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Finding the Charge of the top quark in the Dilepton Channel

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Abstract. There is a question about the identity of the top quark. Is it the top quark of the Standard Model (SM) with electric charge $\frac{2}{3}$ or is it an exotic quark with charge -$\frac{4}{3}$? An exotic quark has been proposed by D. Chang *et al*.[1]. This analysis will use the standard CDF run II dilepton sample. The key ingredients of this analysis are the correct pairing of the lepton and b-jet, the determination of the charge of the b-jet. The analysis proceeds by using a binomial distribution and is formulated so that rejecting one hypothesis means support for the other hypothesis.

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INTRODUCTION

In the SM the top quark decays immediately into $t \to W^+b$, while in the Exotic Model (EM) into $t \to W^-b$ (and cc). We measure the charge of the lepton which is the same as that of it's parent (W). In the top model of D. Chang *et al*. the exotic quark is part of a doublet with the other quark ("top") having a mass of 230 GeV or higher. We are interested in establishing whether the quark we observe(top) has electric charge $\frac{2}{3}$ or -$\frac{4}{3}$ independent of any model. The signature for the SM is that the lepton and the associated b have opposite charges (either -+ or +-), while in the (EM) they have the same charges (either ++ or –).

We plan to look at the dilepton sample for an integrated luminosity = 1 fb^{-1}. The present dilepton sample contains 64 events and corresponds to an integrated luminosity of 0.75 fb^{-1}.

KEY INGREDIENTS

There are two key ingredients to the method. First, we need to know how to do the pairing between the lepton and the b-jet. The top mass has been determined using a kinematic method [2]. In the kinematic method a set of equations is obtained from the measured momentum of the b-quarks and leptons, the two components of the measured missing E_t, and assumptions about the six final-state particles masses, an additional constraint on the longitudinal momentum of the $t\bar{t}$ system, and constraints on the decays of the W, t, and $\bar{t}$. The system in general has 8 solutions, at the final stage there are two solutions left, we choose the solution which has the largest number of entries as corresponding to the correct pairing. Second, we need to find the charge of the b-jet. We determine the charge of the b-quark by looking at the charge of the particles coming from the b-jet. The following equation is used:

$$Q_{\rm jet} = \frac{\sum_{tracks} q_i(\overrightarrow{P_i} \cdot \overrightarrow{P_{\rm jet}})^{0.5}}{\sum_{tracks}(\overrightarrow{P_i} \cdot \overrightarrow{P_{\rm jet}})^{0.5}} \tag{1}$$

CHARGE SYMMETRY

We will refer to the reconstructed charge distribution as P_b(x). The corresponding symmetry relation is $P_b = P_{\bar{b}}$(-x). We use the variable $t_Q = |\, x+l_Q \,|$ where x is the reconstructed b-jet charge and l_Q is the charge of the paired lepton. In

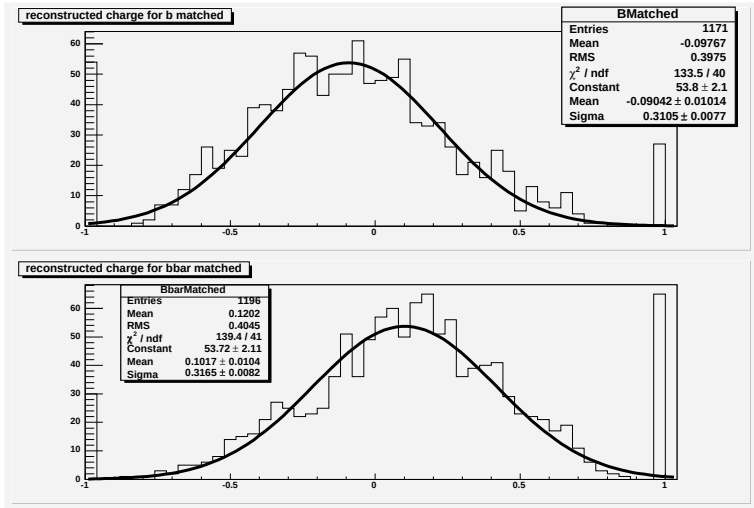

FIGURE 1. Reconstructed $b(\overline{b})$ jet charge distribution.

Fig. 1 (the x-axis is Q_{jet} as defined by Eq. 1) we show the b ($\overline{b}$) charge distribution obtained from the Pythia Monte Carlo for a top mass of 175 GeV/c^2.

BASIC EQUATION

The charge of the top quark is related to the correct pairing of the lepton and the b-quark and knowing the charge probability distribution of the b-jet. P_{lb} is the probability for the correct pairing of the lepton and the b-jet. When the pairing is always correct the probability distribution of the variable t_Q is related to the probability distribution of the b-quark: $P(t_Q) = P_b(t_Q - 1)$. This can be generalized to:

$$P(t_Q) = P_{lb}P_b(t_Q - 1) + (1 - P_{lb})P_b(1 - t_Q). \tag{2}$$

The corresponding equation for the exotic hypothesis is:

$$P^{Ex}(t_Q) = P_{lb}P_b(1 - t_Q) + (1 - P_{lb})P_b(t_Q - 1). \tag{3}$$

We formulate the problem of determining the charge of the top quark as a problem in binomial statistics. We define the charge of the b-jet to be -$\frac{1}{3}$ if the reconstructed b-jet ($\overline{b}$-jet) charge is less(greater) than 0. For the Pythia charge distribution shown in Fig.1 this is the correct determination 63.0 $\pm$ 1.3% of the time. The problem of correctly associating the b-jet and and the lepton is a problem that we have solved in our kinematic analysis of the t quark mass. The smeared distribution of the two possible pairings are compared and the one with the largest number of entries is selected. The correct solution is found 70% of the time.

We define P^{++} to be the probability to measure top charge +$\frac{2}{3}$ given that the SM is true and P^{+-} to be the probability to measure top charge -$\frac{4}{3}$ given the SM is true. For a perfect experiment P^{+-} would be 0.

$$P^{++} = P_b^{charge}P_{lb} + (1 - P_b^{charge})(1 - P_{lb}) \tag{4}$$

For the numbers given we have P^{++} = 0.63$\times$0.7 +(1-0.63)(1-0.7) = 0.55.

BINOMIAL STATISTICS

The probability to observe N^{++} or less pairs out of N pairs (where each pair contains a lepton and b-jet which have opposite charge) is:

$$P(N^{++}) = \sum_{i=0}^{N^{++}} \begin{pmatrix} N \\ i \end{pmatrix} (P^{++})^i (1 - P^{++})^{N-i} \tag{5}$$

BACKGROUNDS

We have verified that the probability for measuring t_Q in background events is 50% by running on Monte Carlo events. The three background processes are Drell-Yan, $W \to l\nu$ + jets (where the jet fakes a lepton) and Dibosons. Our formula is modified to include backgrounds:

$$\mathrm{P}^{++}_{bkg} = \mathrm{P}^{++} f_{top} + 0.5 f_{bkg} \tag{6}$$

Our expectation is that 62% of the events will be signal and 38% background. Thus P^{++}_{bkg} = 0.55×0.62 + 0.5×0.38 = 0.53

IMPROVING THE LEPTON *b* PAIRING

The square of the invariant mass of the lepton and the b can be easily calculated. There are 4 possible values as there are two leptons and two jets. Two of the combinations are associated with the correct pairing and two with the incorrect pairing. By running a Monte Carlo we can see which pairings are correct and which are incorrect. It turns out that only incorrect pairing are observed at very high values of the invariant mass. This means the other solution is the correct one. Using a cut value of 22000 GeV^2/c^4 allows one to select a sample that has a 97% probability of being the correct pairing. The efficiency of this cut is only 40%. We call this method M^2_{lb-max}.

FIGURE OF MERIT

How can we compare different methods? For example is it better to use the kinematic method or the M^2_{lb-max}? The figure of merit is $\varepsilon \mathrm{D}^2$. The efficiency is ε and the Dilution is D. The Dilution D = 2×Purity -1. Thus the figure of merit for the M^2_{lb-max} method is $0.40\times(2\times0.97 - 1)^2 = 0.35$, and the figure of merit for the kinematic method is $1.0\times(2\times0.7 - 1)^2 = 0.16$. For the kinematic method the efficiency is much higher, but the purity is lower and we find the M^2_{lb-max} is more than a factor of 2 better.

PLANS

The most difficult part of the analysis will be to use Calibration data (QCD $b\bar{b}$ dijets) to obtain b-jet charge distribution and to extrapolate these data so that we understand the *b*-jet charge distribution at high p_t. It will be interesting to compare these results with Fig.1. We plan to make measurements in the dilepton channel and also in the lepton plus jet channel.

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