Department of Nuclear Physics and Biophysics (FMPI, Comenius Univ) in experiment CDF / Fermilab.

Measuring of the top quark charge at the experiment CDF

Motivation

Since the discovery of the top quark, CDF has measured several of its properties to confirm its identity as expected in the standard model (SM). Determining whether the top quark decays into a W^+ and a bottom quark while the anti-top quark decays to a W^- and an anti-bottom quark would ensure indirectly that the charge of the top quark is indeed +2/3 as expected in the SM.

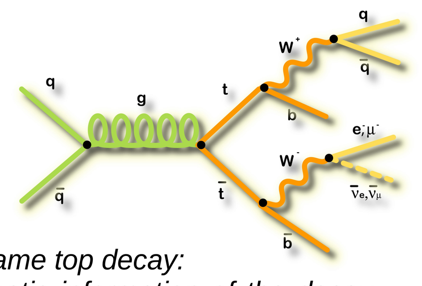
If these events were found to have an object decaying to a W^- and a bottom quark, the charge of this object would be -4/3 and would not correspond to the SM top quark. Such an hypothesis has been put forward and proposes that this new particle would be an exotic quark, part of a fourth generation of quarks and leptons. These authors also calculate that the standard model top quark would be at a mass > 230 GeV/c^2.

Exclusion of the exotic top quark hypothesis has been presented, with less data and less sensitivity than the present measurement.

Methodology

Due to the fact that the top quark life time is too small (smaller than time needed for the hadronisation) we use top quark decay products for the charge measurement. In this study we use top quark pair events ($t\bar{t}$), where one W boson decays leptonically (into lepton and corresponding neutrino, the second W boson decays hadronically (into two jets) and at least two b-jets are present.

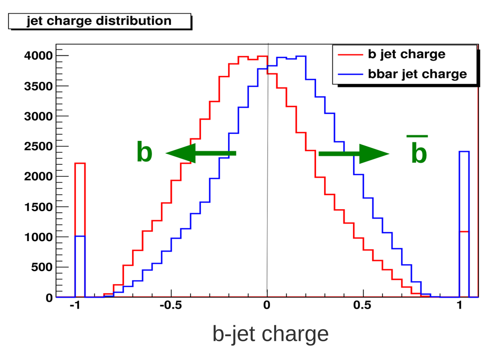
There are three main ingredients to this analysis:



1) Determining the charge of the W (using the charge of the lepton)

2) Pairing the W with the b-jet from the same top decay:
We use CDF fitter which use kinematic information of the decay products, combine them and calculate χ^2 for all combinations. As the true combination we take the one with minimum χ^2. After the optimization we require the events to have minimum χ^2 less then 9.
Efficiency of the χ^2 cut, ε_{pair}, is 53% and the method purity, P_{pair}, (how often gives the right pairing) is 83%.

3) Getting the charge of the b-jet using the Jet Charge algorithm:
The algorithm uses the charge of the tracks associated to the jet weighted by their momentum projection on the jet axis. This algorithm has been optimized to determine the flavor of b jets in high p_T environment. Only the jets which pass the selection criteria (at least 2 tracks with p_T > 1.5 GeV, ...) are used.



$$jet\ Q = \frac{\sum_i^N q_i |\vec{j}\cdot\vec{p}_i|^{\kappa}}{\sum_i^N |\vec{j}\cdot\vec{p}_i|^{\kappa}}$$

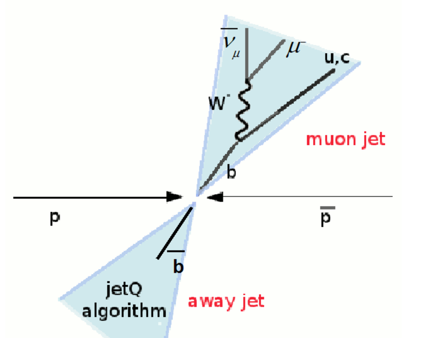
MC distributions of the calculated jet charge for the b-quark jet (red) and anti-b quark jet (blue).
At reconstruction level we assign b-jet to the b (anti-b) quark if the calculated jet charge is negative (positive).

In 61% of cases this algorithm gives the right flavor in MC, we define it as the purity of Jet Charge, p_{JQ}. Efficiency, ε_{JQ}, of the jet selection criteria is 98%.

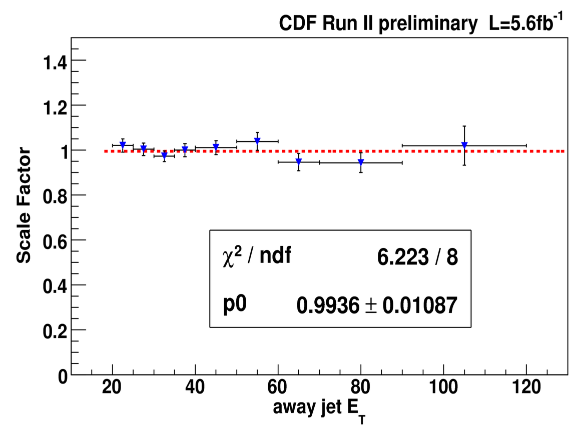
MC performance can not be relied on therefore purity of Jet Charge is calibrated in data.

Jet Charge calibration

Performance of the Jet Charge (JQ) algorithm is calibrated using dijet data on selected $b\bar{b}$ events where one of b's decay semileptonically to a muon. We calculate the observed purity as the fraction of the total events for which the muon and the JQ of the away jet have opposite sign. We correct the purity by taking into account the amount of non $b\bar{b}$ events present in the sample, secondary decays and mixing.



The result of the calibration is expressed in the form of the Scale Factor between the data corrected purity and the JQ purity calculated on b-jets selected from MC (Pythia) samples. The constant fit of the scale factor is shown in figure below.



Systematics Errors (in %)	
Tag Bais	0.5%
Non-b template	0.4%
M_{vtx} 2 templ fit	1.8%
Rec. inefficiency	2.2%
E_T dependence	1.4%
Total	**3.2%**

result: SF_{JQ} = **0.99 ± 0.01 (stat) ± 0.03 (syst)**

Getting the signal purity

The signal purity is defined using pairing purity, p_{pair}, jet charge purity, p_{JQ} and including the corrections for the non-b part (f_{nonb}, p_{nonb}):

$$p_s = f_{nonb} SF_{nonb} p_{nonb} + (1 - f_{nonb} SF_{nonb})(p_{pair} p_{JQ} SF_{JQ} + (1 - p_{pair})(1 - p_{JQ} SF_{JQ}))$$

In above, the measured jet charge purity in MC is corrected by the SF_{JQ}. The measured fraction of non-b in MC, f_{nonb}, is corrected by the mistag rate, SF_{nonb}, between data and MC.

f_{nonb}	0.079 ± 0.001
SF_{nonb}	1.01 ± 0.03
p_{nonb}	0.5 ± 0.01
p_{pair}	0.833 ± 0.001(stat) ± 0.008(syst)
p_{JQ}	0.608 ± 0.001(stat) ± 0.003(syst)
SF_{JQ}	0.99 ± 0.01(stat) ± 0.03(syst)

Expectations

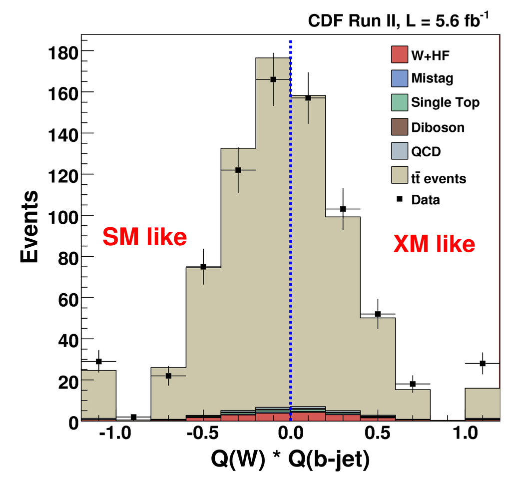
The expected number of background and signal pairs (two pairs per event) after event selection and pairing requirements. The numbers are obtained by multiplying the predictions (using a top cross section of 7.4pb) by the corresponding efficiencies (pairing efficiency and jet charge efficiency).

background	predicted # of events	pairing efficiency	jq efficiency	N_b or N_S (pairs)
L+J (5.6 fb-1)				
W+HF	66.27 ± 21.82	0.15 ± 0.004	0.97 ± 0.003	19.47 ± 6.43
QCD fakes	17.97 ± 13.53	0.17 ± 0.08	0.88 ± 0.12	5.35 ± 4.80
Diboson	4.67 ± 0.70	0.22 ± 0.02	0.97 ± 0.01	1.96 ± 0.35
Mistag	9.68 ± 2.57	0.15 ± 0.02	0.96 ± 0.02	2.79 ± 0.82
Singletop	10.62 ± 1.28	0.21 ± 0.004	0.97 ± 0.003	4.40 ± 0.54
Total	109.20 ± 25.88	-	-	34.0 ± 8.1
Signal	671.30 ± 110.83	0.532 ± 0.001 ± 0.005	0.979 ± 0.0004 ± 0.002	669.6 ± 115.7

Data results

We observed 815 events, from which 774 pairs remains after the χ^2 cut (pairing) and jet charge selection criteria. We observed 416 Standard Model like pairs (N_+) and 358 exotic model (XM) like pairs (N_-).

In figure we show the combined charge (product of the W charge and the associated jet charge) for data and MC. A negative value corresponds to a SM like pair.

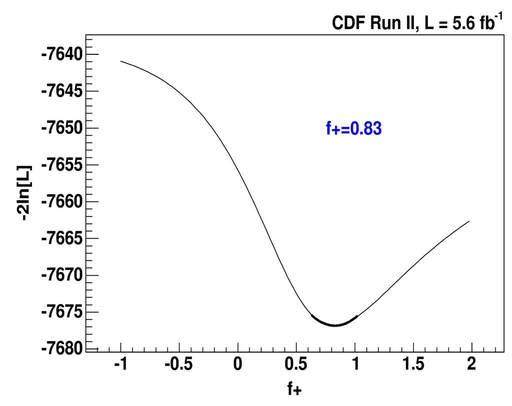


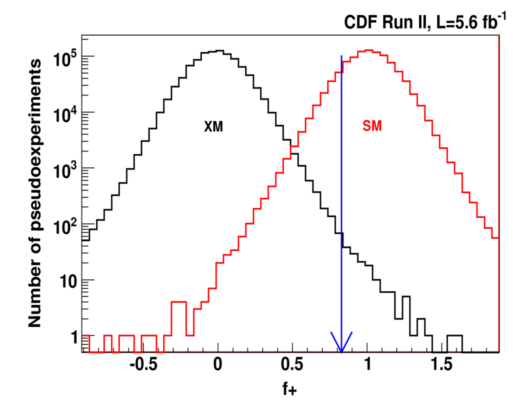
Statistical treatment

We define profile likelihood, L, based on 4 nuisance parameters obtained from MC – number of signal (background) pairs, N_s (N_b), signal (background) purity, p_s (p_b) and parameter of our interest f+. The parameter f+ express the fraction of pairs with top charge +2/3 (expected value for SM is 1 and for XM is 0).

Nuisance parameters	
N_s = 699.6 ± 115.7	p_s = 0.562 ± 0.004(stat) ± 0.011(syst)
N_b = 34.0 ± 8.1	p_b = 0.50 ± 0.01

To obtain the result we minimize negative profile likelihood logarithm (-2.ln L) for the observed numbers of SM and XM like pairs. By running the pseudo-experiments we get distribution of the fraction of SM like pairs (f+) assuming either the XM (black curve) or the SM (red curve). In the figure on the right the measured value of the **f+ = 0.83** is indicated.





Then two p-values (one sided) can be calculated:
p-value under SM: p_{SM} = 0.134 **p-value under XM: p_{XM} = 1.4 × 10^{-4}**

To obtain final conclusions we use **a-priori criteria**:
- if p_{SM} < 0.0013 => 3σ evidence of non-SM effect
- if p_{SM} < 2.87 × 10^{-7} => 5σ observation of non-SM effect
- if p_{SM} > 0.0013 => do not exclude SM
- if p_{XM} < 1% => would exclude XM with 99% CL

Conclusions

We do not exclude the SM. We exclude XM with 99% CL

Forward–backward asymmetry in $b\bar{b}$ production at 1.96 TeV $p\bar{p}$ collistion at the Tevatron

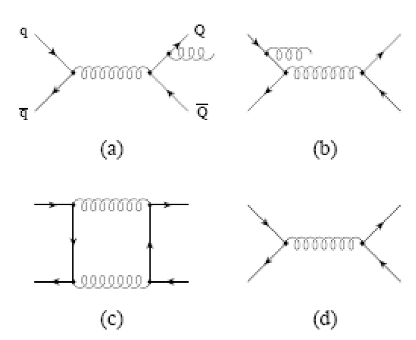
Theory

LO strong interaction processes $q + \bar{q} \to Q + \bar{Q}$ and $g + g \to Q + \bar{Q}$: no asymmetry A_{FB}!

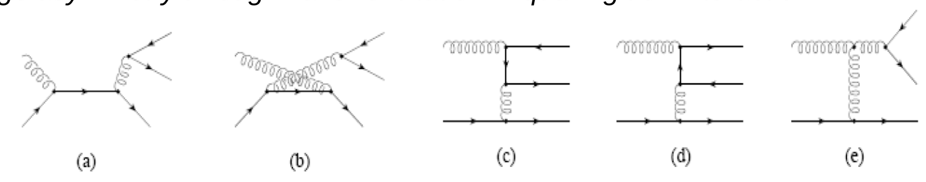
Sources of A_{FB}:

1) Interference of amplitudes with the same initial and final state particles

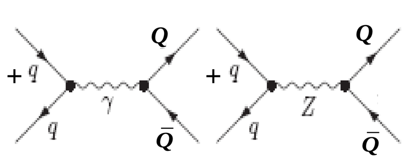
→ Interference of final-state (a) with initial-state (b) gluon radiation amplitude
→ Interference of the box (c) with Born diagram(d) (dominant processes at Tevatron)



2) Charge asymmetry through flavor excitation in quark-gluon interaction



3) Contribution of electroweak processes

→ (1c) + (1d) +


A_{FB} formulae for $q\bar{q}$ rest frame:

charge asymmetry: $\hat{A}_{Ch}(\cos\hat{\theta}) = \dfrac{N_Q(\cos\hat{\theta}) - N_{\bar{Q}}(\cos\hat{\theta})}{N_Q(\cos\hat{\theta}) + N_{\bar{Q}}(\cos\hat{\theta})}$ forward-backward asymmetry: $\hat{A}_{FB}(\cos\hat{\theta}) = \dfrac{N_Q(\cos\hat{\theta}) - N_Q(-\cos\hat{\theta})}{N_Q(\cos\hat{\theta}) + N_Q(-\cos\hat{\theta})}$

where $\hat{\Theta}$ is the production angle of Q quark in the $q\bar{q}$ rest frame

Assuming the CP conservation, one can write: $N_{\bar{Q}}(\cos\hat{\Theta}) = N_Q(-\cos\hat{\Theta}) \Rightarrow \hat{A}_{Ch} = \hat{A}_{FB}$

The **integral asymmetry** is then defined:

$$\bar{\hat{A}} = \frac{N_Q(\cos\hat{\Theta} \geq 0) - N_{\bar{Q}}(\cos\hat{\Theta} \geq 0)}{N_Q(\cos\hat{\Theta} \geq 0) + N_{\bar{Q}}(\cos\hat{\Theta} \geq 0)}$$

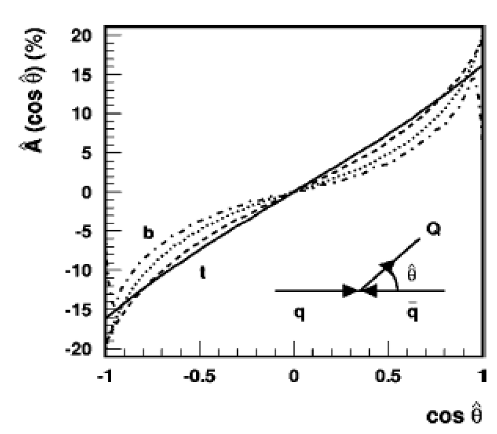
or by using the Lorentz invariant Δy_b:

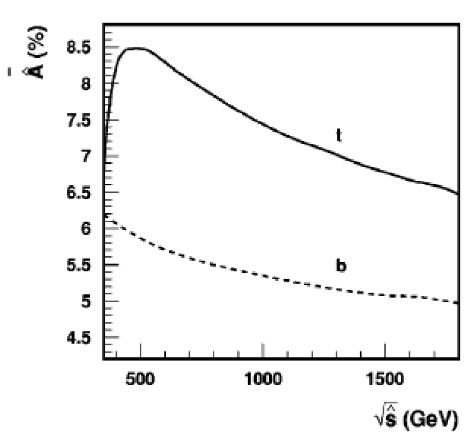
$$\bar{\hat{A}} = \frac{N(\Delta y_b > 0) - N(\Delta y_b < 0)}{N(\Delta y_b > 0) + N(\Delta y_b < 0)}$$

where $\Delta y_b = y_b - y_{\bar{b}}$, $\Delta y_b = 2\tanh^{-1}(\beta\cos\hat{\Theta})$, $\beta = \sqrt{1 - \frac{m_b^2}{\hat{s}}}$

m_b … b quark mass, $\hat{s}$ … center of mass energy

Predictions ... Phys Rev D59 054017 (1999)





Differential asymmetry A_{FB} :
→ maximum at $\cos\hat{\Theta} = \pm 1$

Integrated A_{FB} ~ 5 – 6 %

Suggested approaches:

We plan to use di-jet b-tagged events with two back-to back jets, where one b-jets decays semi-leptonically
→ similar selection was used for Jet Charge algorithm calibration

1) Soft lepton tag is used to determine flavor of b-jet: $b \to c + l^- \bar{\nu}_l$, $\bar{b} \to \bar{c} + l^+ \nu_l$, so l^- (l^+) define b-quark ($\bar{b}$-quark).

variable of interest Δy_b is defined: $\Delta y_b = Q(\mu) \times (y_{away\ jet} - y_{muon\ jet})$

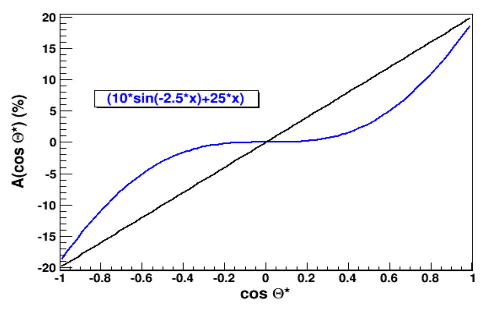
2) Using Jet Charge algorithm to distinguish b and $\bar{b}$ initiated b-jet (purity only 61%, but higher statistics)

variable of interest Δy_b is defined: $\Delta y_b = Q_{forward\ jet} \times (y_{forward\ jet} - y_{backward\ jet})$

Monte Carlo studies

The MC sample do not contain the forward-backward asymmetry, so we **need to add the asymmetry** to the sample

→ we select the $q\bar{q} \to b\bar{b}$ events using the MC parton information and change the weights of these events according the function in figure below. In the case of $qg \to b\bar{b}$ ($gg \to b\bar{b}$) we do not add asymmetry.



The asymmetry study done of the statistics of ~ 40 000 events

The weights for $q\bar{q} \to b\bar{b}$ events:

1) $W_1(x)$ = 1+0.1 * sin(-2.5 * x) + 0.25 * x 2) $W_2(x)$ = 1+0.2 * x

Reconstructed (measured) asymmetry:

1) A_{FB} = 0.0081 ± 0.0051 2) A_{FB} = 0.0221 ± 0.0051

If the asymmetry is present on the level bigger then it is expected for SM, it can be seen on the full CDF statistics!

Pavol Bartoš, Stanislav Tokár, Comenius Univeristy, on the behalf of the CDF collaboration