Recent top quark results from D0
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Abstract

We present two preliminary results: a model-independent measurement of $W$ boson helicity in top quark decays, and a measurement of the top quark mass. Both measurements update previously published D0 results by including over twice the data.

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1. Introduction

The top quark, discovered in 1995 by the CDF and D0 collaborations at the Fermilab Tevatron Collider, is by far the heaviest of the elementary quanta in the standard model of particle physics (SM). Its large mass results in a lifetime of only $\approx 5 \cdot 10^{-25}$ s, smaller than the typical hadronization time of $3 \cdot 10^{-24}$ s. Thus the top quark is the only quark that decays before hadronization, and out of the large program of top pair measurements pursued in D0, we present the preliminary results of two such “bare” top quark measurements: a measurement of $W$ boson helicity in top quark decays, and a measurement of the top quark mass. Both measurements were preceded by published analyses [1,2] based on 1 fb$^{-1}$ of data collected before the 2006 upgrade of the D0 detector.

2. A model-independent measurement of $W$ boson helicity in top quark decays

The standard model (SM) predicts that $B(t \rightarrow bW) \approx 100\%$. Breaking this down by the $W$ boson’s helicity eigenvalues, the SM predictions are $f_+ = 0.1\%$, $f_0 = 69.6\%$, and $f_- = 1 - f_+ - f_0 = 30.3\%$ [3], which are the fractions of right-handed, longitudinally-polarized and left-handed $W$ bosons produced, respectively. The D0 collaboration recently released preliminary results [4] from a simultaneous measurement of $f_+$ and $f_0$, that provide a model-independent test of the SM predictions.
We select events in the "l + jets" channel with \( \geq 4 \) jets with transverse momentum \( p_T > 20 \text{ GeV} \), and with an isolated electron or muon of \( p_T > 20 \text{ GeV} \) and absolute pseudorapidity \( |\eta| < 1.1(e) \) or 2.0(\( \mu \)). We also require that the missing transverse energy \( E_T > 20 \text{ GeV} \), and that it is not along the azimuth of the lepton. We also select events in the \( e\mu \) channel, requiring \( \geq 2 \) jets and that the leptons are isolated and have opposite electric charge. The compositions of the selected samples are shown in Fig. 1, where the sample components with a lepton from \( W \) decay were modeled using Monte Carlo simulation and normalized using discriminants based on kinematic and \( b \)-quark identification variables, while the fake lepton components were modeled using auxiliary data samples.

We distinguish between helicity states by reconstructing the angle between the up-type decay product and the incoming top quark in the \( W \) boson's rest frame, \( \theta^* \)(see Fig. 2). In the \( l + jets \) channel we do so using a kinematic fitter which varies the four-momenta of the detected objects within their experimental resolutions and minimizes a \( \chi^2 \) statistic within the constraints \( M_W = 80.4 \text{ GeV} \) and \( m_t = 172.5 \text{ GeV} \). In the \( e\mu \) channel we account for the resolutions using a statistical procedure.

Combining with the results from Ref. [1], we find using 2.2–2.7 fb\(^{-1}\) of D0 data that \( f_0 = 0.490 \pm 0.106 \text{ (stat.)} \pm 0.085 \text{ (syst.)} \) and \( f_+ = 0.110 \pm 0.059 \text{ (stat.)} \pm 0.052 \text{ (syst.)} \). We note that the results from the two channels are only consistent at the 1.6% level.

3. Top quark mass

The top quark mass is measured in the \( l + jets \) channel. The event selection is similar to that above, but also requires that exactly four jets are selected, of which at least one
is identified as a $b$ jet. The main observable is the three-jet invariant mass, which is very sensitive to uncertainties on the jet energy calibration. Hence the dijet invariant mass peak around $M_{WW}$ is used to fit the overall jet energy scale (JES). The mass is extracted using the “matrix element method” which aims to fully use the measured four vectors, $x$, in each event when calculating the sample likelihood as a function of $m_t$ and JES. This is achieved by estimating an event’s likelihood under the signal hypothesis and a particular jet-to-parton assignment, $\alpha$, using the leading order matrix element, $M$, as follows:

$$P_{t\bar{t},\alpha}(x \mid m_t, \text{JES}) = \frac{1}{\sigma_{tt}(m_t)} \int dq_1 dq_2 f(q_1) f(q_2) d\sigma(y \mid m_t) T(x \mid y, \alpha, \text{JES}),$$

(1)

where $P$ is the event probability, $\sigma_{tt}$ is the total effective cross section which normalizes the probability taking into account experimental acceptance and efficiencies, $q$ are the longitudinal momenta fractions of the incoming partons and $f$ the corresponding parton density functions, $d\sigma(y \mid m_t) \propto |M|^2$ is the differential production cross section, and $T(x \mid y, \alpha, \text{JES})$ is the probability to measure $x$ given the parton-level four vectors $y$.

The method is calibrated using an ensemble of simulated datasets. The calibration accounts for biases due to the approximations used in calculating the likelihood. Both the mean mass and its statistical uncertainty are calibrated, yielding the preliminary results shown in Fig. 4 [5]. Combining with the results from Ref. [2], we find using $2.2 \text{ fb}^{-1}$ of D0 data that $m_t = (172.2 \pm 1.0 \text{ (stat.)} \pm 1.4 \text{ (syst.)) GeV.}$

References