Measuring CP violation on Top events with the Matrix Element Method

("Top B Physics at the LHC", accepted (PRL), arxiv:12124611)

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Outline

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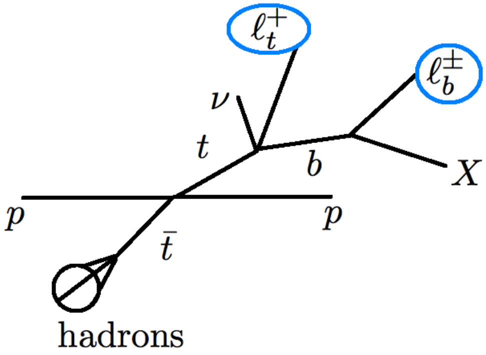
The measurement : B Physics with Top events

Introduction

- B-factories
  - Babar, Belle : Υ(4s) $\rightarrow b\bar{b}$
  - Tevatron, LHCb : g $\rightarrow b\bar{b}$
- Example from D0 experiment :
  - $p\bar{p}\rightarrow b\bar{b}\rightarrow\mu^{\pm}\ \mu^{\pm}$ (like-sign dimuon asymmetry)
  - like-sign dimuon asymmetry : $A_b^{sl} = \frac{N^{++}-N^{--}}{N^{++}+N^{--}}$
  - deviates 3.8 σ from Standard Model
- LHC is a top factory, and t decays 99% to Wb
  - LHC is a b-factory
  - use top event for flavor precision measurements
  - in particular, probe CPV in heavy flavor mixing and decays

General Idea



- $t\bar{t}$ semi-leptonic events for coherent production of b and $\bar{b}$:
- make use of leptonic top decay to tell the initial charge of the b (before oscillation)
  - hard lepton encodes top charge, hence initial b charge
  - soft lepton gives final b charge

Procedure

Two further steps :

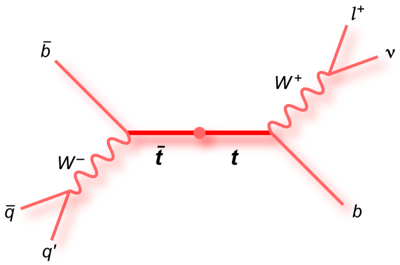
- match soft lepton with one b-jet or the other (not done here)
- associate b-jets with with one top leg or the other :
  - **b-Charge Association**

Then we can :

- count events of type ++, –, +-, -+ (lepton charges)
- form asymmetries quantities :
  - **mixing :** $A^{ss} = \frac{N^{++} - N^{--}}{N^{++} + N^{--}} \sim N(b \to \bar{b} \to \ell^{+}) - N(\bar{b} \to b \to \ell^{-})$
  - **direct :** $A^{os} = \frac{N^{+-} - N^{-+}}{N^{+-} + N^{-+}} \sim N(b \to \ell^{-}) - N(\bar{b} \to \ell^{+})$

b-charge Association

Framework

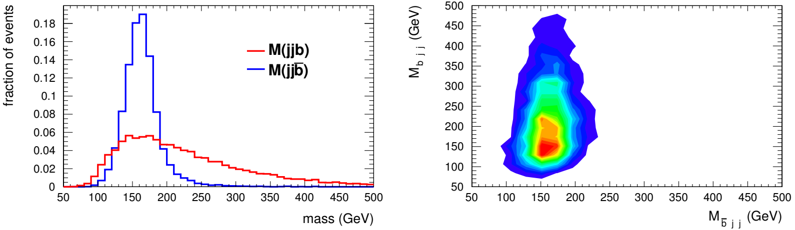


- MadGraph5+PYTHIA6
- DELPHES for fast detector simulation
- event selection :
  - at least one isolated lepton, $p_T > 20$ GeV
  - **two b-jets, (b_{max},b_{min})** , $p_T > 20$ GeV
  - at least two other jets (j_{max},j_{min}), $p_T > 20$ GeV

FIND OUT AMONG (b_{max},b_{min}) which is b and $\bar{b}$

Reconstructing Top (and W) mass

$$t\bar{t} \to \ell^+ \nu b, jj\bar{b}$$



- limited by jet energy resolution, need more sophisticated technique that takes into account all event kinematics
  - kinematic fit (cf. CMS-NOTE-2006-023)
  - matrix element method

MadWeight

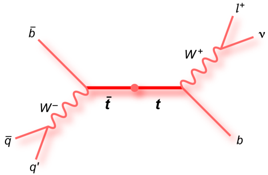
'Automation of the matrix element reweighting method'
(arXiv :1007.3300)

For each event, computes the probability that it originates from some process, defined by its born amplitude :

$$P(x) = \frac{1}{\sigma} \int dy |M(y)|^2 T(x|y)$$

- σ : effective cross section,
- M : born amplitude
- T : transfer function, gives probability of reconstructing particles of momenta x originating from parton level momenta y.

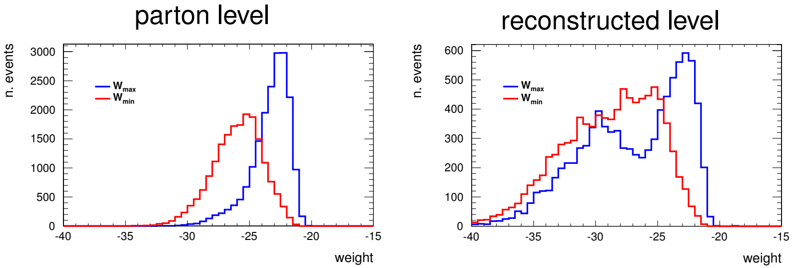
Extract permutation probabilities



- Transfer function : double gauss p_T for jet, δ function for leptons
- correct for ISR by boosting back in ref. frame where $p_T = 0$
- In previous formula, MadWeight averages over possible final state permutations
- We want to extract the probability of each permutation :
  - no ambiguity for ℓ and E_T^{miss}
  - b-jets ($\times 2$)
  - light jets ($\times 2$) $\rightarrow$ degenerate !

For each event, probabilities P_1 and P_2 of two possible choices of the b-charge can be computed.

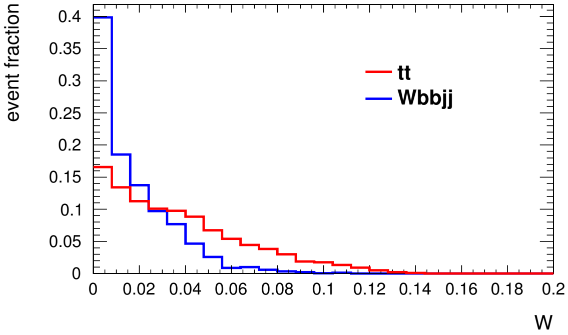
Permutation probabilities



- take four jets and lepton from hard scattering
- excellent discrimination between two assignments
- hardest reconstructed jets
- double peak structure : some assignments hard to discriminate

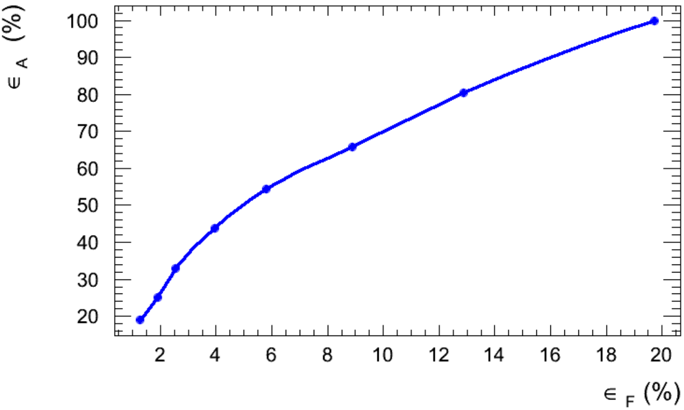
W variable

define $W = \left|\frac{P_1 - P_2}{P_1 + P_2}\right|$



- large values of W correspond to good discrimination between the two association hypothesis
- sample with correct association can be selected.
- bonus : background rejection ! !

Efficiency vs. charge mis-association rate



Can achieve $\leq$ 10% mis-association rate with $\approx$ 70% signal efficiency.

Conclusion and outlook

- With the help of Matrix Element Method, we have shown it is possible to almost unambiguously tag the charge of the b-jet in semi-leptonic top pair decays.
- This new technique is very promising, however :
  - needs to be checked with full simulation
  - validated with data (W variable)
  - check the effect of b-tagging mistag rate on misassociation rate
- Optimization and further studies :
  - study association of lepton with its b-jet
  - optimize transfer function (here trivial double gaussian)
  - quantitative study of backgrounds (other $t\bar{t}$, W+jets)
  - NLO corrections impact on the W variable
  - extend this study to the 1 b-jet sample (possibility to use MEM to b-tag second jet that failed b-tagging)

EXTEND THIS APPROACH TO COMBINATORIAL PROBLEMS
(e.g. ttH)

Backup

In practice in MadWeight ...

If option "bjet_is_jet" is set to F (false), MadWeight will compute 4 weights per event : w_A, w_B, w_C, w_D (accessible in the "vegas_value.out" file).

- look at one final state at a time (e.g. $e^+ jjbb$ MET)
- start with pure parton level (high Q^2 process, no PS, no hadronization)
- produce 2 .lhco files per event :
  - sequence e^+, j_1, j_2, b, and $\bar{b}$ (1)
  - sequence e^+, j_1, j_2, $\bar{b}$, and b (2)
- For both (1) and (2) there will be 2×2 groups of almost equal weights (since only permutation that matters is between b and $\bar{b}$), e.g $w_A \approx w_B$, $w_C \approx w_D$, or $w_A \approx w_C$, $w_B \approx w_D$.
- By comparing results from (1) and (2) it is possible to deduce which group corresponds to the correct pairing, and therefore which entry in the .lhco correspond to the b and $\bar{b}$.