A new method for the detemination of the charge of the Top: Measuring the top charge with soft leptons.

Exclusion of Exotic Top-like Quark with -4/3 Electric Charge using SLT Tags. (CDF Collaboration)

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Abstract: A new method is presented for measuring the electric charge of the top quark. Results using the CDF detector based on 2.7 fb^{-1} of $p\overline{p}$ collisions will be presented. The charge is determined by knowing three things. First the charge of the W ($W \to$ l ν) is determined from the charge of the lepton it decays to. Second the charge of the b-jet is determined by using soft lepton tags ($b \longrightarrow l^-$ ν X). Third, reconstruction of $t\bar{t}$ events in the Lepton + Jets final state allows one to determine which b-jet is associated with the leptonically or hadronically decaying t-quark. The second step is the new element and replaces finding the charge of the b-quark by summing the charge inside a cone.

Madison Meeting May 10-12, 2010

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Outline of Talk

1. Standard Model versus Exotic Model
2. Determining the Charge of the Top Quark
3. Obtaining a clean sample
4. Basic Statistical Elements

   N_{pairs} $Purity_{pair}$

   Binominal Distribution
5. How many pairs?
6. Statistical errors α and β
7. Need a Hypothesis to Test
8. Results
9. Conclusions

1. Standard Model versus Exotic Model

Basic Question for this Analysis
$t\bar{t} \rightarrow W^+ \, b \, W^- \, \bar{b}$ (SM) standard model
$t\bar{t} \rightarrow W^- \, b \, W^+ \, \bar{b}$ (XM) exotic model

We use the lepton plus jet decay mode (L+J)

$t\bar{t} \rightarrow (l^+\nu \; b) \; (qq \; \bar{b})$ (SM) standard model
$t\bar{t} \rightarrow (l^-\nu \; b) \; (qq \; \bar{b})$ (XM) exotic model

The leptons used are e and μ
We use a kinematic fitter to tell which b is associated (paired) with the lepton

- SM Charge of lepton is opposite to the charge of the paired b
- XM Charge of lepton is the same as the charge of the paired b

2. Determining the Charge of the Top Quark

- Correct pairing of lepton and b

  Kinematic Fitter (Purity = P_k = 76%)

  Kinematic Fitter = Reconstruction technique that assigns jets to their partons
- Charge of the lepton
- Charge of the b

Standard Method of Determining the Charge of the b

The determination of the flavor of a b jet is based on jet charge calculation. The charges of tracks inside a jet (cone of radius = 0.4 in η-ϕ space) are summed up with weights defined by momentum amplitude of the track and the closeness of the track to the jet axis.

$$Q_{jet} = \frac{\Sigma\, |\vec{p_i}.\vec{P_{jet}}|^{0.5} Q_i}{\Sigma\, |\vec{p_i}.\vec{P_{jet}}|^{0.5}} \tag{1}$$

Where $\vec{p_i}, Q_i$ is momentum and charge of a track associated with a jet and $\vec{P_{jet}}, Q_{jet}$ momentum and charge of the jet.

- Charge of the b

  $\text{Purity}_{\text{tagger}} = \text{P}_t = 71\%$

New Method of Determining the Charge of the b

Semileptonic Decay Mode

- $b \rightarrow l^- \nu X$
- $\bar{b} \rightarrow l^+ \nu X$

Not easy, one needs to identify electrons embeded in jets.

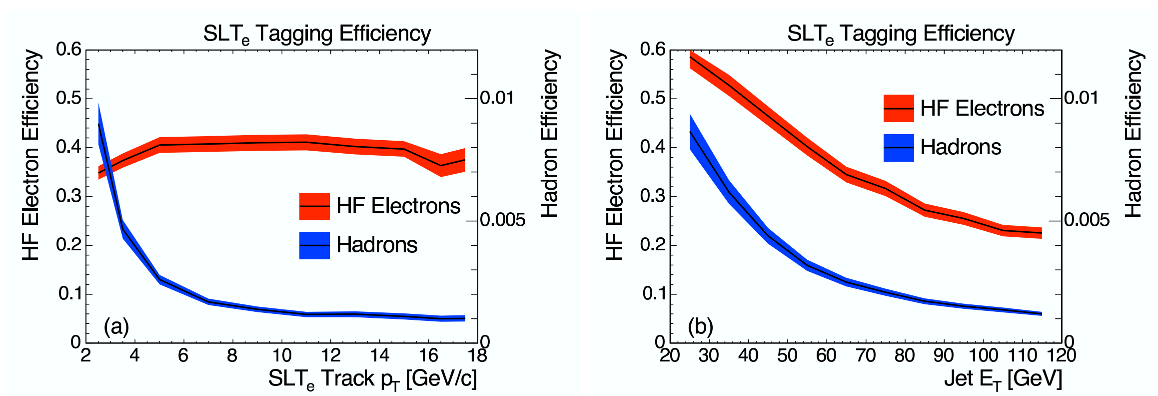

FIG. 1: Predicted efficiency to tag an electron from semileptonic decay of HF and a hadron candidate SLT$_e$ track in $t\bar{t}$ events as a function of the track p_T (a) and corrected jet E_T (b). The left axis indicates the tagging efficiency for the electrons and the right axis indicates the tagging efficiency for the hadrons.

3. Obtaining a clean Sample

- We would like no Background
- We get a Signal/Background = 12.5/1

- soft lepton tag (SLT)
- standard secondary vertex tag (SECVTX)
- high p_T leptons ($p_T > 20$ GeV)
- lepton must be central $(|\ \eta\ |) < 1.$
- lepton must be isolated
  ($>$ 90% of Energy in cone of R = 0.4)
- $\not{E}_T\ > 30$ GeV
- Three or more high E_T jets
- The fourth jet can be lower ($E_T > 12$ GeV)
- $H_T > 200$ GeV (Scaler sum of transverse energy of leptons, jets and neutrinos)
- χ^2 constraint on kinematic fitter
- Reject events containing cosmic muons
- Reject conversion electrons
- Reject events containing a Z
- Reject events with more than one high p_T lepton

4. Basic Statistical Elements

- Two Important Quantaties (Number of Events, Purity)
- Number of Signal Events
  (I assume only one SLT in an event)

- Purity = P = $\frac{N_{SM}}{N_{SM}+N_{XM}}$
- Purity SLT Tagger = P_t = 71%
- Purity Kinematic Fitter = P_k = 76%
- P = $P_k P_t$ + (1. - P_k)(1. - P_t) = 61%

- The figure of Merit for the experiment = ϵD^2
- For the SM, $\epsilon = \frac{N_{SM}}{N_{pre-tag}}$
- Dilution = D = 2P - 1

If you are interested in the XM model replace N_{SM} with N_{XM} and N_{XM} with N_{SM}

5. How many pairs?

- Branching Fraction for:
  $t\bar{t} \rightarrow$ Lepton + Jets(e+μ) = 29.6%
- Pretag Acceptance = $\epsilon_{\rm pretag}$ = 29.6%*0.21 = 6.2%
- $\epsilon_{\rm trigger}$ = 0.96,
  We collect events that fire an inclusive 8 GeV trigger
- (SF = 0.92) to correct between MC and Data,
  $\epsilon_{\rm Dilution(Data)} = {\rm SF}^2 \epsilon_{\rm Dilution(MC)} = 0.85$
- The square is because we need to correct both the lepton-jet and the away-jet
- Pretag Acceptance(corrected)
  $\epsilon_{\rm pretag-c}$ = 6.2% $\times$ $\epsilon_{\rm trigger}$ $\times$ $\epsilon_{\rm Dilution}$ = 5.1%

- $N_{\rm pretag} = \epsilon_{\rm pretag-c} \times \sigma(t\bar{t}) \times \mathcal{L}$
- $N_{\rm pretag}$ = 5.1% $\times$ 6.7pb $\times$ 2700/pb = 922
- $\epsilon_{\rm tag}$(SLT and SECVTX) = 3.2%
- $N_{\rm SLT+SECVTX} = N_{\rm pretag}\epsilon_{\rm tag}$ = 922 $\times$ 0.032 = 30.

- Why is $\epsilon_{(\text{ tag SLT and SECVTX})}$ so small ?
- Branching Fraction($b \rightarrow l\nu X$) $\approx$ = 10%
- Kinematic Fitter both b's are tagged ($\chi^2 < 27$)
  or both tags on the same b ($\chi^2 < 9$)
- p_T(Soft Lepton) > 6 GeV
- p_T(Soft Muons(relative to the jet axis)) > 1.5 GeV

- How many background pairs?

TABLE I:

Process	pretag	SM + XM Tags
Diboson	73.23 ± 4.04	0.13 ± 0.01
Single Top	14.25 ± 0.83	0.24 ± 0.01
Z + Jets	63.85 ± 10.35	0.31 ± 0.06
Drell-Yan	14.08 ± 2.95	0.06 ± 0.01
QCD	198.91 ± 31.96	0.00 ± 0.43
W + LF		0.25 ± 0.04
$W + b\bar{b}$		1.07 ± 0.29
$W + c\bar{c}/W + c$		0.31 ± 0.07
W + Jets	1067.08 ± 149.46	(1.64 ± 0.30)
Total Background	1431.41 ± 133.13	2.36 ± 0.52

- Total sample size
  30. (Signal) + 2.36 (Background) $\approx$ 32.
- Total Purity
  0.608 (Signal) + 0.5 (Background) $\approx$ 0.60

6. Statistical Errors α and β

- Type I Errors called alpha
- Type II Errors called beta

- In a legal proceeding:
- One would say the probability of an innocent person going to jail is alpha.
- The probability of a guilty person going free is beta
- Clearly one wants both alpha and beta to be as small as possible
- http://www.intuitor.com/statistics/T1T2Errors.html

- A pregency test:
- If the test says a women is pregnant when she is not, this is a type I error (alpha).
- Type II error (beta) is when a test shows a women is not pregnant when she is.
- Clearly one wants both alpha and beta to be as small as possible

These questions about statistics have been around for a long time.

J. Neyman and E. Pearson Phil. Trans. of the Royal Soc. of London A31 289 (1933).

7. Need a Hypothesis to Test

- What do we need to know in order to proceed.
- We must have a hypothesis (H_0)

  The person is innocent.

  The women is pregnant

  The exotic model is true.

- We must know the probability distributions for both alternativces.

  Probability distributions for the legal case ?

  Probability distributions for the medical case ?

  For our case it's just the Binominal distribution $(p + q)^n$

  For SM we have p = 0.6 and q = 0.4, n = 30

- We need to set alpha before we do the experiment
- There are four standard choices 95%, 99%, 3σ and 5σ
- For Top charge analysis
  we will choose 95% (alpha =5%)

Are we proceeding correctly?
Yes but, physics could be strange
50% charge 2/3 and 50% charge -4/3

- H_0 = The exotic Model is true

TABLE II: This table represents our understanding before doing the experiment.

Result of Test	H_0 true	H_0 false
Do not reject H_0	OK-1	Type I error
Reject H_0	Type II error	OK-2

- We plot both distributions (SM and XM), and draw a line so that (XM) exotic distribution has 95% of its area to the left of the line. The 5% to the right corresponds to alpha.
- To determine beta we use the same line, but look at the SM distribution. The area to the left of the line corresponds to beta, the area to the right is 1 - β (Sometimes called the power of the method.)

TABLE III: This table represents our understanding before doing the experiment.

Result of Test	XM true	XM false
Do not reject XM	95%	5%
Reject XM	28.6%	71.4%

- If we reject the Hypothesis we will publish a 95% CL of excluding the XM model.
- If we do not reject the Hypothesis we will look at the alternative hypothesis.

8. Results

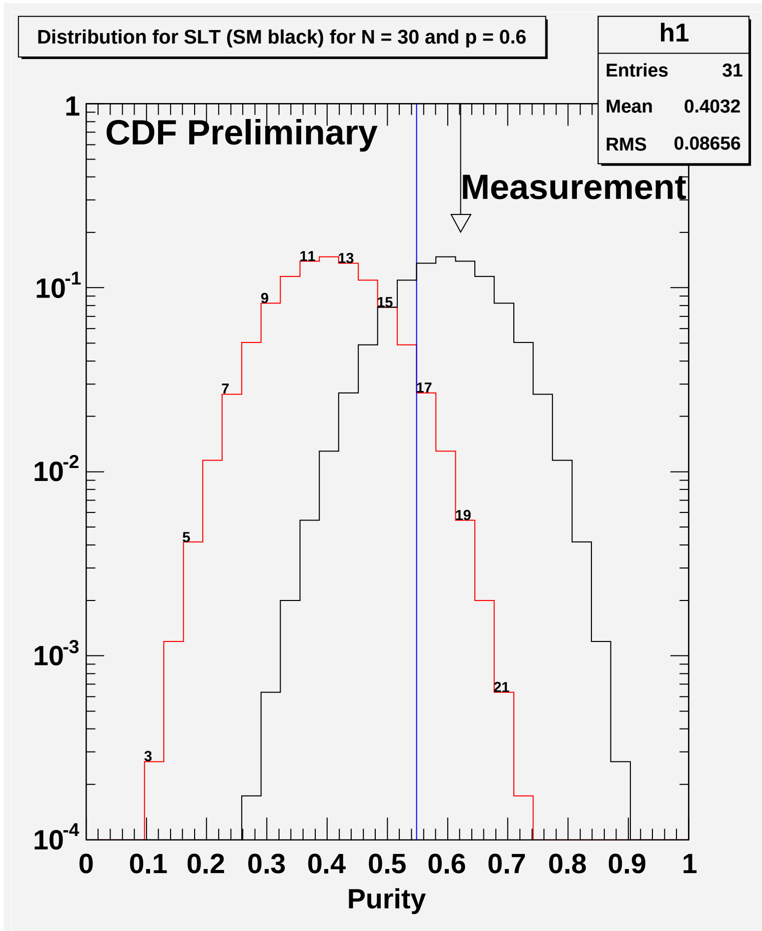

FIG. 2: The blue line has approximately 5% of the XM curve to it's right.

- If we observe 17 or more SM pairs out of 30 we will have excluded the XM model at a 95% CL.
- We observe 19.3
- The reason for the strange number is that we reconstructed 45 events (SM = 29, XM = 16)

9. Conclusions

- Many important aspects of this analysis are not presented in this talk (kinematic fitter, systematic errors, ...)

  This experiment is not symmetric we can not exclude the SM using a 95% CL, but should use 3σ

- This presentation has simplified the analysis to make the important points clearer
- A Lepton + Jet sample has been analyzed corresponding to 2.7 fb^{-1}
- The sample contains 45 SLT of which 29 are consistent with the SM
- WE are able to exclude the
  exotic hypothesis
  (top quark charge = -4/3) at the 95% CL
- The basic approach of dealing with well defined random experiments is usual called the frequentist method
- The basic statistical ideas are applicable to a large range of problems

Backup Slides

1. More details for alpha and beta

   http:/en.wikipedia.org/wiki/Type_I_and_type_II_errors

2. Possible Results

3. Systematic Errors

4. Subsamples

1. More details for alpha and beta.

Possible combinations

1. Accept H_0 when it is true "true positive" OK-1
2. Reject H_0 when it is false "true negative" OK-2
3. Reject H_0 when it is true "false positive" α
4. Accept H_0 when it is false "false negative" β

- You obtain a "true" when the results of the test agrees with the actual conditions

TABLE IV: If we know the actual conditions

	Actual Conditions	
	H_0 true	H_0 false
	Present	Absent
Result of Test		
Do not reject H_0(positive)	OK-1 (true positive)	Type I error (false positive)
Reject H_0 (negative)	Type II error (false negative)	OK-2 (true negative)

Hypothesis H_0 Person is Guilty

TABLE V: If we know the actual conditions

	Actual Conditions	
	Guilty	Innocent
Result of Test		
Guilty	OK-1 (true positive)	Type I error (false positive) innocent but convicted
Innocent	Type II error (false negative) guilt not detected	OK-2 (true negative)

2. Possible Results

- SM will be a number between 0 and 30 for this experiment

  SM $\geq$ 17 Exclusion of XM at 95% CL)

  SM $\leq$ 9 Exclusion of SM at the 3σ level

  Some thing that it's ok to exclude the SM at 99% CL

  See the next two backup pages

  SM $\geq$ 10 and SM $\leq$ 16, no decision

- In general there are 4 possible decisions

  Exclusion of XM

  Exclusion of SM

  Exclusion of SM and XM

  No decision

- Based on the Monte Carlo first decide on alpha

  The systematic errors need to also be included in the MC

  Once alpha is determined so is beta

- H_0 = The Standard Model is true

TABLE VI: This table represents our understanding before doing the experiment.

Result of Test	H_0 true	H_0 false
Do not reject H_0	OK-1	Type I error
Reject H_0	Type II error	OK-2

- We plot both distributions (SM and XM), and draw a line so that (SM) exotic distribution has 99.87% of its area to the right of the line. The 0.13% (3σ) to the left corresponds to alpha.
- To determine beta we use the same line, but look at the XM distribution. The area to the right of the line corresponds to beta, the area to the left is 1 - β (Sometimes called the power of the method.)

TABLE VII: This table represents our understanding before doing the experiment.

Result of Test	SM true	SM false
Do not reject SM	99.87%	0.13%
Reject SM	82.4%	17.6%

- If we reject the Hypothesis we will publish a 3σ exclusion of the XM model.

Results

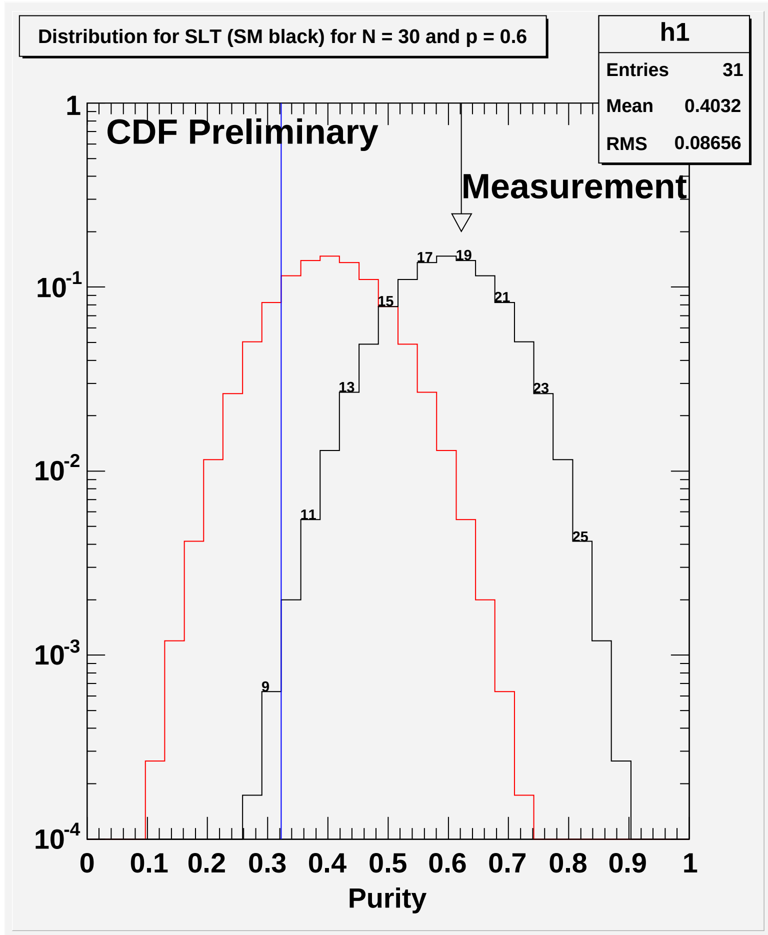

FIG. 3: The blue line has approximately 0.13% of the SM curve to it's right.

- If we observe 9 or less SM pairs out of 30 we will have excluded the SM model at the 3σ level.
- We observe 19.3
- The reason for the strange number is that we reconstructed 45 events (SM = 29, XM = 16)

3. Systematic Errors

TABLE VIII:

Systematics	Uncertainty in Purity (%)
ISR/FSR	3.6
PYTHIA/HERWIG	2.2
Dilution Scale Factor	2.0
Jet Energy Scale	1.6
PDF's	< 1.0
Top Mass	< 1.0
Cross Section	0.0
Luminosity	0.0
W + Lepton ID	0.0
SECVTX Tagger	0.0
SLT tagger's (e , μ)	0.0
Total	4.9

- Total sample size
  30. (Signal) + 2.36 (Background) $\approx$ 32.
- Total Purity
  0.608 (Signal) + 0.5 (Background) $\approx$ 0.60

4. Subsamples

TABLE IX: Tag configurations in various subsamples of the data, including divisions according to the primary lepton flavor, the number of b-jets, and the SLT flavor. Shown are the number of SM and XM tags as well as the total.

Subsample	N	N_{SM}	N_{XM}
Primary Electron	25	16	9
Primary Muon	20	13	7
1 Tagged Jet	7	4	3
$\geq$ 2 Tagged Jets	38	25	13
SLT_e	25	15	10
SLT_μ	21	15	6
ALL	45	29	16

Subsamples Madison Meeting May 10-12, 2010