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PROCEEDINGS OF SCIENCE

TOP-MASS MEASUREMENTS FROM D0

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We present three recent analyses (Abstracts 169, 170 and 174) of the mass of the top quark (M_t) using top-antitop candidate events collected by the D0 experiment at the Fermilab Tevatron Collider: (i) a 3.6 events/fb sample of data in the lepton+jets channel analyzed to extract a precision value of M_t using the "Matrix-Element" (ME) method, wherein each event probability is calculated from the differential production cross section as a function of M_t and the overall jet energy scale, with the latter constrained by the two jets from W decay into $q'\bar{q}$, (ii) a first measurement of the mass difference between top and antitop quarks as a check of CPT invariance in the quark sector, also based on the ME method in lepton+jets channels, and corresponding to a 1 event/fb data sample, and (iii) measurements of M_t in dilepton final states (updated to 3.6 events/fb), based on "matrix" weighting, "neutrino" weighting and the ME method, which rely, respectively, on the likelihood of observing the events in data for a range of assumed M_t values, distributions generated from event weights that compare calculated and reconstructed missing transverse energies, and event probabilities based on the leading-order differential cross section as a function of assumed M_t. In addition, we provide a combination of recent top-mass measurements from D0.

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We report three analyses of the mass of the top quark (M_t) using top-antitop candidate events collected by the D0 experiment at the Tevatron Collider. The t ($\bar{t}$) quarks decay to W^+b ($W^-\bar{b}$), with both b quarks evolving into jets, and W decaying to $\ell\nu_\ell$ or $q'\bar{q}$: (i) a 3.6 events/fb data sample in lepton+jets channels (with one $W \to \ell\nu_\ell$ and the other $W \to q'\bar{q}$), analyzed to extract a precision value of M_t using the "matrix-element" method (ME), wherein each event probability is calculated from the differential production cross section for signal ($t\bar{t}$) and background (W+jets), as a function of M_t and an overall jet energy scale (JES), with the latter constrained by the two jets from W $\to q'\bar{q}$ decays from one of the top quarks; (ii) a measurement of the mass difference between top and antitop quarks (Δ), as a first direct check of CPT invariance in the quark sector, utilizing the ME method in lepton+jets channels, but for a smaller 1 event/fb data sample (from "Run 2a"); and (iii) measurements of M_t in dilepton final states (both W decaying to $\ell\nu_\ell$, with the eμ sample updated to 3.6 events/fb), based on analyses using "matrix" weighting, "neutrino" weighting and the ME method, relying, respectively, on: (1) a likelihood for observing events in data for a range of assumed M_t values, (2) distributions generated from event weights that compare the calculated and reconstructed missing transverse energies, and (3) event probabilities for the eμ channel based on the leading-order (LO) differential cross section as a function of assumed M_t, with Z($\tau\tau$)+jets serving as background for the ME analysis.

Selections for lepton+jets events, where lepton (ℓ) refers to either electron (e) or muon (μ) are by now relatively standard, and optimized to minimize background (from multijets and W+jets), without adversely affecting signal efficiency: (i) backgrounds and kinematics set the requirements for the energy scale typically at > 20 GeV for jets and isolated leptons, as well as for the imbalance in transverse momentum (MET), with the latter expected from the presence of undetected neutrinos, (ii) accepted ℓ+jets events must have only four jets (exclusively), of which at least one must be a b-tagged jet, and (iii) a neural-network-based discriminant that provides a probability for tagging any observed jet as a b-jet is used to sharpen the analysis.

Selection of dilepton+jets events is also straightforward, but since dilepton channels are cleaner than ℓ+jets, there is more flexibility in playing off rejection of background against acceptance of signal. Thus, we require: (i) either two good leptons or one good lepton and an isolated track (but only if there is a b-tagged jet) and at least two jets (not necessarily b-tagged), (ii) the two leptons (or lepton and isolated track) must have opposite electric charge, (iii) the lepton energy scale is set lower for all dileptons (> 15 GeV) than in ℓ+jets, and (iv) additional criteria on MET and $M_{\ell\ell}$ to minimize background from Z+jets for ee and $\mu\mu$ events, and a large value for the sum of transverse energies for the jets and the leading-ℓ for $e\mu$ events.

All analyses rely on calibrations of response based on sets of simulated signal and background events. Such events are generated for fixed values of input parameters (e.g., mass values, assumed helicities, etc.) and processed through the same D0 reconstruction and analysis packages as applied to data. Specifically, ensembles of sets of Monte Carlo (MC) events from signal and background contributions, each set corresponding to a "pseudo-experiment," are studied to calibrate (and to correct) the extracted values of parameters and their uncertainties.

The MC events are usually generated using leading-order (LO) ALPGEN or PYTHIA programs, with PYTHIA also used to evolve partons to jets. The analysis is carried out on MC events using the same procedure applied to data in order to check for biases in the extracted parameters and their uncertainties. The parameters and their uncertainties extracted from data are then corrected for any biases. The uncertainties on such parameters are corrected using the observed "pull widths" in the MC relative to expectations of purely Gaussian behavior.

In the ME approach, transfer functions, calculated through fits to separate samples of MC events, are used to correlate energies of reconstructed jets with those of their progenitor partons. Since LO matrix elements are used in the ME analyses, exclusively 4 jets are required in ℓ+jets, and 2 jets in dilepton+jets events, to minimize the impact of higher-order QCD corrections on these analyses. The ME for signal is based only on $q\bar{q} \to t\bar{t}$, and ME for background uses LO VECBOS (for W+jets and Z+jets). (Additional information on these analyses can be found in Ref. [1], and in the plenary summary of C. Schwanenberger, and, for Abstract 170, in the Poster section of these Proceedings.)

In the ME analysis, event probability densities for different values of the mass for top and antitop quarks, for signal fraction f, with $A(x)$ signifying the acceptance, can be written as:

$$P_{evt}(x; M_t, M_{\bar{t}}, f) = A(x)[f P_{sig}(x; M_t, M_{\bar{t}}) + (1-f) P_{bkg}(x)]$$

This is identical to what is used for the assumption of equality of masses, except that the two parameters (M_{top}, JES) in that standard analysis are replaced here with ($M_t, M_{\bar{t}}$). The signal probability densities are calculated from the differential cross section for $t\bar{t}$ production and decay, using a modified version of PYTHIA that provides different values for $M_{\bar{t}}$ and M_t:

$$P_{sig}(x; M_t, M_{\bar{t}}) = \frac{d\sigma(x; M_t, M_{\bar{t}})}{\sigma_{obs}(M_t, M_{\bar{t}})} = \frac{1}{\sigma_{obs}(M_t, M_{\bar{t}})} \times \int d\sigma(y) dq_1 dq_2 f(q_1) f(q_2) W(y, x)$$

where x represents observed jet variables (angles, energies, etc), and y their nascent partonic values, and $W(y,x)$ is a transfer function, based on Monte Carlo that relates the two, with the differential cross section given by:

$$d\sigma = \frac{(2\pi)^4 |M|^2}{4\sqrt{q_1 \cdot q_2 - m_1 m_2}} d\Phi_6$$

where M is the LO matrix element for any process, with that for background not dependent on M_t (e.g., from VECBOS). After integrating over phase space, the product of n event probabilities defines a likelihood function in terms of the observables and the parameters of interest:

$$L(x_1 \dots x_n; M_{top}) = \prod_{i=1}^{n} P_{evt}(x_i; M_{top})$$

L maximized over f provides an estimate of the most likely values of any remaining parameters as well as their uncertainties.

Figure 1(a) displays the calibrated result of the precision mass analysis in ℓ+jets as a function of M_{top} and JES, with the JES prior constrained by the mass of W in $W \to q'\bar{q}$ and the accepted value of M_W. Figure 1(b) shows the projection of $L(M_{top}$, JES) onto the M_{top} axis. Uncertainties have already been corrected for small departures of pull widths from unity, and agree with expectations from ensemble studies. The precision of this measurement is limited mainly by theoretical and experimental systematic uncertainties.

Figure 2 shows the results of the mass analysis performed to extract Δ as a function of the two masses, based on the JES derived from a previous extraction of the mass that assumed same

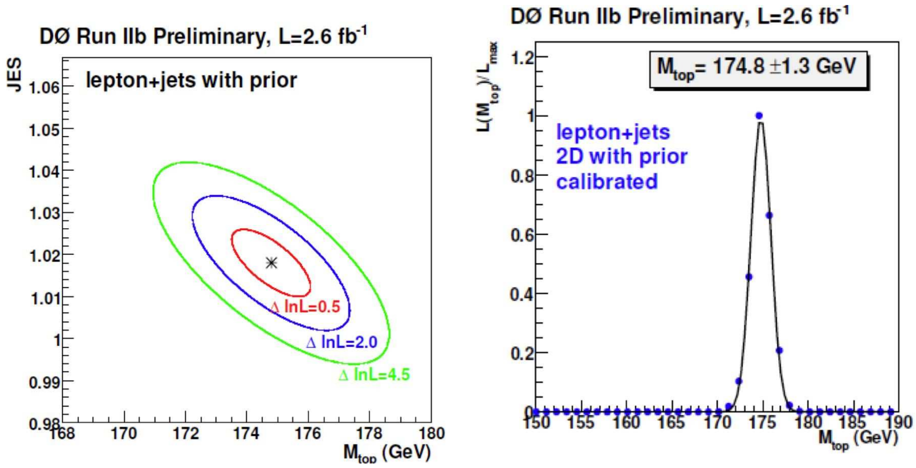

Figure 1: $L(M_{top}$, JES) for the precision mass analysis and its projection on the M_{top} axis (see text).

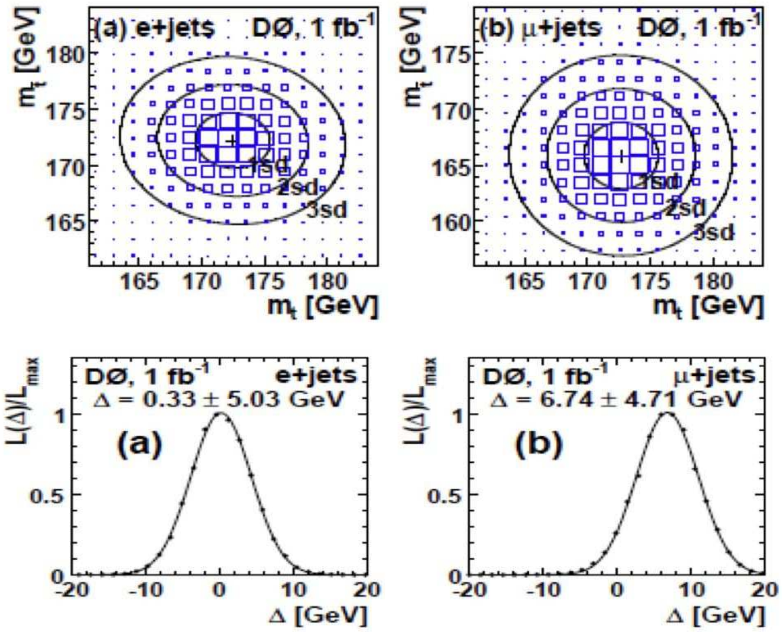

Figure 2: $L(M_t, M_{\bar{t}})$ and Δ as a function of the two masses for e+jets and μ+jets.

values of antitop and top mass. The small correlation in the fit to data is not significant, and results from e+jets and μ+jets agree. The 2-dimensional likelihood fit is integrated along the diagonal axes. One yields Δ (shown in Fig. 2), and the other the mean of $\frac{1}{2}(M_t + M_{\bar{t}})$. The latter agrees with the single mass extracted in a previous study, and Δ is consistent with no mass difference between antitop and top quarks.

Figure 3 shows the application of the ME method to Run 2a (left) and Run 2b (right) for the eμ channel (before calibration). The combined analysis of all dilepton channels now yields a highly precise value of 174.7±3.8 GeV, with comparable contributions from systematic and statistical uncertainties. Figure 4(a) provides the result of extracting the mass of the top quark from the

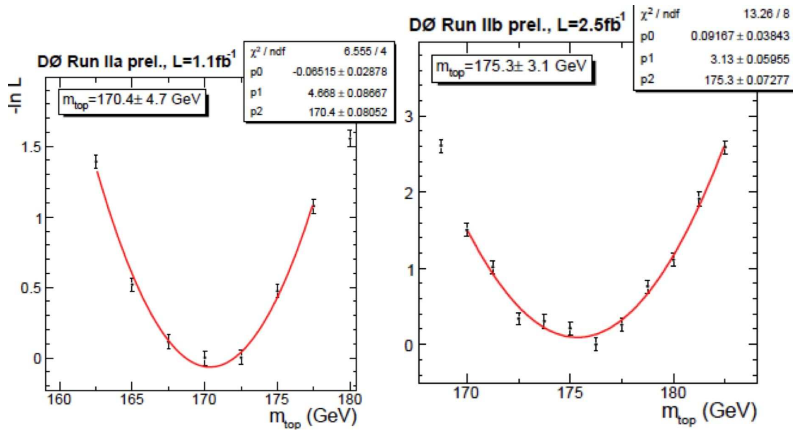

Figure 3: Application of the ME method to Run 2a (left) and Run 2b (right) data for the eμ channel (prior to calibration).

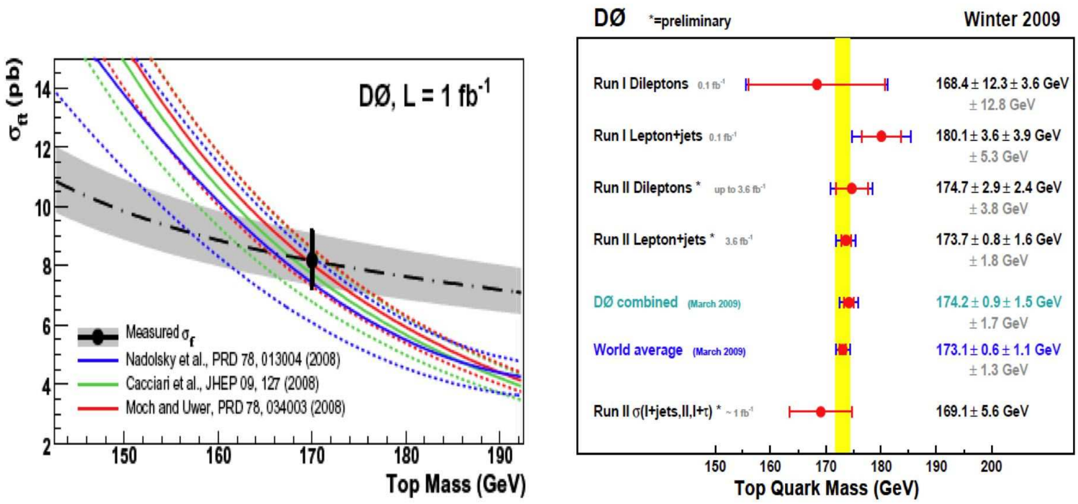

Figure 4: The pole mass of the top quark obtained from a comparison of the observed cross section for $t\bar{t}$ production with NNLL corrections to NNLO QCD of Moch et al (left). A recent summary of the mass measurements from D0 is given on the right.

observed cross section for $t\bar{t}$ production, and indicates that the pole mass from that comparison agrees with the value obtained using LO generators to $\approx 3\%$ uncertainty. Finally, we provide a recent summary of the mass measurements in Fig. 4(b), which along with the value of $\Delta = 3.8 \pm 3.7$ GeV comprise the latest such results from D0.

References

[1] V. M. Abazov et al., Precise measurement of the top-quark mass from lepton+jets, Phys. Rev. Lett. **101**, 182001 (2008); *ibid*, Direct measurement of mass difference between top and antitop quarks, arXiv.org:0906.1172, submitted to Phys. Rev. Lett. (June 2009); *ibid*, Measurement of top-quark mass in final states with two leptons arXiv.org:0904.3195, submitted to Phys. Rev. D (April 2009); *ibid*, Measurement of the $t\bar{t}$ production cross section and top quark mass extraction using dilepton events arXiv.org:0901.2137, accepted by Phys. Lett. B (July 2009)