CDF exclusion of exotic top-like quark with -4/3 electric charge using soft lepton tagging

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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.

Outline & Background

$2.7fb^{-1}$ gathered from
Feb 2002 to April 2008

- Top quark discovered by CDF/D0 in 1995
- Possibility of exotic -4/3 charge
  - -excess due to exotic 'XM top'
  - -SM top escapes detection

- Measure charge of top quark by reconstructing ttbar pairs in *l*vbjjb final states. Label b quarks associated to W bosons 'leptonic b' and 'hardronic b'.

This experiment 2-3x less efficient than D0 (2007) but higher charge purity.
=>2-3 times less sensitivity

TOP CHARGE

- Identify (hadr. or lept.) b quark, determine flavour (b or bbar).

- ID of bjets using el/mu SLT and SecVertex tagger (in $b \rightarrow l^{-}\nu X$ (BR=10%))
- Kinematic fitter to determine hadr./lept. b-jet
- b-jet flavour determined with SLT

➡Event considered SM if charge of W and charge of lept.(hadr.) bjet are opposite(same). Else event is considered XM.

Note: if both the kinematic fitter and the bjet ID are wrong, we still get the correct top charge.
- Top charge correctly reconstructed in 61% events.

Event Selection and Optimization

SELECTION

- |eta|<1
- P_T > 20 GeV (muons)
- E_T > 20 GeV (electron)
- at least 4 jets with corrected E_T>20 GeV and |eta|<2.0
- Allow one of 4 to pass looser selection: E_T > 12 GeV and |eta| <2.4 (not allowed to be tagged SLT or SV).
- H_T>250GeV (scalar sum of 1st lept, MET and jets)
- MET>30GeV

1357 (996) pretag electron (muon) channel events

SecVtx TAGGING

- Combined tracks with displaced sec vtx. from interaction point
- 50% efficient/2.5% mis-tag rate

SLT TAGGING

- Either e or mu SLT tag and >0 SecVtx tags
- SLTe uses track close to jet (dR < 0.4) extrapolated to ECAL.
- SLTmu uses tracks with p_T > 3 GeV, dR < 0.6 from jet
- Track p_T > 6 GeV to remove b-cascades (and $p_{T,rel}$>1.5GeV for SLTmu)

KINEMATIC FITTER

- Minimize Chi2 function to ttbar hypothesis
- All jet permutations (to final state quarks) considered
- Take lowest chi2 (<27 if 2 jets, <9 if one jet)

OPTIMIZATION

- Requirement of chi2, SLT track p_T and SLTmu $p_{T,rel}$ chosen by optimising εD^2
- Use MC generator to evaluate εD^2

	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}.

Expect 30.0±5.9 events from ttbar in tag sample

Backgrounds and Purity

MC/data driven bkdg estimate:

- WW, WZ, ZZ, single top, Z+jets and Drell-Yan+jets. Expect 0.7±0.1 to tag sample (equal in SM/XM)

- Template method (fit MET dist. to bkdg and sig. templates) used to evaluate multijet production faking lepton. Expect 0.0±0.4 tagged multijet events.

- W+jets determined by subtraction of signal/other bkgds
- MC used to measure tagging eff. of W+HF and W+LF. W+HF calibrated with some factor.
- Expect 1.6±0.4 tag events.

Purity Calibration:

- MC with data-driven calibration
- Measure dilution scale factor SF_D in pure bbar sample (constructed from djet event. 8 GeV lep. trigger, both jets SecVtx tagged)
- Find SF_D=0.92±0.11, used to correct MC estimate for ttbar purity. Final value = 60±3%
- Vary generator and ISR/FSR contribution for error

- SF is not applied to background. Instead apply 11% systematic uncertainty. background purity = 50±6%

Measurement & Interpretation

- Find 45 total events: 29 SM and 16 XM
- Total 1 std. dev. above expectation

Asymmetry normalised to ±1

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

Total ttbar contribution from MC normalised to data and split between various contributions.
Expected XM shown in red.

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_μ	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.

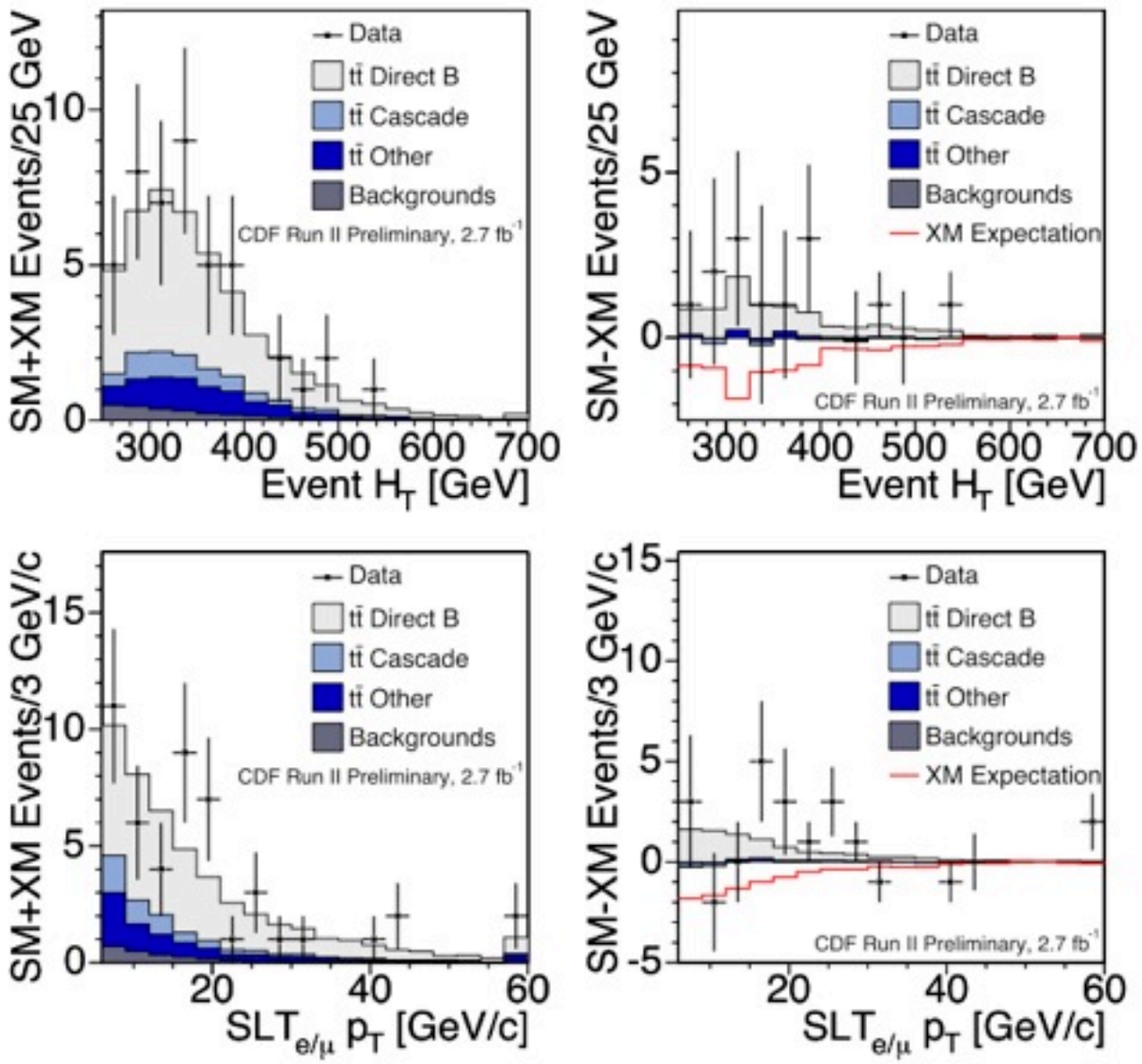

FIG. 1: Distribution of the SM+XM (left) and SM-XM tags (right) as a function of the event H_T (top) and SLT track p_T (bottom). The total $t\bar{t}$ contribution is normalized to the data. Contributions from direct semileptonic decay of b-jets, semileptonic cascade decays and other sources of SLT tags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

- Statistical signficance determined using pseudo-experiments.
- Derive p-values from this: $p_{SM} = p(A < A_0|SM)$ and $p_{XM} = (p(A>A_0|XM)$.
- Measure p_{SM}=0.69 (0.5 mean) and p_{XM}=0.0094 (0.028 mean)
- Error consideration: type I and type II, assuming XM null hypothesis
- Also express the result with Bayes Factor = 85.8, or 2xlog(BF)=8.9

Exclude exotic top quark with -4/3 charge at 95% CL. Also observe strong evidence for +2/3 charge. SLT works well, and is complemetary to higher efficiency techniques.

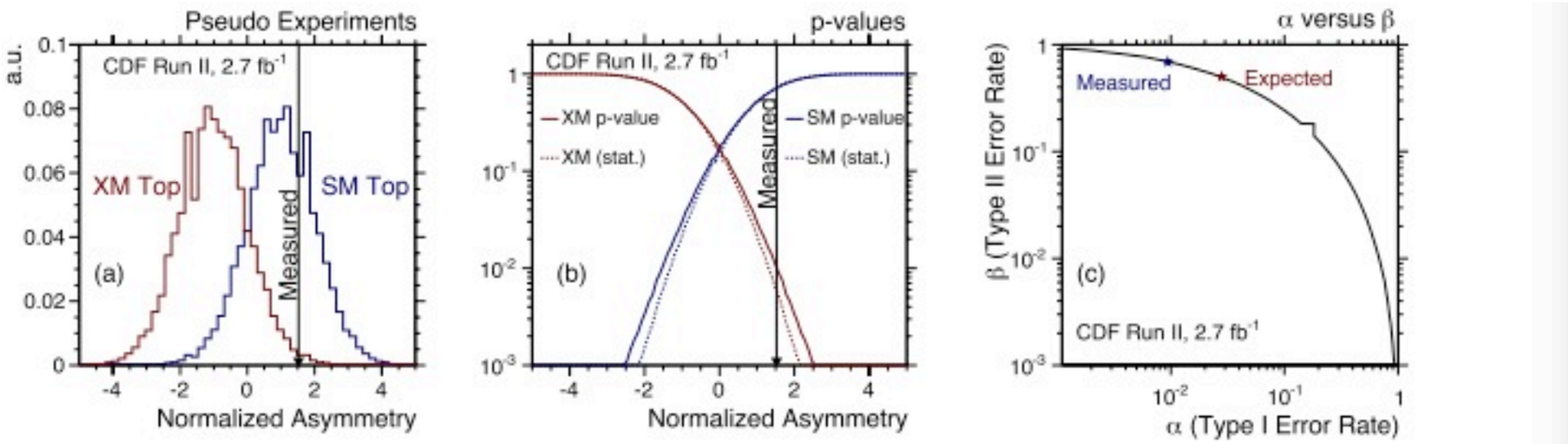

FIG. 2: (a) Psuedo-experiments distribution of the normalized asymmetry, A, from the SM and XM hypotheses; (b) the resulting SM and XM p-values shown with systematic uncertainties and statistical uncertainties only; (c) the type-I versus the type-II error rate, assuming an XM null hypothesis. Artifacts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

Source	Expected p-value	Observed p-value
Stat. only	0.020	0.0054
Dilultion 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.