CDF/PUB/TOP/PUBLIC/9939

Exclusion of Exotic Top-like Quark with $-4/3$ Electric Charge Using Soft Lepton Tags

The CDF Collaboration
URL *http://www-cdf.fnal.gov*
(Dated: January 11, 2010)

We present a measurement of the electric charge of the top quark using 2.7 fb^{-1} of $p\bar{p}$ collisions at the CDF detector. We reconstruct $t\bar{t}$ events in the lepton+jets final state, and use kinematic information to determine which b-jet is associated with the leptonically or hadronically decaying t-quark. Soft lepton taggers are used to determine the b-jet charge. Along with the charge of the W lepton, this information permits the reconstruction of the top quark's electric charge. Out of 45 total reconstructed events with ~ 2 expected background events, 29 are reconstructed as $t\bar{t}$ with the Standard Model $+2/3$ charge, whereas only 16 admit an open exotic $-4/3$ possibility. This excludes the exotic scenario at 95% Confidence Level.

I. INTRODUCTION

Since the discovery the top quark in 1995 [1], the CDF and DØ collaborations have scrutinized its properties. Measurements of the production cross section [2], mass [3], and kinematics [4] all present a consistent picture of top as the third generation Standard Model (SM) isospin partner of the bottom. Still remaining to be determined is the electric charge of the top quark, which is expected by the SM to be $+2/3$ although an exotic $-4/3$ possibility [5] $-$ where the top decays into the wrong signed W and a SM b-quark $-$ remains open. In this scenario, the observed excess traditionally attributed to the SM top, is attributed to a different particle, called 'XM top,' and the true SM top is massive enough to escape detection.

In this paper, we measure the electric charge of the top quark by reconstructing $t\bar{t}$ pairs in the $\ell\nu b\,jjb$ final state, where one W boson decays leptonically and the other hadronically. The b-quark associated with each W is called the 'leptonic' b-quark and 'hadronic' b-quark, respectively. Reconstructing the charge of the top quark involves i) identifying either the leptonic or hadronic b and ii) determining its flavor, either b or $\bar{b}$ [6]. We use a soft electron tagger (SLT$_\mathrm{e}$) [7], a soft muon tagger (SLT$_\mu$) [8], and a secondary vertex tagger (SecVtx) [9] to identify the b-jets. A kinematic fitter [10] is used to determine which b-jet is leptonic and which is hadronic. The SLT taggers are also used to determine the b-jet flavor, since the flavor is preserved through the semileptonic decay, $b \to \ell^- \bar{\nu} X$. Each event is considered SM if the charge of W lepton and the charge of the leptonic (hadronic) b-jet are the opposite (same). The event is considered XM if it is otherwise. This binary event reconstruction implies that if both the kinematic fitter and the SLT tagger are incorrect, then the correct top charge is still reconstructed. The purity of the SLT taggers at flavor reconstruction is approximately 71%, and the purity of the fitter at kinematic reconstruction is approximately 76%; therefore, this method correctly reconstructs the top charge in 61% of events.

This technique complements the measurement of the top charge in Ref. [11] which uses a $\mathrm{p_T}$ and charge weighted average of the tracks in a b-jet to determine its charge. The SLT method is much less efficient since the semileptonic branching fraction for b-jets is only approximately 10%; however, the charge determination is much more pure. Since this measurement is essentially an asymmetry measurement, the relevant figure of merit for the sensitivity is ϵD^2, where ϵ is the reconstruction efficiency, $D = 2P - 1$ is the dilution, and P is the purity. We estimate that for the same event reconstruction, our method is only a factor of 2-3 less sensitive, despite the significant loss of efficiency due to the soft lepton requirement. For this paper, we collect data corresponding to an integrated luminosity of 2.7 fb^{-1}, gathered from February 2002 to April 2008.

II. DETECTOR

The CDF detector is an azimuthally and forward-background symmetric general-purpose detector with silicon tracking [12] and drift chamber tracking [13] immersed in a 1.4 T solenoidal magnetic field. The entire silicon tracker is comprised of 8 layers in the radial range of 1.5 to 28 cm of mostly double-sided silicon, which allows precise reconstruction of the primary vertex and other secondary vertices. The drift chamber consists of 96 layers of sense wires covering a radial range from 40 to 140 cm, which - when combined with the silicon detector - provides excellent tracking and $\mathrm{p_T}$ resolution. Projective electromagnetic and hadronic sampling calorimeters [14] lie beyond the solenoid, providing jet and missing E_T ($\not\!\!E_\mathrm{T}$) reconstruction. The calorimeter towers are finely segmented in the central ($|\eta| \leq 1.1$) region [15] allowing reconstruction of electrons. Muon chambers [16] lie beyond the calorimeter providing coverage up to $|\eta| \leq 1.0$. Gaseous Cherenkov counters [17] measure the average number of inelastic $p\bar{p}$ collisions to determine the luminosity with a 6% relative uncertainty.

III. EVENT SELECTION AND RECONSTRUCTION

We select events with an isolated, central ($|\eta| \lesssim 1$) $\mathrm{p_T} > 20$ GeV muon or $E_\mathrm{T} > 20$ GeV electron, which we call the 'primary' lepton. At least four jets [18] with corrected $E_\mathrm{T} > 20$ GeV [19] and $|\eta| \leq 2.0$ must be present in the event. To increase our acceptance for $t\bar{t}$ events, we allow one of the four jets to pass a looser selection ($E_\mathrm{T} > 12$ GeV and $|\eta| \leq 2.4$) instead, but we do not allow it to be tagged by either SLT or SecVtx. We explicitly reject cosmic muons, conversion electrons, Z bosons, and events with more than one energetic and isolated lepton. We also require $H_\mathrm{T} > 250$ GeV and $\not\!\!E_\mathrm{T} > 30$ GeV, where H_T is the scalar sum of the transverse energy of the primary lepton, $\not\!\!E_\mathrm{T}$, and jets. With these requirements, we reconstruct a total of 1357 (996) 'pretag' events in the electron (muon) channel.

We tag each pretag event with ≥ 1 SLT (either e or μ) tag, and ≥ 1 SecVtx tag. The SLT$_\mathrm{e}$ is reconstructed with the same method described in Ref. [7], where a well-measured track close to a jet axis ($\Delta R \leq 0.4$) and originating close to the primary vertex is extrapolated into the central electromagnetic calorimeter. A combination of 'cut'-based and likelihood-based techniques are applied to identify the electromagnetic shower embedded in the jet. Conversion electrons are suppressed with a combination of geometric requirements and missing silicon hit elements. To suppress cascade decays of b-jets (*i.e.* $b \to c \to \ell\nu X$) which result in flavor misidentification we require that the track $\mathrm{p_T} >$ 6 GeV/c. With these requirements, the tagging efficiency for heavy flavor (HF) electrons is approximately 40% per track, while the misidentification efficiency for hadrons in $t\bar{t}$ is only 0.3% per track. A data-derived parameterization of the tagging efficiency for electrons and hadrons as a function of $\mathrm{p_T}$, η, and isolation is used to predict the efficiency in MC. A multiplicative scale factor is used to corrected the difference in conversion identification between data and MC.

The SLT_μ is reconstructed with the same method described in Ref. [8]. The SLT_μ algorithm uses well-measured tracks with $\mathrm{p_T} > 3$ GeV/c, originating close to the primary vertex, and within $\Delta R \leq 0.6$ to a jet axis. The tracks are extrapolated to the muon chambers and are selected with a likelihood analysis. Unlike in Ref. [8], we make no requirement on the electromagnetic fraction of the nearby jet, nor do we place any requirement on the invariant mass between the SLT and the primary lepton. We suppress cascade decays and mistags by requiring the SLT_μ $\mathrm{p_T} > 6$ GeV, and the $\mathrm{p_T}$ relative to the jet axis $p_{\mathrm{T,rel}} > 1.5$ GeV/c. The SLT_μ tagging efficiency is 73% per track and the misidentification efficiency for hadrons in 0.4% per track. A data-derived parameterization of the tagging efficiency for muons and hadrons as a function of $\mathrm{p_T}$ and η is used to predict the efficiency in MC.

The SecVtx tagger, described in Ref. [9], relies on the precise resolution of the silicon tracker to reconstruct tracks that, when combined, form a displaced secondary vertex from the primary interaction point. We use a loose operating point of the SecVtx tagger, which is approximately 50% efficient at tagging central b-jets from $t\bar{t}$, but has a per-jet mis-tagging rate of 2.5%. A multiplicative scale factor is used to correct the tagging efficiency for HF jets, and a parameterization of the mistag rate for light jets from multijet samples is used to determine the efficiency for LF jets.

Finally, we use a kinematic fitter described in detail in Ref. [10] which minimizes a reduced χ^2-like function to fit to the $t\bar{t}$ event hypothesis. The experimental resolution of the final state particles are accounted for, and the particles are kinematically constrained to the W and top mass (assumed to be 175 GeV/c^2), within the known decay width. There are nominally 12 permutations in which the jets may be assigned to four final state quarks, and jets tagged by either the SLT or SecVtx algorithms are constrained to be either one of the two b-jets. All possible permutations are considered and the lowest χ^2 value is chosen. If two different jets are both tagged, then we require that the lowest $\chi^2 < 27$, however if only one jet in the event is tagged - by both SecVtx and the SLT - then we require $\chi^2 < 9$. The tighter requirement on the χ^2 enforces a higher top charge reconstruction purity since there is a greater ambiguity when only one jet is identified as a b by the taggers.

IV. OPTIMIZATION

The choice of requirement for the χ^2, SLT track $\mathrm{p_T}$, and SLT_μ $p_{T,rel}$ variables were chosen by simultaneously optimizing for the highest total expected ϵD^2. Table I presents the expected ϵD^2 figure of merit using the Pythia MC generator [20] to model $t\bar{t}$, EvtGen [21] to control the decay of particles, and assuming $\sigma_{t\bar{t}} = 6.7 \pm 0.8$ pb [22], $M_t = 175$ GeV/c^2, and $\int \mathcal{L} = 2.7$ fb^{-1}. We choose the pretag expectation as the choice of denominator for the efficiency, although for the optimization, the choice is arbitrary. Shown are the values for the total, as well as separately for events with one or two tagged jets, and each SLT tagger. We expect 30.0 ± 5.9 events from $t\bar{t}$ in the tag sample, where the uncertainty is dominated by the theoretical cross section uncertainty and the jet energy scale uncertainty.

	ϵ (%)	P (%)	ϵD^2 (%)	$\langle N_{SM} \rangle$	$\langle N_{XM} \rangle$
Total	3.26	60.8	0.152	18.3	11.8
1 tagged jet	0.92	58.2	0.025	4.9	3.5
$\geq$ 2 tagged jets	2.34	61.8	0.130	13.4	8.3
SLT_e only	1.62	61.9	0.092	9.2	5.7
SLT_μ only	1.69	59.4	0.060	9.3	6.3

TABLE I: Expected efficiency, purity, ϵD^2, and number of events reconstructed as SM and XM, assuming $\sigma_{t\bar{t}} = 6.7$ pb for $\int \mathcal{L} = 2.7$ fb^{-1}.

V. BACKGROUND ESTIMATION

We estimate the background contribution to this sample with a combination of MC and data-driven techniques. Backgrounds from WW, WZ, ZZ, single top, Z+jets, and Drell-Yan+jets are simulated and normalized to their theoretical, or - in the case of the Z+jets and Drell-Yan - measured cross sections. The total expected contribution from these backgrounds is 0.7 ± 0.1 events to the tag sample. We expect a nearly equal contribution to SM and XM event reconstruction. The uncertainty is dominated by uncertainty from the cross sections and the luminosity.

Contributions from multijet production where a lepton is mimicked by a jet or produced via semileptonic decay and the $\not\!\!E_{\mathrm{T}}$ is mismeasured is extremely small. We determine the contribution by releasing the $\not\!\!E_{\mathrm{T}} > 30$ GeV requirement and fitting the $\not\!\!E_{\mathrm{T}}$ distribution to different signal and background templates. The background template is created from a sample of $E_{\mathrm{T}} > 20$ GeV electron-like clusters which fail at least two electron identification requirements. These events have the property of having a similar $\not\!\!E_{\mathrm{T}}$ distribution to the multijet sample. The signal templates are alternatively W+jet MC events and $t\bar{t}$ MC events. We expected 0.0 ± 0.4 tagged multijet events, where the uncertainty is derived from the fit. The result is consistent regardless of the signal template used.

The background contribution from W+jets is determined by assuming that, after subtracting the contributions from all other backgrounds and the signal, whatever remains of the pretag sample must be due to W+jets. A combination of ALPGEN [23] for generation and PYTHIA for fragmentation is used to measure the tagging efficiency for $W + b\bar{b}$, $W + c\bar{c}$, $W + c$, and W+light flavor (LF), as well as the relative components of each. The contribution from W+HF is calibrated by a multiplicative K-factor $= 1.4 \pm 0.4$, derived from calibrations in the W+1 jet sample. We expect 1.6 ± 0.4 tag events from W+jets, with a nearly equal contribution to SM and XM events. In total, we expect 2.4 ± 0.8 background events in the tagged sample, where the uncertainty is dominated by the jet energy scale, the multijet fit, and the K-factor.

VI. PURITY CALIBRATION

The measurement of the purity of the charge reconstruction for both $t\bar{t}$ and backgrounds is carried out with MC simulation; however, we calibrated it with a data-driven technique. We measure a dilution scale factor, SF_D, in a sample of pure $b\bar{b}$ events. The sample is constructed from dijet events which pass an 8 GeV lepton (e or μ) trigger, and in which both jets are SECVTX tagged. The trigger lepton must be close to one jet, while we use SLT tag tracks in the other jet. We use the equation $SF_D = \sqrt{D_{data}/D_{MC}}$ where $D = 2P - 1 = (\epsilon_{OS} - \epsilon_{SS})/(\epsilon_{OS} + \epsilon_{SS})$, and ϵ is the tagging efficiency when the trigger lepton and the SLT have the opposite sign (OS) or same sign (SS) charge. The square root originates from the fact that both b-jets decay semileptonically and so are subject to the same dilution factor.

Subsample	N	N_{SM}	N_{XM}	A
Primary Electron	25	16	9	1.55
Primary Muon	20	13	7	1.70
1 tagged jet	7	4	3	1.09
≥ 2 tagged jets	38	25	13	1.69
SLT$_e$	25	15	10	1.11
SLT$_\mu$	21	15	6	2.42
All	45	29	16	1.53

TABLE II: Tag configurations in various subsamples of the data, including divisions according to the primary lepton flavor, the number of tagged b-jets, and the SLT flavor. Shown are the number of SM and XM tags and the resulting normalized asymmetry with statistical uncertainties.

The MC sample is a $2 \to 2$ dijet sample filtered on an 8 GeV lepton, generated by PYTHIA and decayed by EVTGEN just as in the $t\bar{t}$ sample. This comparison allows a proper dilution calibration in the MC due to differences in the decay branching fractions, contributions from neutral B mixing, as well as a potential (but unlikely) charge bias by the SLT taggers. We find that $SF_D = 0.92 \pm 0.11$, which is dominated by the statistical uncertainty but which cover dependencies on other variables, such as the jet E_{T}. We use this to correct the MC simulation estimate for the $t\bar{t}$ purity, for which our final estimate is $(60 \pm 3)\%$. The uncertainty is dominated by the choice of MC generator, the total initial state radiation (ISR) and final state radiation (FSR), and the dilution SF. The generator uncertainty is determined by replacing PYTHIA generator with the HERWIG generator [24] and remeasuring the purity. Similarly, the total ISR and FSR contribution to the $t\bar{t}$ production is varied, and the result on the purity is remeasured.

Because the background has a large non-b-jet contribution to the tags, it would be inappropriate to apply the dilution SF directly to the background purity measurement as well. Moreover, the accuracy of the background purity modeling is difficult to ascertain. However, because the background contribution is very small, we apply a very conservative 11% systematic uncertainty derived by using the $t\bar{t}$ purity as an upper and lower-bound. We conclude that the background has a purity of $(50 \pm 6)\%$.

VII. MEASUREMENT AND STATISTICAL INTERPRETATION

When we reconstruct the top charge in data, we measure 45 total events, of which 29 are reconstructed as SM and 16 are reconstructed as XM. The total number of events is approximately one standard deviation above the expectation. Table II shows the number of tags by subsample, including i) the flavor of the primary lepton, ii) the

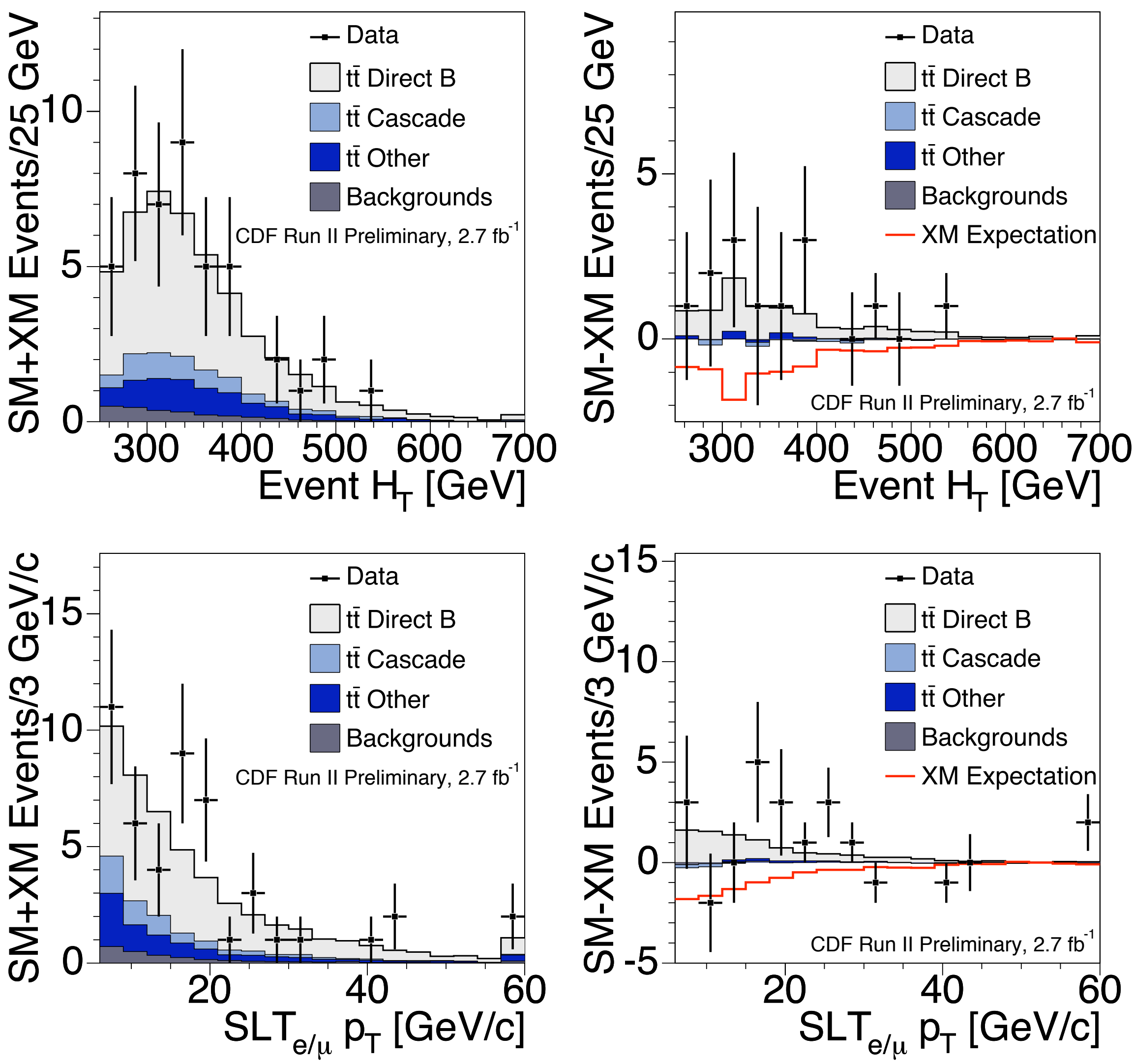

FIG. 1: Distribution of the SM+XM (left) and SM-XM tags (right) as a function of the event H_{T} (top) and SLT track p_{T} (bottom). The total $t\bar{t}$ contribution is normalized to the data. Contributions from direct semileptonic decay of b-jets, semileptonic cascade decays and other sources of SLT tags are shown separately, along with the expected SM background. The expectation for a hypothetical XM top is shown in red.

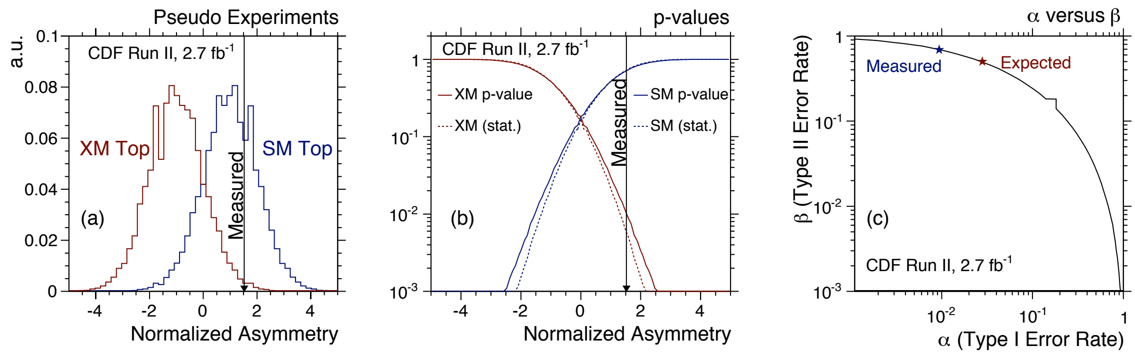

FIG. 2: (a) Psuedo-experiments distribution of the normalized asymmetry, A, from the SM and XM hypotheses; (b) the resulting SM and XM p-values shown with systematic uncertainties and statistical uncertainties only; (c) the type-I versus the type-II error rate, assuming an XM null hypothesis. Artifacts due to the discreteness of the asymmetry test statistic can be seen.

number of tagged b-jets, iii) and the flavor of the SLT tag. Also shown is the asymmetry

$$A \equiv \frac{1}{D_S} \frac{N_{SM} - N_{XM} - \langle B \rangle D_B}{N_{SM} + N_{XM} - \langle B \rangle} \tag{1}$$

which has been normalized to give on median +1.0 for the SM hypothesis and −1.0 for the XM hypothesis. In the equation, D_S and D_B are the signal and background dilution, respectively, and $\langle B \rangle$ is the total background expectation.

Fig. 1 shows the distribution of SM and XM events as a function of the event H_{T} and the SLT tag $\mathrm{p_T}$. The total $t\bar{t}$ contribution (SM+XM) from simulation is normalized to the data, and divided between SLT contributions from direct semileptonic b decay, cascade semileptonic decay, and other sources. The expected distribution assuming a $-4/3$ charge XM top is shown in red.

The statistical significance of the measurement is determined by running 'pseudo-experiments,' whereby the signal and background expectations and purities are modeled by drawing random numbers from an underlying distribution. A Gaussian probability distribution is used to model the systematic uncertainties. We use the normalized asymmetry, A, as the test statistic. From the pseudo-experiments, we derive a SM and XM p-value, $p_{SM} = p(A \leq A_0|SM)$ and $p_{XM} = p(A \geq A_0|XM)$. We measure $p_{SM} = 0.69$ and $p_{XM} = 0.0094$, while we expect on median $p_{SM} = 0.50$ and $p_{XM} = 0.028$, assuming the SM. The median value for p_{XM} is also a useful quantification of the sensitivity of the measurement. We choose α, the type-I error rate, *a priori*, by using the standard threshold for exclusion of exotica: $\alpha = 0.05$. From this we exclude the exotic $-4/3$ charged top quark at 95% confidence level. Fig. 2 shows the pseudo-experiment distributions, p-values, and the type-I error rate versus the type-II error rate, assuming an XM null hypothesis. Table III shows the expected and measured XM p-value with the significant systematic errors added cumulatively.

Source	Expected p-value	Observed p-value
Stat. only	0.020	0.0054
Dilution SF	0.021	0.0058
ISR/FSR	0.022	0.0062
Cross Sections	0.023	0.0069
Jet Energy Scale	0.026	0.0080
Generator	0.028	0.0094

TABLE III: Cumulative systematics uncertainties. Systematic uncertainties associated with the W lepton identification, W+HF K-factor, PDFs, QCD background fitting, SLT and SecVtx taggers, Top quark mass, and luminosity are negligible.

We can also quantify the result of this measurement with a Bayes Factor (BF), which is the ratio of posterior odds assuming equal prior odds for the SM and XM hypothesis. Systematics are taken into account by integrating separately, numerator and denominator, over nuisance parameters. We measure a Bayes Factor of 85.8, or what is usually quoted is $2 \cdot \log(\mathrm{BF}) = 8.9$. A test statistic of 6−10 is called "strong" support (in our case for the SM).

VIII. CONCLUSIONS

In conclusion, we have presented the exclusion of an exotic top quark with 4/3 charge (at 95% C.L.), while observing very strong evidence for the Standard Model +2/3 electric charge of the top quark. We demonstrate the power of a soft lepton tagging method to measure the b-jet flavor. While the method has a lower efficiency, the increased charge determination purity makes this an important complementary technique.

IX. ACKNOWLEDGMENTS

We thank the Fermilab staff and the technical staffs of the participating institutions for their vital contributions. This work was supported by the U.S. Department of Energy and National Science Foundation; the Italian Istituto Nazionale di Fisica Nucleare; the Ministry of Education, Culture, Sports, Science and Technology of Japan; the Natural Sciences and Engineering Research Council of Canada; the National Science Council of the Republic of China; the Swiss National Science Foundation; the A.P. Sloan Foundation; the Bundesministerium fuer Bildung und Forschung, Germany; the Korean Science and Engineering Foundation and the Korean Research Foundation; the Particle Physics and Astronomy Research Council and the Royal Society, UK; the Russian Foundation for Basic Research; the Comision Interministerial de Ciencia y Tecnologia, Spain; and in part by the European Community's Human Potential Programme under contract HPRN-CT-2002-00292, Probe for New Physics.

[1] F. Abe *et al.*, Phys. Rev. Lett. **74**, 2626 (1995); S. Abachi *et al.*, Phys. Rev. Lett. **74**, 2632 (1995).
[2] A. Abulencia *et al.*, Phys. Rev. D **74**, 072006 (2006); V. Abazov *et al.*, Phys. Lett. B **626**, 35 (2005); D. Acosta *et al.*, Phys. Rev. Lett. **93**, 142001 (2004); V. Abazov *et al.*, Phys. Rev. D **76**, 052006 (2007).
[3] Tevatron Electroweak Working Group, arXiv:0808.1089v1 [hep-ex], FERMILAB-TM-2413-E.
[4] D. Acosta *et al.*, Phys. Rev. D **72**, 052003 (2005); V. Abazov *et al.*, Phys. Rev. D **76**, 092007 (2007).
[5] D. Chang, W. Chang, and E. Ma, Phys. Rev. D **59**, 091503 (1999).
[6] We assume that the electric charge of the b-quark is $-1/3$, as measured in C. Berger *et al.*, Phys. Lett. B **76**, 243, 1978; C.Darden *et al.*, Phys. Lett. B **76**, 246, 1978; J. Bienlein *et al.*, Phys. Lett. B **78**, 360, 1978.
[7] J.P. Chou, "$t\bar{t}$ Production Cross Section Measurement using Soft Electron Tagging in $p\bar{p}$ Collisions", Ph.D. Thesis, Harvard University.
[8] D. Acosta *et al.*, Phys. Rev. D **72**, 032002 (2005); T. Aaltonen *et al.*, Phys. Rev. D **79**, 502007 (2009).
[9] D. Acosta *et al.*, Phys. Rev. D **71**, 052003 (2005).
[10] A. Abulencia *et al.*, Phys. Rev. D **73**, 032003 (2006).
[11] A. Abazov *et al.*, Phys. Rev. Lett. **98**, 041801 (2007).
[12] C. Hill *et al.*, Nucl. Instrum. Meth. A **530**, 1 (2004); A. Sill *et al.*, Nucl. Instrum. Meth. A **447**, 1 (2000); A. Affolder *et al.*, Nucl. Instrum. Meth. A **453**, 84 (2000).
[13] T. Affolder *et al.*, Nucl. Instrum. Meth. A **526**, 249 (2004).
[14] L. Balka *et al.*, Nucl. Instrum. Meth. A **267**, 272 (1988); S. Bertolucci *et al.*, Nucl. Instrum. Meth. A **267**, 301 (1988).
[15] We define the pseudorapidity variable, $\eta \equiv -\ln\tan(\theta/2)$.
[16] G. Ascoli *et al.*, Nucl. Instrum. Meth. A **268**, 33 (1998).
[17] D. Acosta *et al.*, Nucl. Instrum. Meth. A **494**, 57 (2002).
[18] We reconstruct jets using a fixed-cone algorithm with a cone size of $\Delta R \equiv \sqrt{\Delta\eta^2 + \Delta\phi^2} \leq 0.4$.
[19] A. Bhatti *et al.*, Nucl. Instrum. Meth. A **566**, 2 (2006). We correct jet energies for detector variation, multiple interactions, and un-instrumented regions of the detector.
[20] T. Sjostrand, S. Mrenna, and P. Skands, J. High Energy Phys. **0605**, 026 (2006). We use Pythia version 6.216.
[21] D. J. Lange *et al.*, Nucl. Instrum. Meth. A **462**, 152 (2001).
[22] M. Cacciari, S. Frixione, M. Mangano, P. Nason, and G. Ridolfi, J. High Energy Phys. **0404**, 068 (2004); N. Kdonakis and R. Vogt, Phys. Rev. D **68**, 114014 (2003).
[23] M.L. Mangano *et al.*, J. High Energy Phys. **0307**, 001 (2003). We use Alpgen version 2.10 prime.
[24] G. Corcella *et al.*, J. High Energy Phys. **0101** (2001). We use Herwig version 6.510.