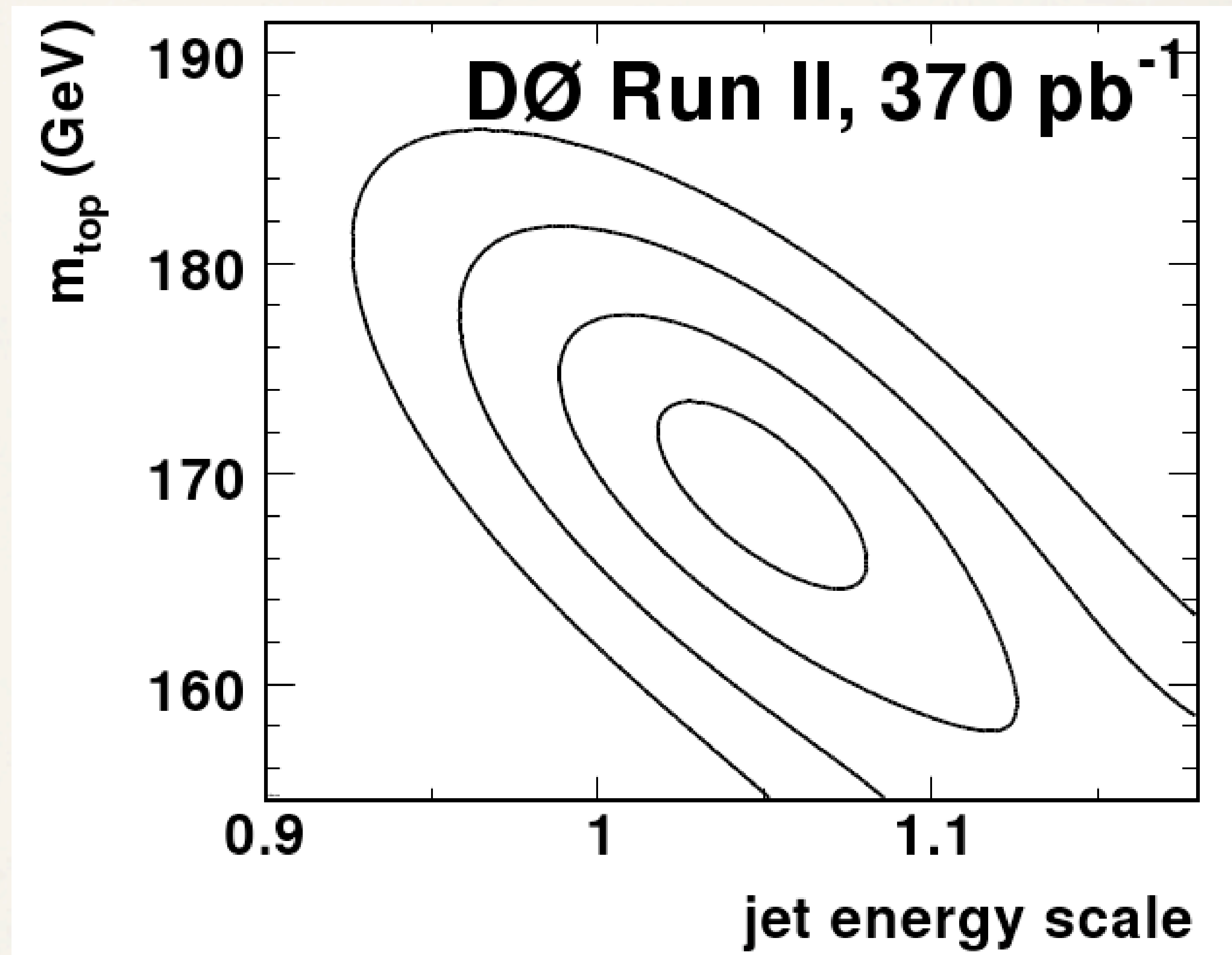


Early matrix element analyses at the Tevatron

Top-quark mass measurement from $t\bar{t}$ production in hadron collisions







[DO Phys. Rev. D75 092005, 2006]

Significant improvement for the measurement of the top-quark mass

Practical evaluation of the weights

$$P(\boldsymbol{x}_i, \alpha) = \frac{1}{\sigma} \int d\phi_{\boldsymbol{y}} \; |M|^2(\boldsymbol{y}) \; W(\boldsymbol{x}_i, \boldsymbol{y})$$

☐ Phase-space integrator

☑ Amplitude generator (MadGraph)

☑ Fit from MC tuned to the resolution of the detector

Practical evaluation of the weights

$$P(\boldsymbol{x}_i, \alpha) = \frac{1}{\sigma} \int d\phi_{\boldsymbol{y}} \; |M|^2(\boldsymbol{y}) \; W(\boldsymbol{x}_i, \boldsymbol{y})$$

- ☑ Phase-space integrator
- ☑ Amplitude generator (MadGraph)
- ☑ Fit from MC tuned to the resolution of the detector

[PA, F. Maltoni, M. Mattelaer, V. Lemaitre]

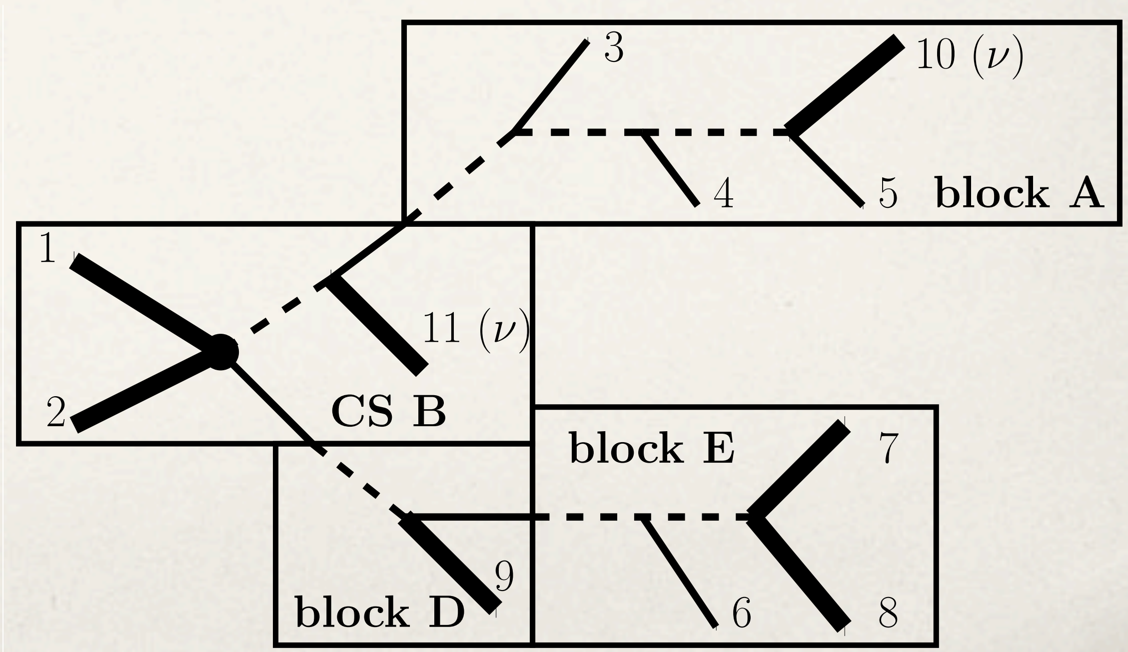
MadWeight phase-space generator

To perform the integrations that define the weights using adaptive Monte Carlo techniques, one has to use a phase-space measure $d\tilde{\phi}_{\boldsymbol{y}}$ that flattens the peaks in the integrand

$$P(x) \sim \int d\phi_{\boldsymbol{y}} |M|^2(\boldsymbol{y}) W(x,y) \quad \rightarrow \quad \int d\tilde{\phi}_{\boldsymbol{y}} \frac{|M|^2(\boldsymbol{y})\, W(x,y)}{g(\boldsymbol{y})}$$

For a generic decay chain and an arbitrary transfer function this is achieved automatically by

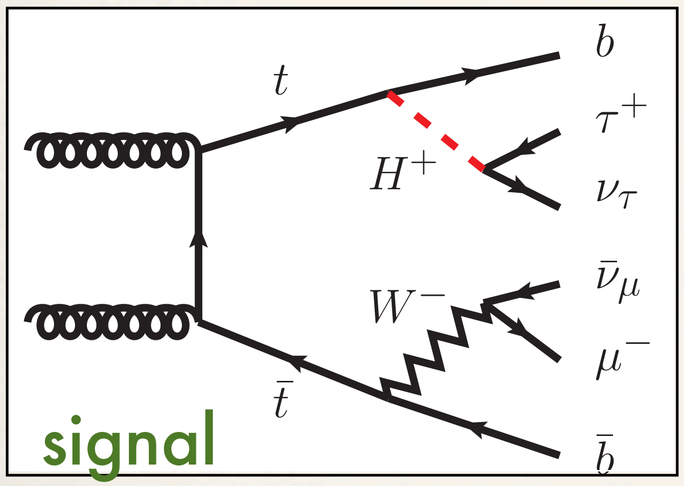
1. defining optimal phase-space mappings obtained by applying local variable transformations on the canonical parametrization,
2. combining these mappings in a multi-channel integration

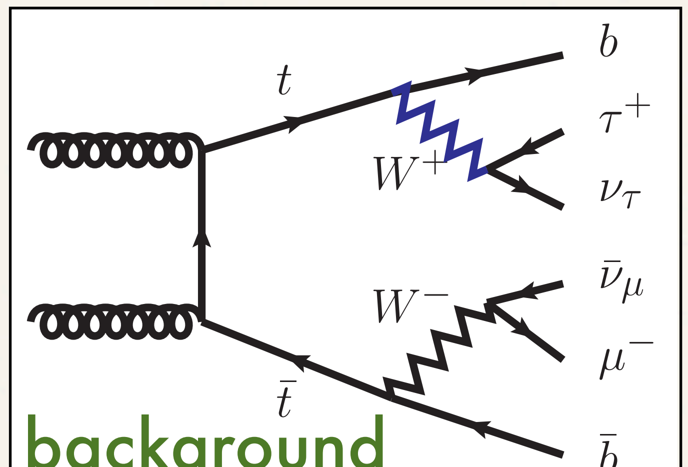


Capabilities of the code: a toy example

Disentangling different spin hypotheses in decay chain with missing E_T

$t \to H^+ b$ vs. $t \to W^+ b$





we set

$m_H \approx m_W$ (keep only the spin correlation effects)

$|m_H - m_W| \gg \Gamma_H, \Gamma_W$

(neglect the interference terms)

Possible discriminators:

- keeping only information from P_T of the tau:

$$D(\boldsymbol{x}) = \frac{\sigma_H^{-1} \frac{d\sigma_H}{dp_{T,\tau}}}{\sigma_H^{-1} \frac{d\sigma_H}{dp_{T,\tau}} + \sigma_W^{-1} \frac{d\sigma_W}{dp_{T,\tau}}}$$

- matrix element method (keeps all information):

$$D(\boldsymbol{x}) = \frac{P_H(\boldsymbol{x})}{P_H(\boldsymbol{x}) + P_W(\boldsymbol{x})}$$

Capabilities of the code: a toy example

Disentangling different spin hypotheses in decay chain with missing E_T

$$t \to H^+ b \quad \text{vs.} \quad t \to W^+ b$$

Analysis based on the p_T weight:

- discriminator:

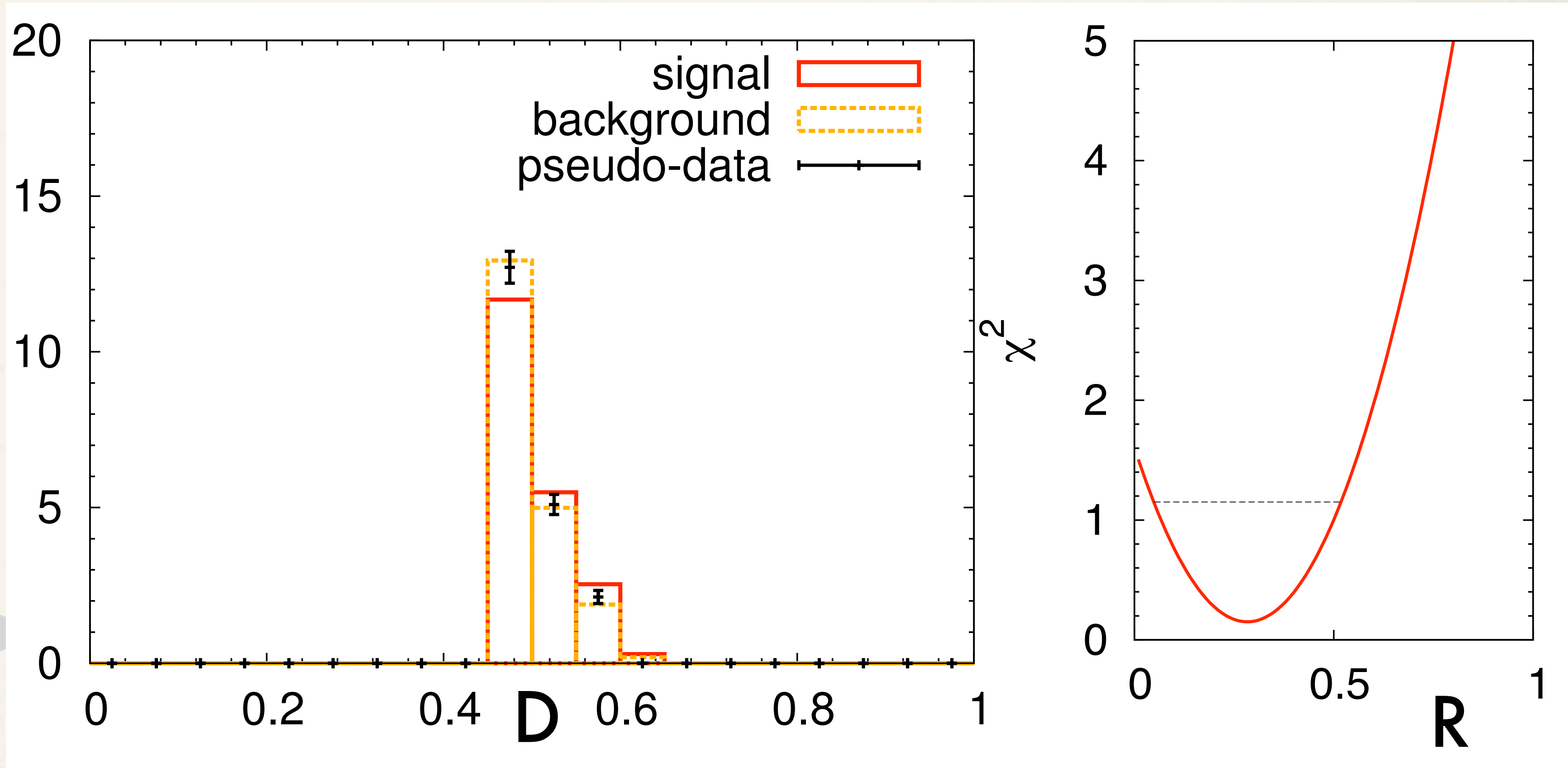
$$D(\boldsymbol{x}) = \frac{\sigma_H^{-1} \frac{d\sigma_H}{dp_{T,\tau}}}{\sigma_H^{-1} \frac{d\sigma_H}{dp_{T,\tau}} + \sigma_W^{-1} \frac{d\sigma_W}{dp_{T,\tau}}}$$

- data: 240 signal events

760 background events

fraction of signal events:

R_{in}=24%



By fitting the event density distribution of the pseudo data by a superposition of the expected distributions for the signal and for the background, we get

reconstructed fraction of signal events (R_{out}) = 28±24%

Capabilities of the code: a toy example

Disentangling different spin hypotheses in decay chain with missing E_T

$$t \rightarrow H^+ b \quad \text{vs.} \quad t \rightarrow W^+ b$$

Analysis based on the matrix element weight:

- discriminator:

$$D(\boldsymbol{x}) = \frac{P_H(\boldsymbol{x})}{P_H(\boldsymbol{x}) + P_W(\boldsymbol{x})}$$

- data: 240 signal events

760 background events

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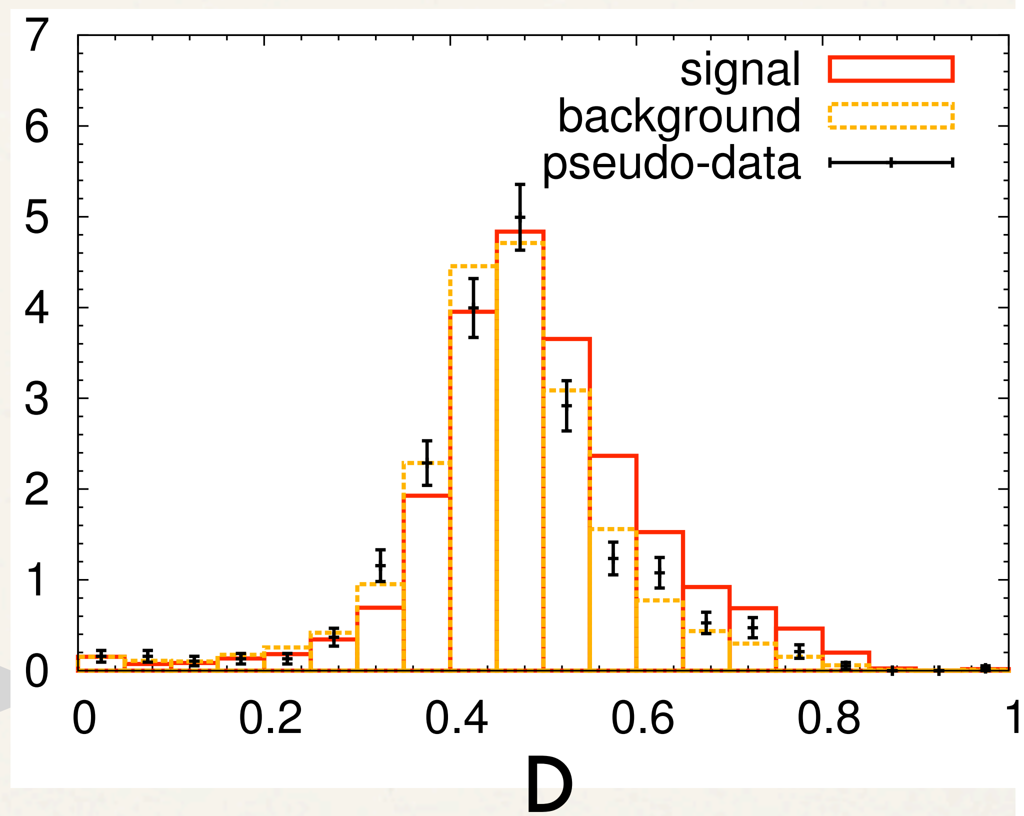

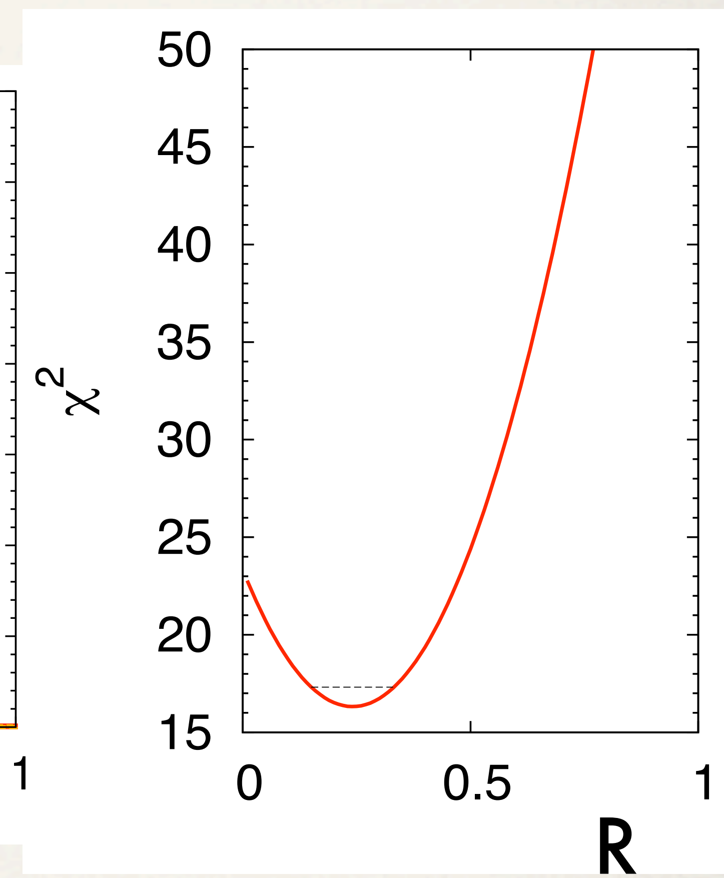

The discriminating power is substantially improved. The fit of the distribution associated with the pseudo-data gives:

reconstructed fraction of signal events (R_{out}) = 24±9%

Conclusion and perspectives

- The matrix element method is conceptually a powerful technique, as it makes an optimal use of both the experimental and the theoretical information.
- I have presented MadWeight, a tool that computes the matrix element weights for arbitrary decay chains and transfer functions.
- The code is fully automatic and highly parallel in nature, and therefore reduces dramatically time computation issues associated with the matrix element techniques.
- The control on the systematic errors introduced by the matrix element method remains a delicate issue. Beside the Monte Carlo analyses that can be done under ideal conditions, it is important to identify which measurements can be achieved with a good control on the systematics. We hope that MadWeight will motivate works in this direction.