In the year 2004 several milestones in the measurement of the top quark mass were reached. The DØ collaboration published a significant improvement of their Run I measurement of the top quark mass, and both Tevatron experiments released preliminary measurements based on Run II data sets collected in the period 2002-2004. The preliminary Run II results presented here do not yet surpass the current world average in precision, but this is expected to change soon. With larger data sets ready to be analyzed, a better understanding of the Run II detectors and improved analysis methods, 2005 promises to be a remarkable year for Top physics.

1 Introduction

The recent publication of the improved Run I measurement of the top mass by DØ was exciting for two reasons. First of all it demonstrated how much improvement in measurement precision could be achieved using a more advanced analysis technique like the Matrix Element method. Secondly, it was a reminder of how little we yet know about the properties of the top quark and that new experimental information about the top quark can have big implications for electroweak fits in the Standard Model. The current (Run I only) world average value for the top quark mass is $178.0 \pm 4.3$ GeV/$c^2$. In the coming years the measurements of CDF and DØ combined should lead to a precision of about 2 GeV. Together with expected improvements in the measurement of the W boson mass this will allow to further constrain the Higgs boson mass to a relative precision of approximately 30%, as discussed elsewhere in these proceedings.

Since the start of Run II both CDF and DØ have recorded more than 600 pb$^{-1}$ of data, already 5 times the Run I luminosity. The preliminary results presented here are based on fraction of the recorded data ranging from 160 to 230 pb$^{-1}$. 
Figure 1: Reconstructed mass distributions for the CDF di-lepton neutrino weighting analysis (left), and the DØ Template method with b-tagging (right).

2 Run II Top mass results

In $p\bar{p}$ collisions with $\sqrt{s} = 1.96$ TeV at the Tevatron, top quarks can be produced via the strong interaction in $t\bar{t}$ pairs, or as single top quarks through the weak interaction. Single top production is predicted to have a lower cross-section and a more challenging event signature, and has not yet been observed at the time of this conference. For the Top mass measurement therefore only top pair events are used. Each top quark decays immediately to a $W$ boson and a $b$ quark, and the $W$ bosons decay either hadronically or leptonically, giving rise to 3 possible decay channels: di-lepton, lepton+jets and all-jets.

An overview of recent $t\bar{t}$ cross-section results from the CDF and DØ experiments in all three of the above final states is given elsewhere in these proceedings. In both collaborations several top mass analyses are being developed in the di-lepton and lepton+jets decays channels, mostly based on very similar event selections. No preliminary Run II results in the all-jets channel have been presented so far.

A complete and up-to-date overview of ongoing Run II analyses can be found on the collaborations’ public results web pages. A description of all analyses is outside the scope of these proceedings. Below a few of the analyses are briefly described in order to highlight some important aspects of the top mass measurement.

2.1 Final states with two leptons plus jets

The striking signature due to the presence of two leptons in the final state allows for a relatively pure selection of top events, typically with a signal-to-background ratio of 4/1. The main challenge however is to fully reconstruct the kinematics of the final state, which are underconstrained due to the presence of two neutrinos. Different approaches exist to add an extra constraint to the system, and see for which value of the top mass the observed events are most likely.

In Table 1 several Run II analyses are listed with their preliminary results. Currently the most precise result was obtained by CDF with the neutrino weighting analysis using a loosened lepton identification (one lepton + one isolated track), optimizing the statistical precision by using a higher efficiency (and slightly lower purity) selection. In this method the rapidities of both neutrinos are used as extra constraints, and a weight as function of the top mass is calculated by integrating over all possible rapidity values and comparing the reconstructed missing transverse momentum with the observed momentum imbalance using a Gaussian resolution. For each event the top mass value which leads to the highest weight is plotted and fitted using Monte Carlo Templates, as shown in Figure 1.
Table 1: Overview of preliminary Run II top mass results

|                          | data set (pb$^{-1}$) | top mass (GeV/c$^2$) |
|--------------------------|----------------------|----------------------|
| **di-lepton channel**    |                      |                      |
| CDF neutrino-weighting   | 200                  | 168.1$^{+11}_{-9.8}$ (stat) ± 8.6 (sys) |
| CDF $M_{reco}$ Template + $t\bar{t}$ $p_z$ | 194                  | 176.5$^{+17.2}_{-16.0}$ (stat) ± 6.9 (sys) |
| CDF $M_{reco}$ Template + $\phi$ of $\nu_1$ and $\nu_2$ | 194                  | 170.0 ± 16.6 (stat) ± 7.4 (sys) |
| DØ Dalitz and Goldstein  | 230                  | 155$^{+14}_{-13}$ (stat) ± 7 (sys) |
| **lepton+jets channel**  |                      |                      |
| CDF Template with b-tagging | 162-193             | 177.2$^{+4.9}_{-4.7}$ (stat) ± 6.6 (sys) |
| CDF Multi-Variate Template | 162                | 179.6$^{+6.4}_{-6.3}$ (stat) ± 6.8 (sys) |
| CDF Dynamic Likelihood   | 162                  | 177.8$^{+5.5}_{-5.0}$ (stat) ± 6.2 (sys) |
| DØ Ideogram              | 160                  | 177.5 ± 5.8 (stat) ± 7.1 (sys) |
| DØ Template topological  | 230                  | 169.9 ± 5.8 (stat)$^{+7.8}_{-7.1}$ (sys) |
| DØ Template with b-tagging | 230                | 170.6 ± 4.2 (stat) ± 6.0 (sys) |

2.2 Final states with one lepton plus jets

While the lepton+jets channel benefits from a higher branching ratio, it suffers from significant backgrounds from $W+$jets and non-$W$ multi-jet events.

Since only one neutrino is present the final state can be fully reconstructed. Some analyses use a constrained kinematic fit to further improve the measurement of lepton and jets beyond detector resolution. The CDF Dynamic Likelihood Method (DLM) follows a different approach, similar to the DØ Matrix Element method$^1$, transfer functions are derived from Monte Carlo simulation describing the jet energy resolution. These functions are subsequently used in a multi-dimensional integration over phase space calculating the likelihood that the event is compatible with matrix elements describing top pair production and decay.

In order to reconstruct the invariant mass of the top decay products, a choice has to be made to assign jets and lepton to the corresponding top or anti-top quark. In a lepton+jets event 12 ways exist to do this assignment. Some analyses take only one jet assignment per event in consideration. The CDF Dynamic Likelihood Method and the DØ Ideogram analysis include all possible jet assignments in the fit.

The CDF and DØ template methods use an overall fit of Monte Carlo templates to the data in order to extract the mass. The CDF Dynamic Likelihood Method and DØ Ideogram analysis derive an event-by-event likelihood to maximize the statistical information extracted from each event. The Ideogram method also includes the hypothesis that the event could be background, weighted according to an estimated event purity.

Both experiments apply b-tagging in some of the top mass analyses. One advantage of b-tagging is to strongly reduce the backgrounds. A second advantage of b-tagging for the top mass measurement in the lepton+jets channel is the reduction of the number of possible jet assignments in the case that one or two jets are b-tagged. The CDF Template analysis combines the 0-tag, 1-tag and double tagged event samples in the fit to optimize the statistical precision. DØ’s first top mass analysis with b-tagging uses events with at least one tag, which applied to a data set of 230 pb$^{-1}$ leads to the most precise preliminary Run II top mass result presented so far. Figure$^1$ shows the fitted mass for the lowest-$\chi^2$ solution for the b-tagged DØ Template
analysis, compared to the Monte Carlo prediction.

An overview of the current preliminary results is shown in Table I.

3 Prospects for the Top mass measurement

In all results reported here the dominant component of the systematic uncertainty is the uncertainties related to the jet energy scale. In the last year a lot of work has been done to improve the calibration of the reconstructed jet energies. CDF reports an improvement of a factor two or more in jet energy scale uncertainties compared to a year ago. Similar improvements are expected in DØ. This will have a direct effect on the systematic uncertainties quoted.

Further improvements in understanding the Jet Energy Scale can come from performing an in-situ calibration of the light-jet energy scale using the jets from the hadronic decay of the $W$ in the same $t\bar{t}$ events used to measure the top mass, and from studies in progress aimed at determining the b-jet energy scale from data.

Other systematics that are being studied are the modeling of initial state and final state gluon radiation in the $t\bar{t}$ Monte Carlo.

Very soon both experiments hope to present preliminary results with updated jet energy scale and an integrated luminosity of more than 300 pb$^{-1}$.

All together the prospects are very good for having new top mass results this year with a precision comparable to or better than the current world average for each of the Tevatron experiments. This will open the door to an exciting new area of top physics to be further explored in the coming years at the Tevatron.

References

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