Matrix Element technique at NLO to extract m_{top} from dileptonic events

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Pierre Artoisenet
CP3, UCLouvain

based on ongoing work in collaboration with

Fabio Maltoni

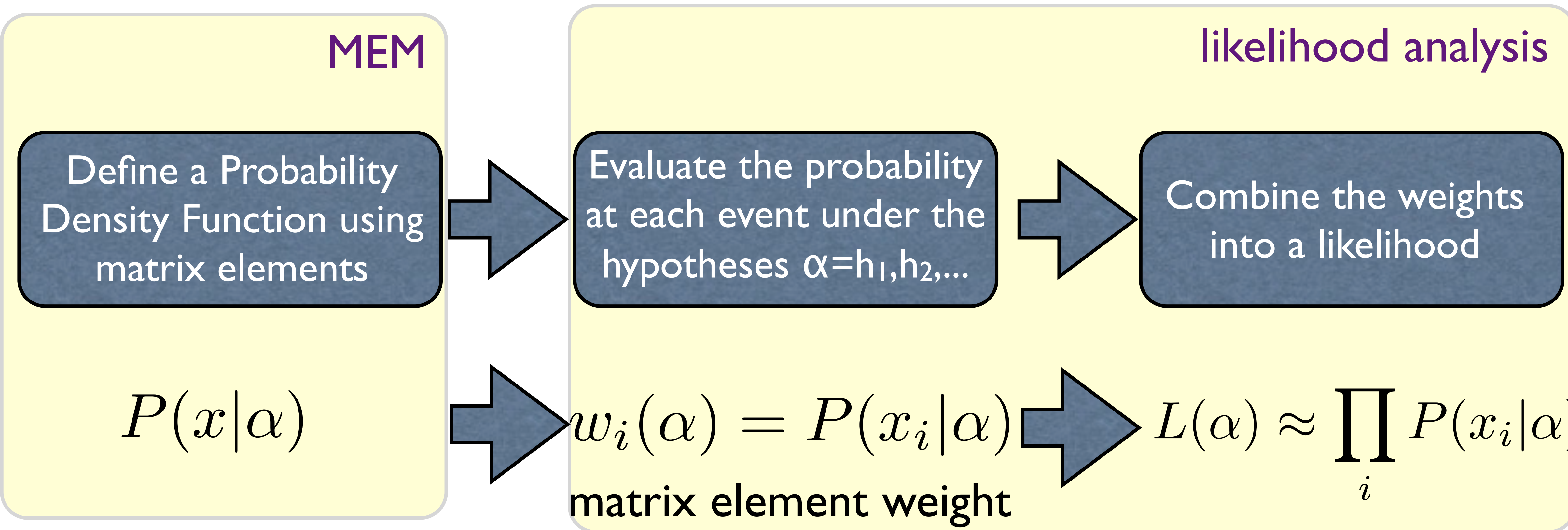
Michele Selvaggi

Outline

- Matrix Element Method (MEM)
- New formulation of the MEM to measure m_{top}
- Results
- Conclusion

Matrix Element Method

- Construction of the PDF based on hard scattering matrix elements
- Definition of the discriminating variable: likelihood built upon this PDF



x : kinematics of the reconstructed event

α : theoretical assumption, in our case the mass of the top quark

Definition of the Probability Density Fct in the MEM

- Hard scattering matrix element integrated over unconstrained information and convoluted with the resolution function W for the measured quantities

F. Canelli (D0 collaboration) 2003

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

integration on the parton-level phase-space

tree-level matrix element

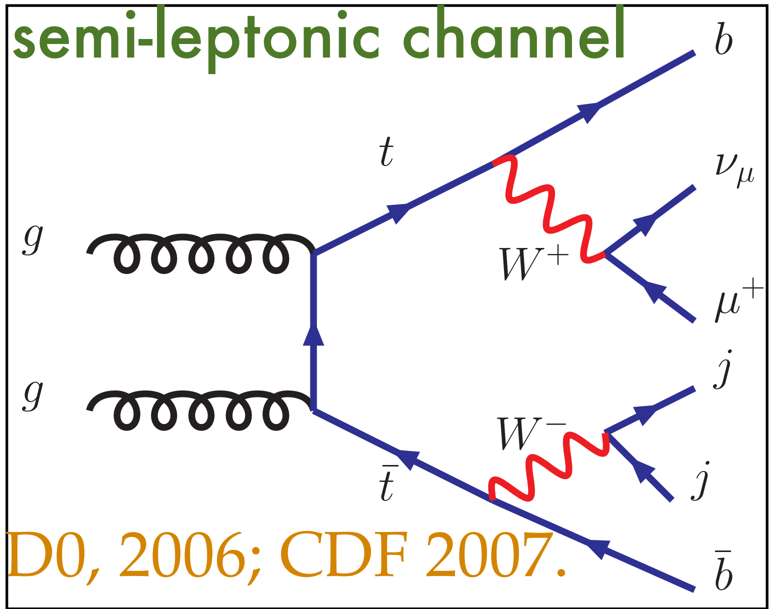
transfer function extracted from MC simulation

- In this talk: propose a new formulation of the PS integration that is fast and more convenient for the inclusion of QCD correction and parton shower effects

Measurement of m_{top} with the MEM at the Tevatron

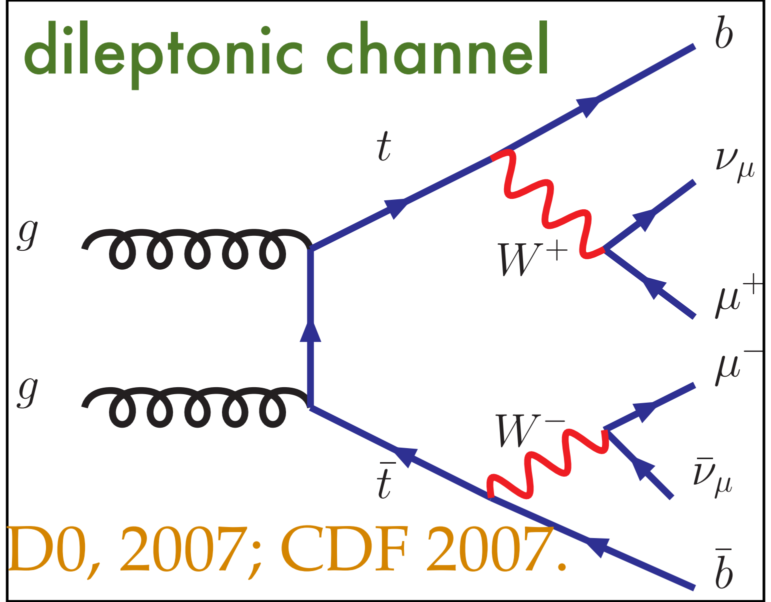
Top-quark mass measurement from $t\bar{t}$ production in hadron collisions

semi-leptonic channel

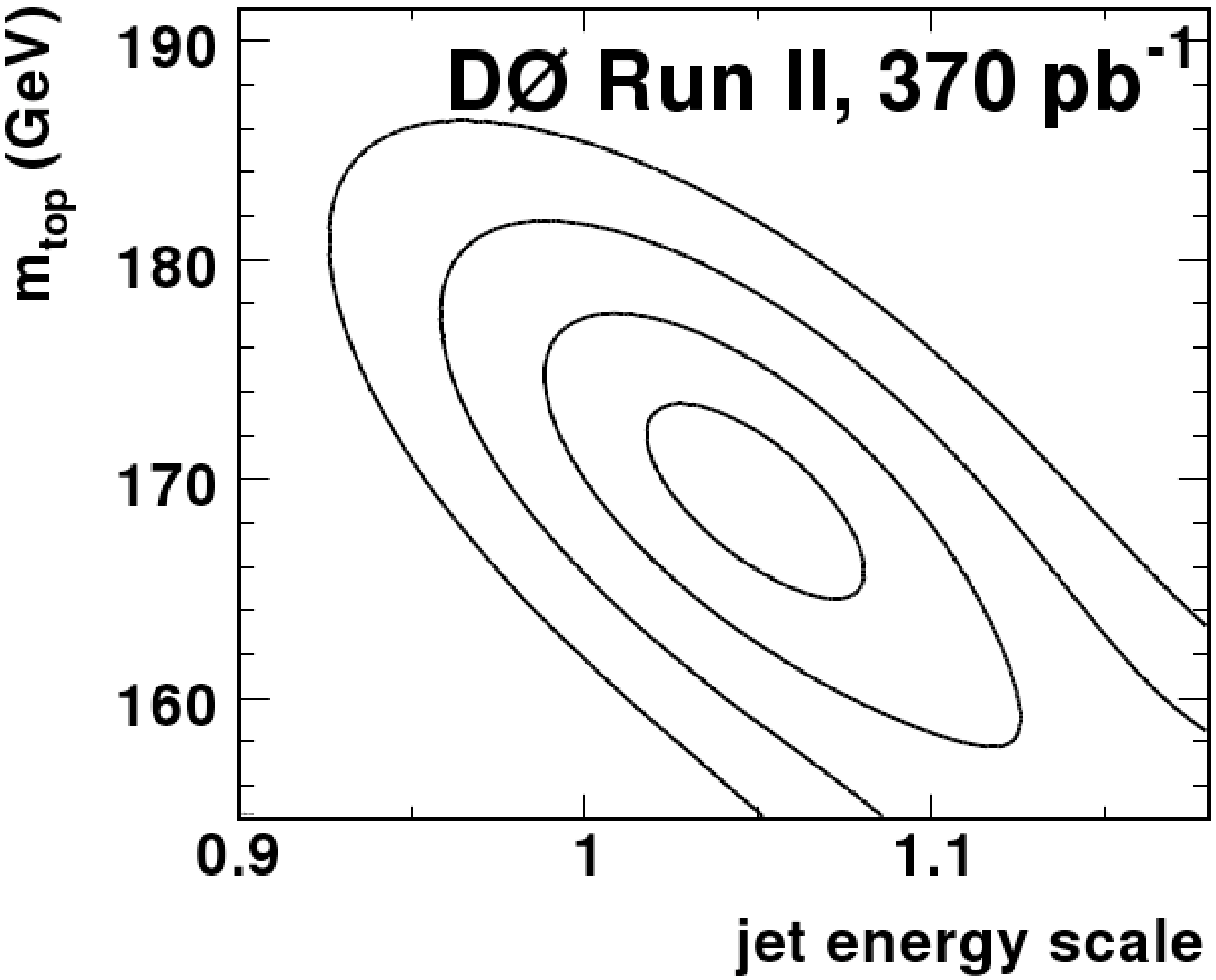


D0, 2006; CDF 2007.

dileptonic channel



D0, 2007; CDF 2007.



[DO Phys. Rev. D75 092005, 2006]

Significant improvement for the measurement of the top-quark mass

MEM for the measurement of m_{top}: prospects

Improving the measurement of mtop with the MEM is challenging:

1. Uncertainties in the transfer functions on jet energies
2. CPU Expensive method when the statistic is large
3. Lack of NLO information in the MEM weights

→ In this talk we consider the production of top quark pair in the dilepton channel and suggest a new formulation of the method that is fast and flexible enough to account for QCD correction

General idea

- Consider top quark pair production in the dilepton channel
- Consider only the information from the lepton kinematics P_l, P_2

  → use only best determined quantities in the events

- Set the MEM Probability Density Function to the cross section differential in the kinematics of the leptons

$$P(p_{l_1}, p_{l_2} | m_t) = \left(\frac{d\sigma}{[dp_{l_1}][dp_{l_2}]} \right)_{m_{\rm top}}$$

$[dp_{l_i}] =$ LIPS measure for lepton i

For this specific case, we show that QCD corrections and parton shower effects can be included with no additional CPU costs

Formulation of the method

Starting point for the evaluation of the PDF: use the Narrow Width Approximation for the tops to factorize the production and decay phase-space measures

$$P(p_{l_1}, p_{l_2} | m_t) = \frac{1}{\sigma_{\rm prod}} \sum_i w_i \frac{1}{|M_{\rm prod}(X_i)|^2} \left(\frac{1}{2 m_t \Gamma_t(m_t)} \right)^2$$

$$\int \prod_j \left(\frac{d\Phi^j_{\rm dk}(X_i)}{[dp_{l_j}]} f_{\rm BW}(p^2_{W_j}, m_W, \Gamma_W) \right) |\tilde{M}_{\rm dk}(X_i^{\rm dk})|^2$$

- The sum over i runs over a sample of production events (w/o top quark decay), w_i = weight of production event i
- The sum over j runs over the decay branches
- $d\Phi^j_{\rm dk}(X_i)$ is the phase-space measure associated with the decay products in branch j,
- $|\tilde{M}_{\rm dk}(X_i^{\rm dk})|^2$ = decayed ME, (whole process) $|M_{\rm prod}(X_i)|^2$ = production ME

Formulation of the method

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covers the phase space for the production

$$P(p_{l_1}, p_{l_2} | m_t) = \frac{1}{\sigma_{\text{prod}}} \sum_i w_i \frac{1}{|M_{\text{prod}}(X_i)|^2} \left(\frac{1}{2 m_t \Gamma_t(m_t)} \right)^2$$

$$\int \prod_j \left(\frac{d\Phi^j_{\text{dk}}(X_i)}{[dp_{l_j}]} f_{\text{BW}}(p^2_{W_j}, m_W, \Gamma_W) \right) |\tilde{M}_{\text{dk}}(X_i^{\text{dk}})|^2$$

covers the phase space for the decay

- The sum over i runs over a sample of production events (w/o top quark decay), w_i = weight of production event i
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Formulation of the method

Observations:

- The phase-space integration associated with each decay branch is 2-dimensional and can be parametrized as follows:

$$\frac{d\Phi^{j}_{\rm dk}(X_i)}{[dp_{l_j}]} = d\phi_j dp^2_{W_j} \sum_{\rm sol} g_j(p_{t_j}, p_{l_j}, \phi_j, p^2_{W_j})$$

$p^2_{W_j}$: squared invariant mass of W boson

ϕ_j: azimuthal angle of neutrino in the frame where b, ν are back-to-back

- The matrix element with the decay (but Breit-Wigner distributions for W pulled out) is independent of the variables $p^2_{W_j}$, ϕ_j

indeed polarized matrix elements for the decay itself read:

$$|\tilde{M}_{\uparrow}(t(p_t) \to l(p_l) + b + \nu)|^2 = g_w^4 (2p_l \cdot p_t^a)(m_t^2 - m_b^2 - 2p_t \cdot p_l)$$

$$|\tilde{M}_{\downarrow}(p_t \to l(p_l) + b + \nu)|^2 = g_w^4 (2p_l \cdot p_t^b)(m_t^2 - m_b^2 - 2p_t \cdot p_l)$$

Formulation of the method

So ME's need to be evaluated at most once per production event:

$$P(p_{l_1}, p_{l_2} | m_t) = \frac{1}{\sigma_{\text{prod}}} \sum_i w_i \frac{|\tilde{M}_{\text{dk}}(X_i^{\text{dk}})|^2}{|M_{\text{prod}}(X_i)|^2} \left(\frac{1}{2 m_t \Gamma_t(m_t)} \right)^2$$

$$\int \prod_j \left(d\phi_j dp^2_{W_j} f_{\text{BW}}(p^2_{W_j}, m_W, \Gamma_W) \sum_{\text{sol}} g_j(p_{t_j}, p_{l_j}, \phi_j) \right)$$

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$$\int \prod_j \left(d\phi_j dp^2_{W_j} f_{\text{BW}}(p^2_{W_j}, m_W, \Gamma_W) \sum_{\text{sol}} g_j(p_{t_j}, p_{l_j}, \phi_j) \right)$$

$$= \sum_j G(p_{t_j}, p_{l_j}, m_W, \Gamma_W)$$

can be evaluated analytically !

The loop over production events is performed by

1. reading a production event,
2. computing $\sum_j G(p_{t_j}, p_{l_j}, m_W, \Gamma_W)$ ~overlap |b| the lepton & top momenta,
3. multiplying this overlap by the event weight and by the decayed ME over production ME

Formulation of the method

Advantages:

- FAST

Integration over the phase-space for production is optimized by considering a sample of unweighted events

Calculation of one weight (looping over100k LO production events, 0.5 - 1% accuracy) takes 8 seconds (on average)

- TH SYSTEMATICS EASILY INCLUDED

Uncertainties from variation of the scales available in the production event file, can be propagated to the weights at no cost

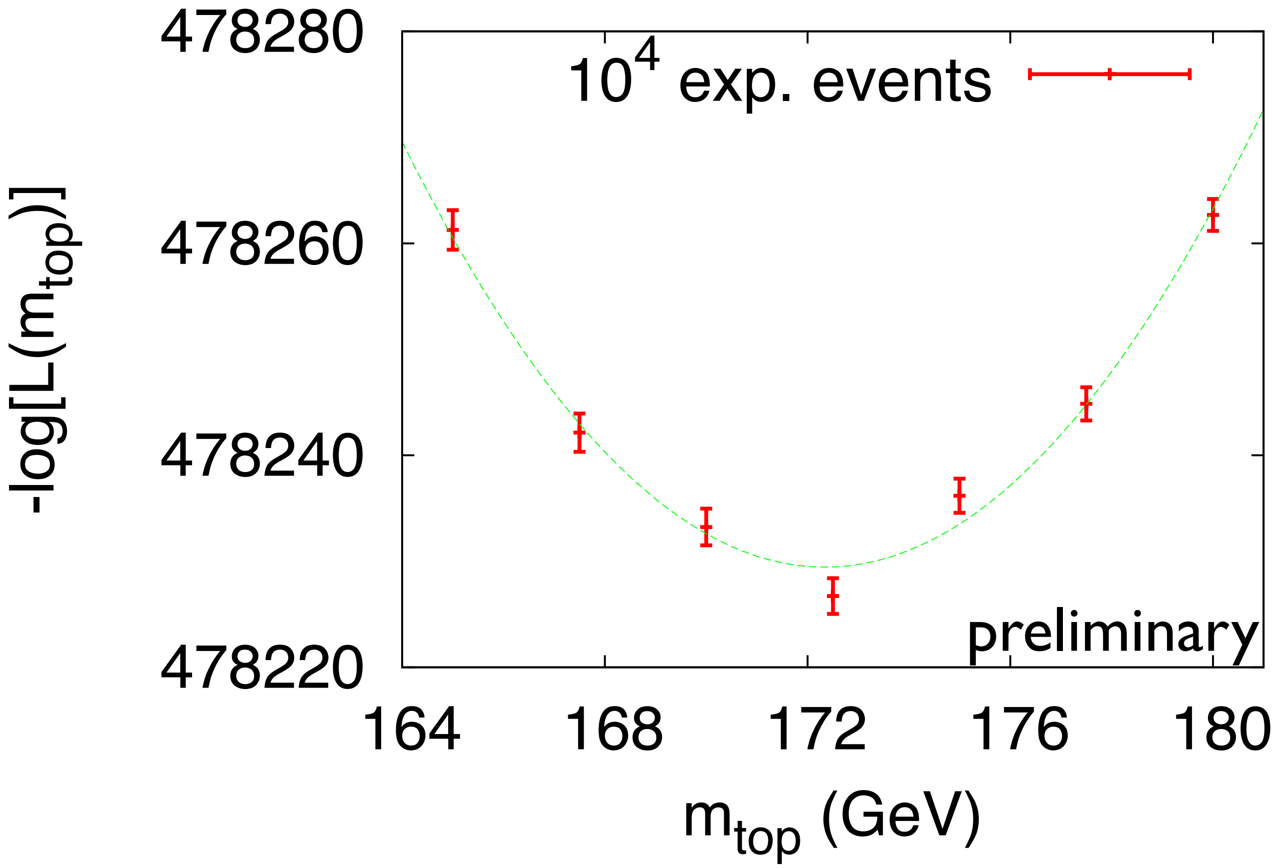
- CAN ACCOUNT FOR QCD CORRECTION (in the production)

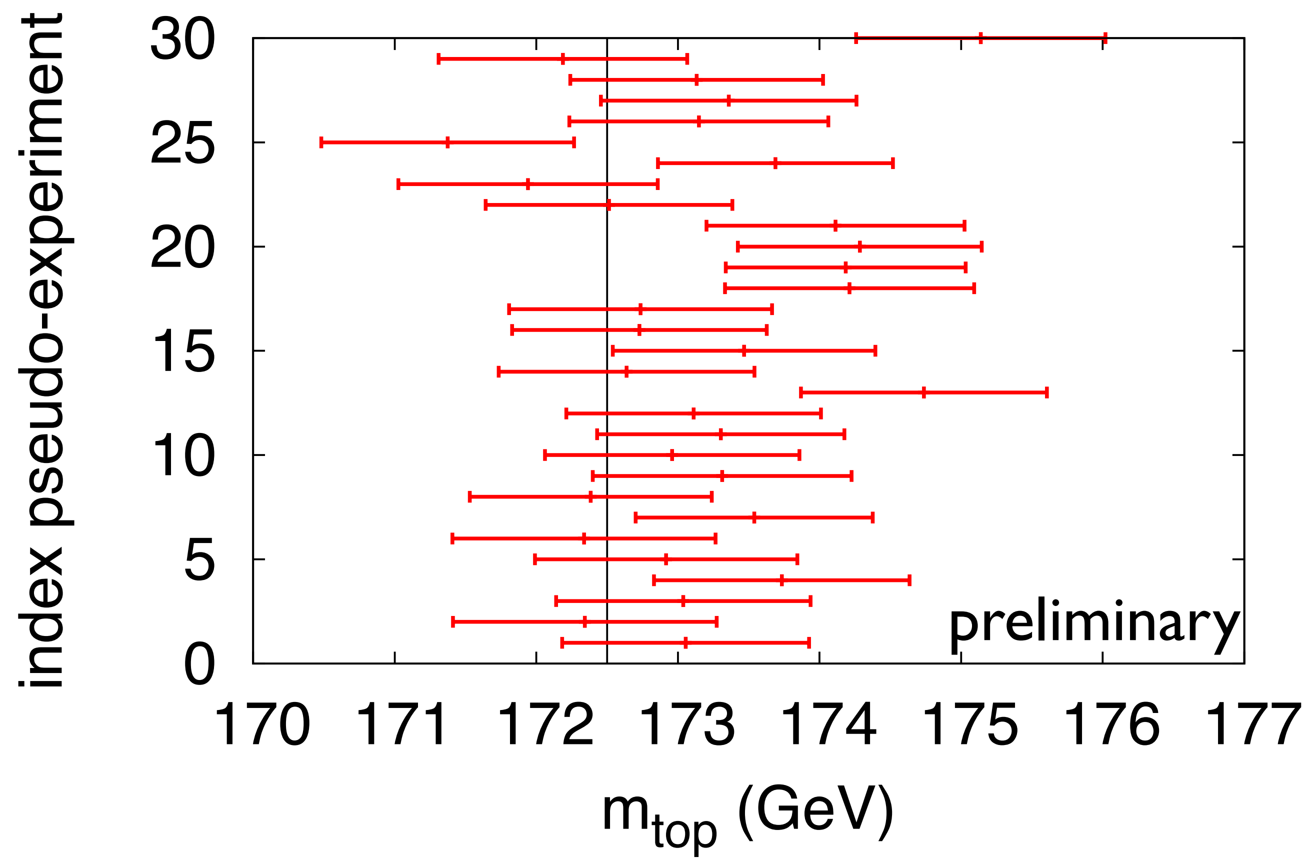
Simply loop over a sample of NLO production events

Application (LHC@13TeV)

30 pseudo-experiment samples of 10K events, no cut,

generated with m_{top}=172.5 GeV, at LO, no shower





small bias, need to be investigated

mean: 173.19 GeV

std: 0.82 GeV

Including shower effects

Parton shower impacts the kinematics of the top quarks, hence also the kinematics of the leptons

In our setup; such effects can be included by slightly modifying the previous prescription

For each production event,

1. read the momenta of the top quarks after shower $p_{t_1}^{\mathrm{sh}},\ p_{t_2}^{\mathrm{sh}}$
2. reconstruct the kinematics of the top quark decays from $p_{t_1}^{\mathrm{sh}},\ p_{t_2}^{\mathrm{sh}},\ p_{l_1},\ p_{l_2}$
3. boost the kinematics of each branch in a frame where the momenta of the top quarks match those of the "matrix-element event" (= event before the shower)
4. Use the matrix-element event to evaluate the ME's

Ongoing work

- Extend the analysis at NLO

  ⇨ loop over a sample of NLO production events

- Assess the sensitivity of the method w.r.t different production scheme (LO, LO +PS, LO merged samples with different parton multiplicities, NLO matched to PS)

  ⇨ loop over different samples of production events

- Assess the impact of cuts on the leptons and on the jets (ex: b-tagging effects)

  ⇨ reconstruction of m_{top} via a calibration procedure

- Assess the impact of systematic uncertainties

  ⇨ propagate the variation of the scales to the value of the weights and the likelihood

Conclusion

- In this talk we explored the use of MEM to measure m_{top} from dilepton top quark pair events using only the lepton information
- For this very specific case, reweighing events with matrix elements can be achieved by means of a new formulation for the calculation of the weights, that is faster and more appropriate to include QCD effects beyond leading order
- Beside its possible capabilities to improve the mass measurement of the top quark, this analysis represents an interesting case of study to assess the impact of QCD correction on the calculation of the weights
- Whether this option will deliver a competitive measurement of m_{top} remains to be established