First Multi-dimensional Top Quark Mass Measurement on D0 Data

P. Haefner, F. Fiedler, O. Biebel, P. Calfayan, A. Grohsjean, T. Nunnemann, M.P. Sanders, D. Schaile, R. Ströhmer, and B. Tiller

Top pair production with a semileptonic decay $t\bar{t} \rightarrow W^{\pm}W^{\mp}\, b\bar{b} \rightarrow q\bar{q}\, l\nu\, b\bar{b}$ is the "golden channel" for mass measurements, due to a large branching fraction and a relatively low background contamination compared to other decay channels. Top mass measurements based on this decay, performed with the matrix element method, have always been among the single best measurements in the world. In 2007, the top mass world average broke the 1% level of precision. Its measurement is no longer dominated by statistical but instead by systematic uncertainties. The reduction of systematic uncertainties has therefore become a key issue for further progress.

This work introduces two new developments in the treatment of b jets. The first improvement is an optimization in the way b identification information is used. It is described in detail in [1,2]. It leads to an enhanced separation between signal and background processes and reduces the statistical uncertainty by about 16%. The second improvement determines differences in the detector response and thus the energy scales of light jets and b jets (cf. [1,3]). Thereby, it addresses the major source of systematic uncertainty in the latest top mass measurements (see below).

After validation on Monte Carlo events at the generator level and calibration with fully simulated events, this improved matrix element method has been applied to data for the first time. The full D0 Run IIa data set corresponding to about 1 fb^{-1} of integrated luminosity was used. A total of 543 events were selected with about equal contributions from the e+jets and μ+jets decay channels. The signal fraction in the full l+jets sample was measured to be $f_{sig} = (35.2 \pm 2.4)\%$.

So far, only a general jet energy scale (JES) is derived at D0 and effects of differences in b and light quark jets, e.g. particle composition, are not considered. As each $t\bar{t}$ event contains two b quarks this is a large source of uncertainty. Therefore, this analysis employs a method, similar to the one that was applied to reduce the general JES error. In addition to a variation of the assumed top mass, the matrix element method probability calculation includes assumptions on JES and b-JES scale factors (s_{jes}, s_{bjes}). A three-dimensional likelihood fit (3D) is performed to extract the most likely values of all three observables at once. The measurement of the jet energy scales yields:

$$s_{jes} = 1.038 \pm 0.023 \qquad (1)$$

$$s_{bjes} = 1.056 \pm 0.045\,, \qquad (2)$$

indicating that the nominal D0 jet energy scale derived from γ+jets events slightly underestimates the energy of both types of jets in $t\bar{t}$ decays.

For the top mass measurement different possible sources of systematic uncertainties were studied [1]. Including these, the top mass is measured to be:

$$m_t = (169.2 \pm 3.5\,(stat.) \pm 1.0\,(syst.))\ \mathrm{GeV}\,. \qquad (3)$$

Fig. 1 compares this result to top mass measurements contributing to the world average as of March 2008 [4]. It can be seen that it agrees very well with the world average and is competitive with the current best measurements. The analysis labelled D0-II l+j/a* is a measurement on the same data set with the same method but only fitting the two observables m_t and s_{jes}. As expected, the uncertainty of the 3D measurement presented here is slightly larger due to the larger statistical uncertainty. Nevertheless, the systematic uncertainty due to the b jet energy scale could be reduced from 800 MeV to 150 MeV, which was the goal of the three dimensional fit. As of now, more than 4 fb^{-1} have already been recorded by D0. This means four times the statistics analyzed here is readily available. With the plan to double this amount of data again before the end of the Tevatron run, there are good prospects to reduce the statistical uncer tainty by a factor of about three. For this analysis, the statistical uncertainty would then decrease to about 1 GeV. If no further improvements concerning the method were developed, the systematic uncertainty would stay in the same range. According to this conservative estimate, it will be possible to determine the top mass with less than 1% total precision in a single measurement.

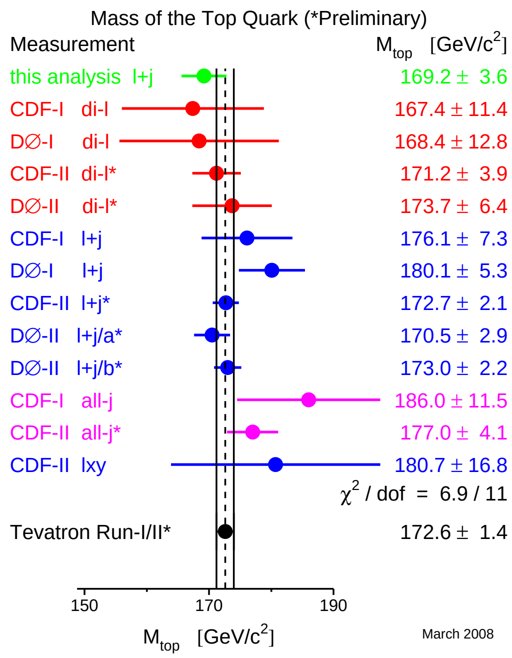

Fig. 1: Comparison of the top quark measurement of this analysis to measurements contributing to the top mass world average as of March 2008 [4]. Preliminary and published analyses of CDF and D0 in various channels contribute.

References

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[3] P. Haefner *et al.*, Annual report 2007, p. 36.
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