Differential Matrix Element Method

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1st Mini-Workshop on « Theoretical advances in the Matrix Element Method »
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In Collaboration with
Olivier Mattelaer.

Motivations

➢ For What ?

- Search for new physics looking at differential cross sections with respect to kinematic variables.
- For topologies that cannot be fully reconstructed using the detector information only (i.e. with neutrinos in final state).

Example: Search of new physics in $t\bar{t}$ dileptonic channel.
- Study the Kinematic of $t\bar{t}$ system (invariant mass, angular correlation).

➢ Why MEM ?

- Matrix Element Method maximize the information that you can extract from a sample of events using theoretical constraints.

Prospect at LHC:

Determination of differential cross sections from $t\bar{t}$ fully leptonic, using the matrix element method.
O.Mattelaer - A.Pin
IL NUOVO CIMENTO 35C

Presented in this talk

Similar Method also used at Tevatron for $t\bar{t}$ in the semi-leptonic decay channel.

A search for resonant production of $t\bar{t}$ pairs in 4.8 bf^{-1} of integrated luminosity of $p\bar{p}$ collisions at $\sqrt{s} = 1.96\ TeV$.
CDF Collaboration
FERMILAB-PUB-11-350-E

The method: DMEM

➢ How ?

The probability equation:

$$P(p_{vis}|\vec{\alpha}) = \frac{1}{\sigma_{\vec{\alpha}}} \int dq_1 dq_2 f(q_1) f(q_2) dp |\mathcal{M}_{\vec{\alpha}}(p)|^2 W(p, p_{vis})$$

where $\vec{\alpha}$ is fixed as the set of parameters for the standard model, becomes a probability density function:

$$\frac{\partial \mathcal{P}(p^{vis})}{\partial m}|m_0 = \frac{1}{\sigma} \int dx_1 dx_2 f(x_1) f(x_2) d\Phi |\mathcal{M}_{(}p)|^2 W(p, p^{vis}) \times \delta(m_p - m_0)$$

Where $"m"$ represents an arbitrary variable (invariant mass of tt system)

But too complex to be performed with the δ function.
Evaluated on small intervals → binned pdf.

$$\int_{m_0}^{m_{0+i}} dm^* \frac{\partial \mathcal{P}(p^{vis})}{\partial m}|m^*$$

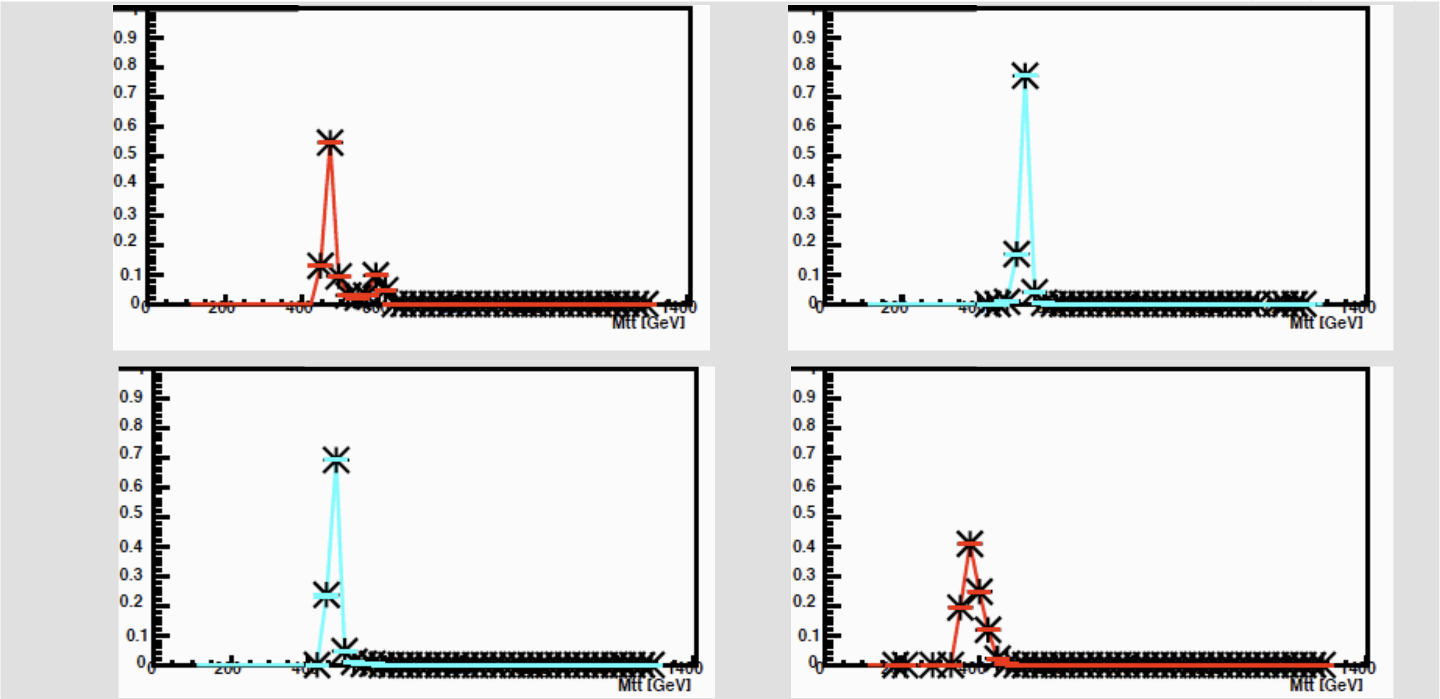
Practically:
- Quantities of interest are evaluated for each generated partonic state.
- The corresponding bins are incremented by the value of the integrand.
- This way to evaluate on small intervals introduces a binning of the differential variable.

The method

Example: $t\bar{t}$ invariant mass system for dileptonic events

- Matrix element for $t\bar{t}$ production and decay. (MadGraph)
- Integration performed with MadWeight[1].
- Distribution obtained for each event:

Partonic level



- Both jet permutations are considered: reflected with double peak for some event

These distributions are normalized to 1 (pdf) and combined as: $\frac{1}{\sigma}\frac{\partial\sigma}{\partial m}\sum_{event}\frac{1}{\mathcal{P}}\frac{\partial\mathcal{P}}{\partial m}$

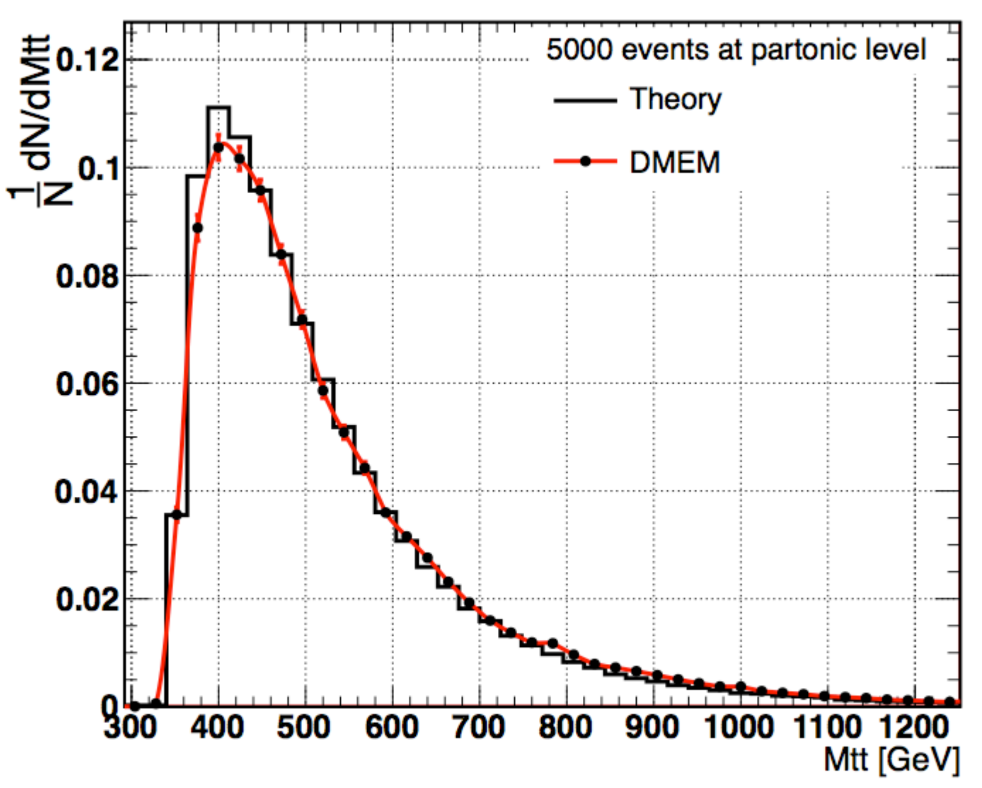
1 : Pierre Artoisenet, Vincent Lemaitre, Fabio Maltoni, Olivier Mattelaer, « Automation of the matrix element reweighting method » , JHEP 2010

validation

Comparison with theory at leading order for :

- $M_{t\bar{t}}$: sensitivity to $X \rightarrow t\bar{t}$.
- $Cos(\theta^*_{t\bar{t}})$: sensitivity to the spin of X .
- selected events :
  - 2 isolated muons pt>20 GeV and |η|<2.4 .
  - Exactly 2 jets pt>30 GeV and |η|<2.4 and b-tagged.
  - MET > 30 GeV.

$$\sqrt{s} = 14TeV$$



Partonic level

Perfect detector

transfer function :

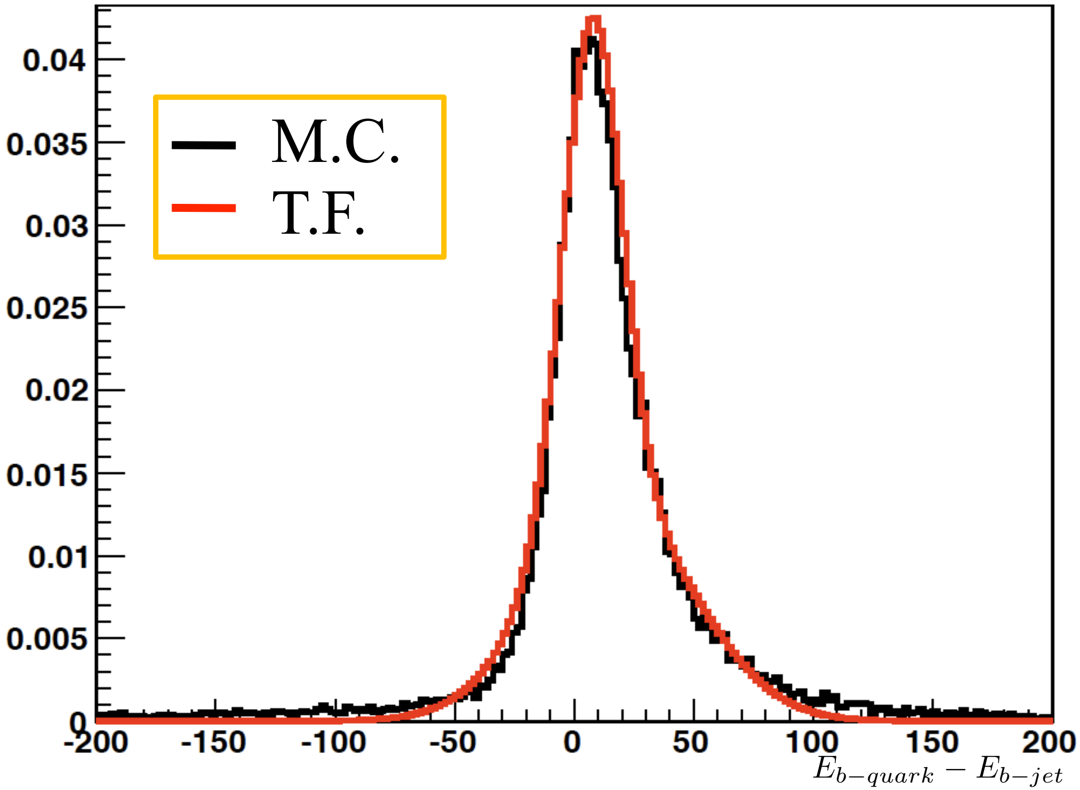
$W = \delta$ function

- Theory estimated from llbbνν final state.
- DMEM applied on llbb+MeT final state.
  - The neutrino momenta are in fact fixed by the mass constraints.

realistic situation

- Parton shower: Pythia (add ISR/FSR)
  No correction used.
- Fast detector simulation response with Delphes[2]
- Transfer function on jet energy:

$$W(E_j, E_{part}) = \frac{1}{\sqrt{2}(P_2 + P_3.P_5)} . \left(e^{-\frac{[(E_{part}-E_j)-P_1]^2}{2.P_2^2}} + P_3.e^{-\frac{[(E_{part}-E_j)-P_4]^2}{2.P_5^2}} \right).$$

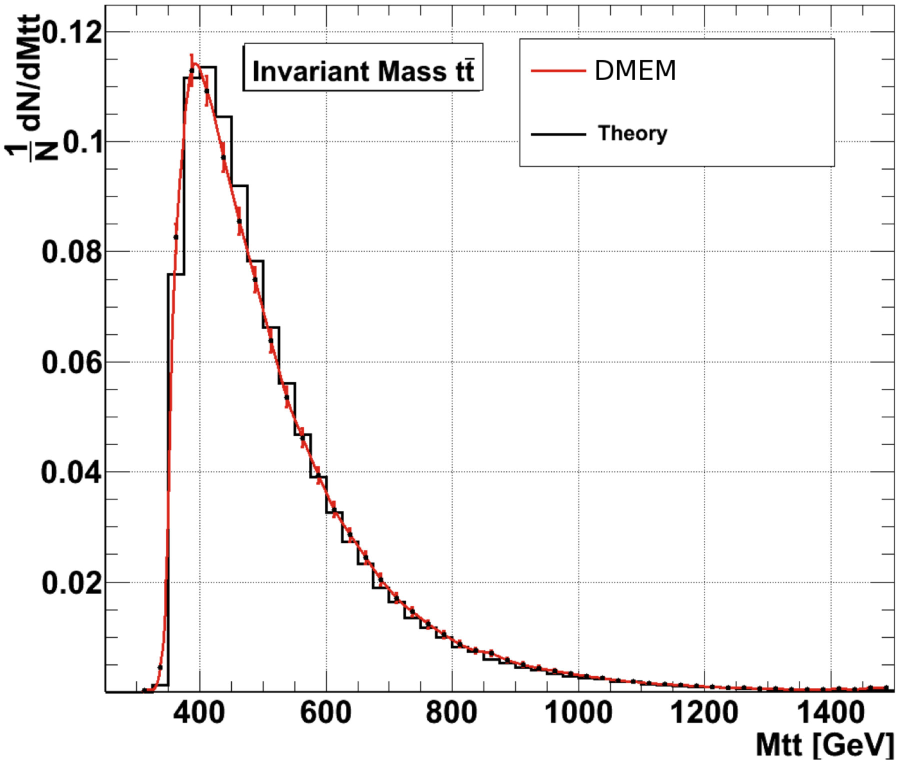


- 150.000 pairs of jets/partons
- 10 parameters :

$$P_i = a_{i0} + a_{i1}.E$$

2 : S. Ovyn and X.Rouby, « Delphes, a framework for fast simulation of a generic collider experiment » ,

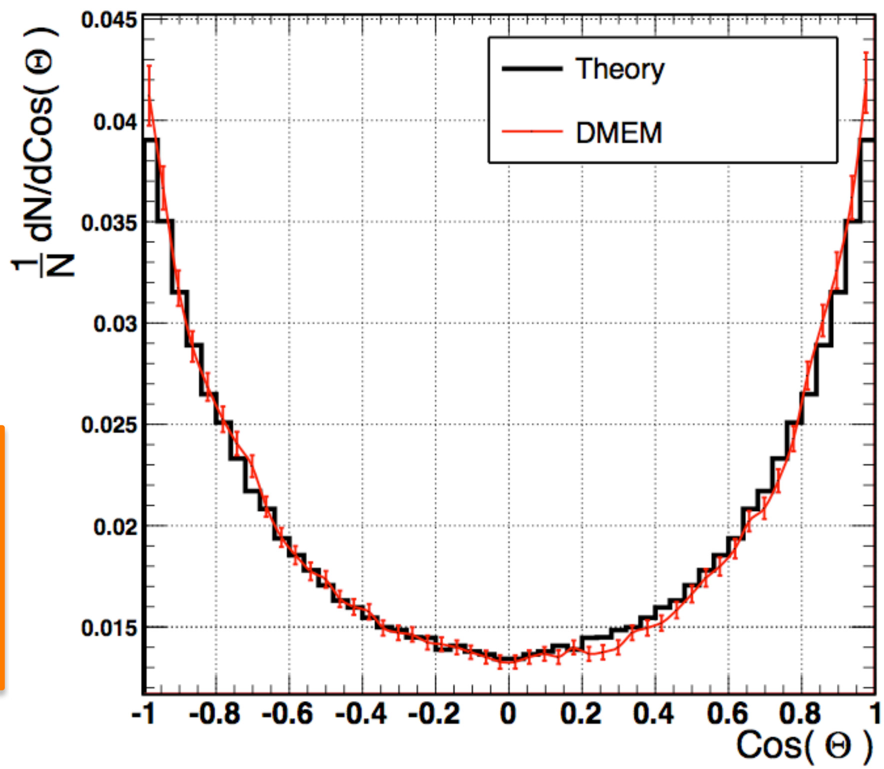
realistic situation: Validation



- Good agreement with the theory.
- No bias due to the transfer function

Reconstruction of other variables as $Cos(\theta^{*}_{t\bar{t}})$

(top-diffusion angle in the tt̄ rest frame)



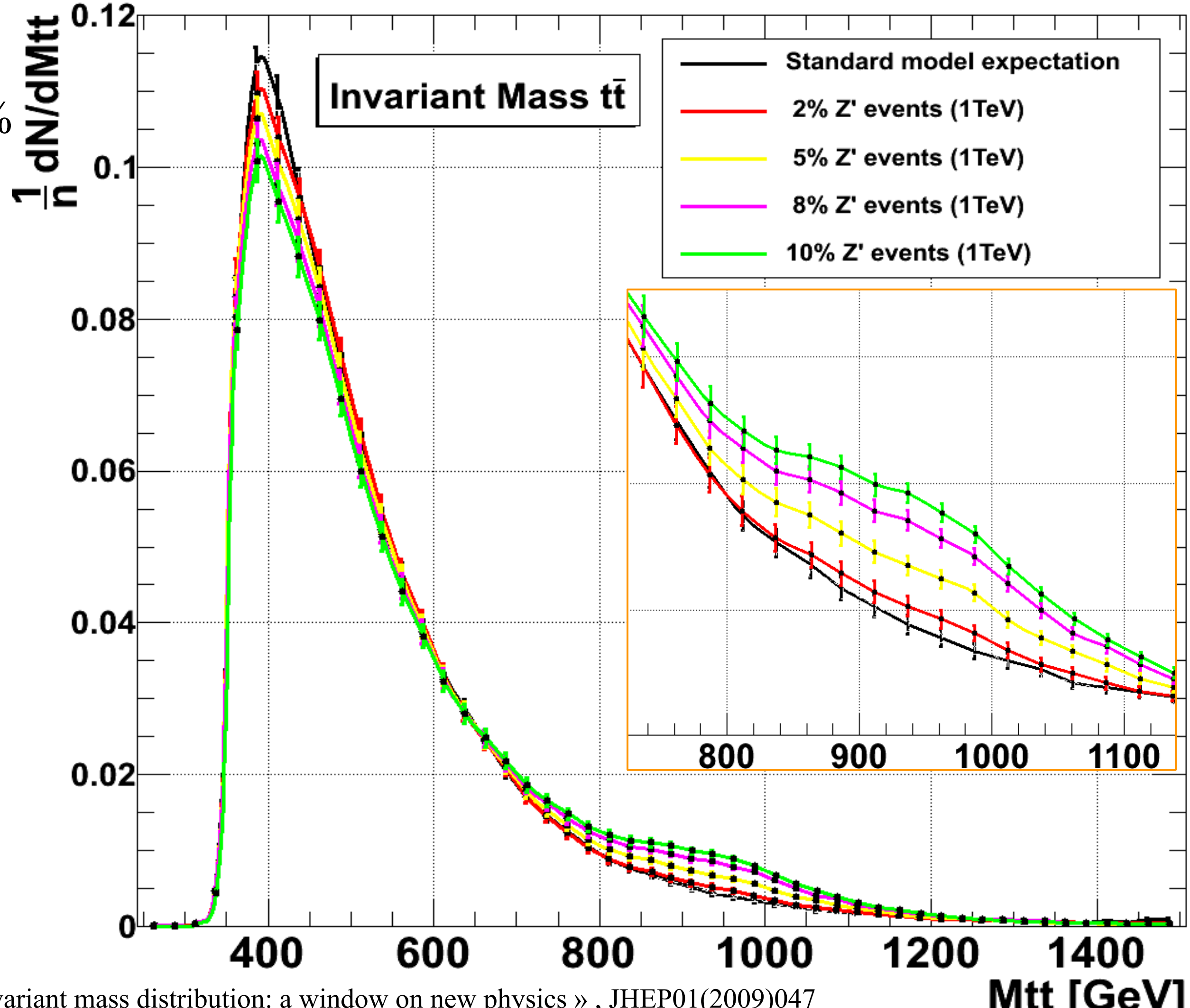
Prospect at LHC : $(pp)\sqrt{s} = 14$ TeV

ONLY standard model $t\bar{t}$ dileptonic Matrix Element is used.

Deviation from the standard model introducing a resonance decaying in $t\bar{t}$.

- Spin 1 particle (Z') [3] .
- 1 TeV
- Various $\frac{N_{Z'}}{N_{tot}}$: 2%, 5%, 8% 10%

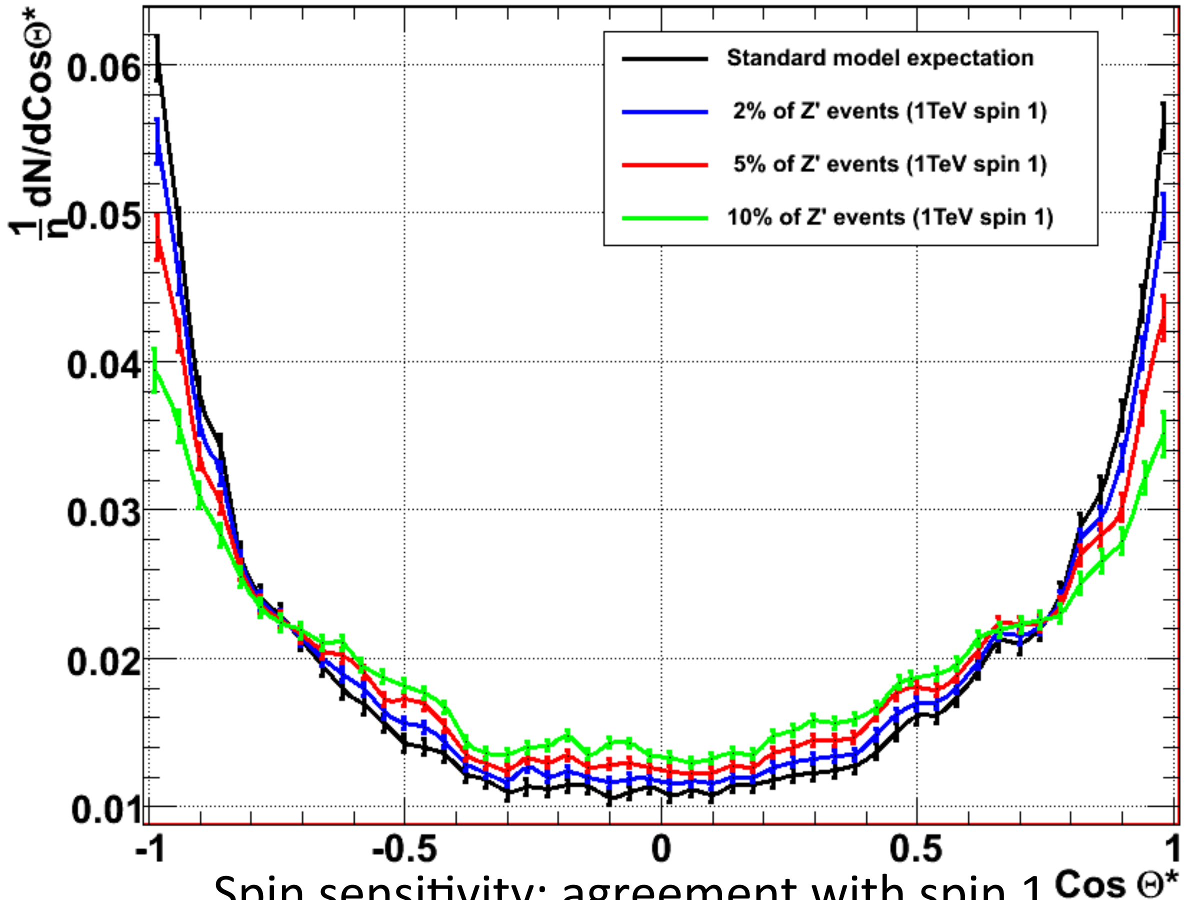
Compatibility with the S.M.	
$N_{Z'}/N_{tot}$	NOT S.M. C.L.
2%	72 %
3%	95.6 %
5%	> 99.998%
8%	
10%	



3 : Rikkert Frederix and Fabio Maltoni , « Top pair invariant mass distribution: a window on new physics » , JHEP01(2009)047

Prospect at LHC : $(pp)\sqrt{s} = 14$ TeV

$Cos(\theta^*_{t\bar{t}})$ reconstructed for events with $M_{t\bar{t}}$ reconstructed above 700 GeV.



Spin sensitivity: agreement with spin 1

Refering to « Top pair invariant mass distribution: a window on new physics » , JHEP01(2009)047

Statistical uncertainties

- Each event contributes to a few bins. Errors on each bin (k) are correlated.
- Correlation matrices have been computed :
  - using 100.000 standard model events.
  - following : $COR(k,l) = \frac{Cov(k,l)}{\sigma(k)\sigma(l)}$ with $cov(k,l) = \frac{1}{N} \sum_{events} (k_i - \bar{k})(l_i - \bar{l})$

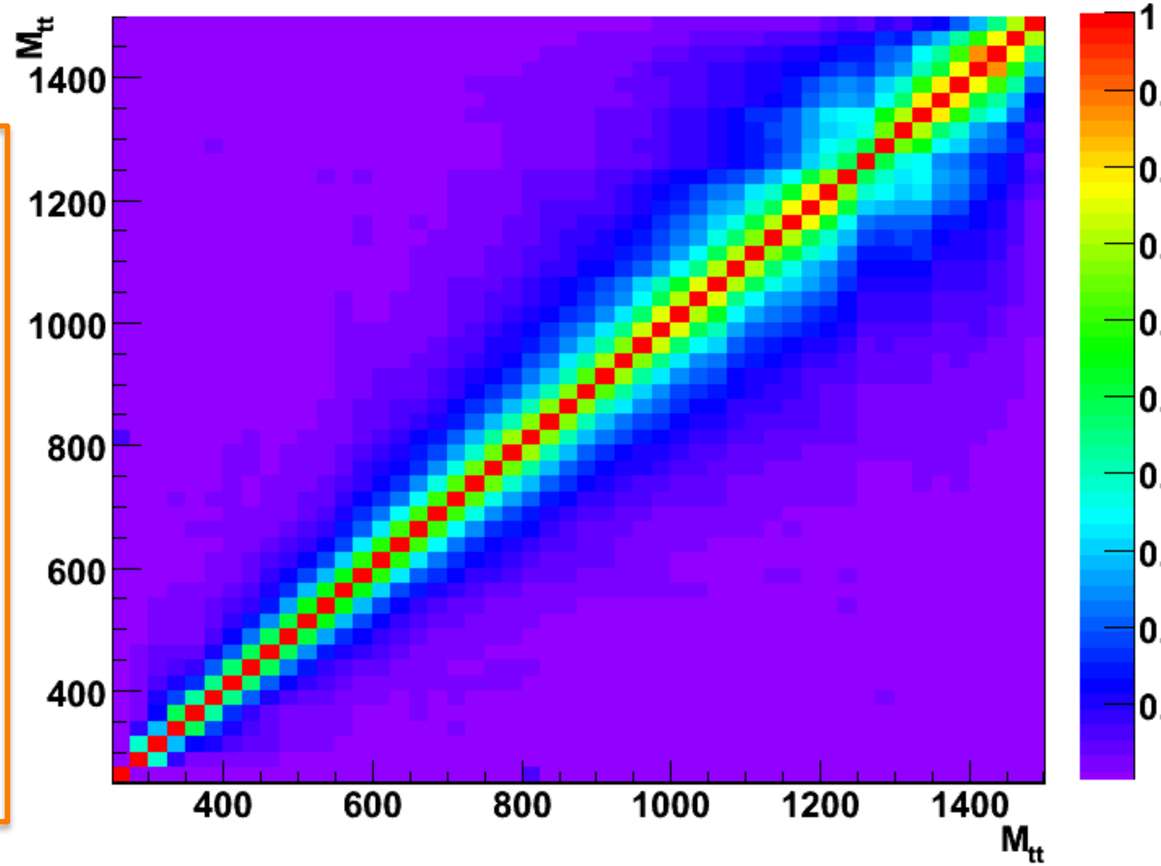
S.M. deviation

χ^2 is defined between the standard model expectation and the observed result.

$$\chi^2 = \sum_i \frac{(x_i - x_i^{th})^2}{\sigma_i^2}$$

Taking into account the correlation :

$$\chi^2 = \sum_{ij} C_{ij}^{-1}(x_i - x_i^{th})(x_j - x_j^{th})$$



Summary

The Matrix Element Method:

- is not only for precise measurement.
- Is adapted to perform differential analysis: $\frac{d\sigma}{dm}$.
  - It is an inclusive search approach.

This technique allows the observation of resonances decaying in $t\bar{t}$:

- Visible in the invariant mass spectrum.
- Sensitivity to the spin of the resonance.