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Search for Anomalous Single Top Production in ep Collisions at HERA

H1 Collaboration

Abstract

A search for single top quark production is performed in $e^{\pm}p$ collisions at HERA. The search exploits the full data set with centre of mass energies up to 320 GeV corresponding to an integrated luminosity of 482 pb^{-1}. The investigated model considers anomalous production of top quarks in a Flavour Changing Neutral Current process involving the coupling $\kappa_{tu\gamma}$. Decays of top quarks into a b quark and a W boson with subsequent decay of the W in the leptonic electron and muon channels are included. A multivariate analysis is performed to discriminate anomalous top quark production from Standard Model background processes, dominated by real W production. An upper limit on the anomalous top production cross section $\sigma_{ep\rightarrow etX} < 0.16$ pb, corresponding to $\kappa_{tu\gamma} < 0.14$, is established at the 95% confidence level.

1 Introduction

In ep collisions at the HERA collider the production of single top quarks is kinematically possible due to the large centre of mass energy up to $\sqrt{s} = 320$ GeV. In several extensions of the Standard Model (SM), the top quark is predicted to undergo Flavour Changing Neutral Current (FCNC) interactions, which could lead to a sizeable top production cross section [1]. The dominant process for SM single top production at HERA has a cross section of less than 1 fb and is neglected [2].

The signature of top decay to b and W would be the lepton and the missing transverse momentum associated with a leptonic decay of the W boson ($W \rightarrow \ell\nu$), accompanied by a high P_T hadronic final state X from the fragmentation of the b quark. Events with such a topology may be present in the event sample with energetic isolated electrons and muons together with missing transverse momentum observed at HERA [3–6].

The present analysis investigates the leptonic W decay channels to electrons and muons. The strategy follows the search for anomalous single top production using the H1 detector with the data collected in HERA I [7]. Advances in the detector understanding and software are taken into account.

2 Phenomenology

Anomalous single top production is described by an effective Lagrangian where the interaction of a top with u-type quarks via a photon is described by a magnetic coupling $\kappa_{tU\gamma}$. Contributions from the charm quark are neglected ($\kappa_{tc\gamma} \equiv 0$). The vector couplings to a Z^0 boson v_{tUZ} are also neglected for now ($v_{tUZ} \equiv 0$). The simulation of the anomalous single top signal relies on an event generator [8], which uses the leading order (LO) matrix elements of the complete $e + q \rightarrow e + t \rightarrow e + b + W \rightarrow e + b + f + \bar{f}'$ process as obtained from the CompHEP program [9]. The main SM background process is the production of real W bosons, modelled by the EPVEC generator [10]. NLO QCD corrections are taken into account by reweighing the generated events [11]. A theoretical error of 15% is assumed on the W contribution and 30% on the remaining SM background.

3 Top Reconstruction and Selection

The search for single top production is based on the full sample of isolated lepton events selected in HERA I+II data by H1 [5]. To extract the top contribution to this sample, first a top quark candidate is reconstructed as the sum of the reconstructed four-vectors of the b quark candidate, the lepton ℓ and the neutrino ν_ℓ. The b quark candidate is reconstructed as the sum of the four-vectors of all hadronic jets in the event. The neutrino four-vector ν is reconstructed from the transverse and longitudinal momentum balance of the event. Only events where a good reconstruction of a top quark is possible, defined by physical solutions in the range $0 < M_{\ell\nu b} < 300$ GeV, are considered. Furthermore a charge requirement $q_\ell \cdot \frac{\kappa}{\delta\kappa} > -2$

is imposed on the lepton, where q_ℓ is the charge of the lepton, κ is the curvature of the track associated to the lepton and $\delta\kappa$ is the error on the curvature. This requirement is only applied in the central region $20^\circ < \theta_\ell < 160^\circ$ where the charge determination by the tracking detectors is reliable. At this level, called *top preselection*, the following observables are combined using a multi-variate method to discriminate single top production from SM background:

- P_T^b, the transverse momentum of the reconstructed b quark candidate.
- $M_{\ell\nu b}$, the reconstructed top mass.
- θ_W^ℓ, the W decay angle calculated as the angle between the lepton momentum in the W rest frame and the W direction in the top quark rest frame.

Distributions of these observables are shown in figure 1 separately for the electron and muon channels. In the electron channel, 24 events are selected, while 26 ± 4.0 are expected from the SM. In the muon channel, 10 events are selected, while 9.3 ± 1.3 are expected from the SM. In all distributions the data agree well with the SM expecation within the errors.

The observables are then combined into a multi-variate discriminator. For the training of the discriminator, the single top MC is used as the signal model and the W MC as the background model. Electron and muon channels are treated separately. Several multi-variate methods were trained and evaluated in parallel using a software toolkit [12]. The methods are found to perform comparably. In particular, the current likelihood method was checked for compatibility with that used in the HERA I analysis [13]. Comparable results were reproduced using only the HERA I data. A comparison with a cut based top selection (selecting events in the phase space $P_T^b > 30$ GeV, $M_{\ell\nu b} > 140$ GeV) was also found to yield comparable results with the HERA I analysis and the multi-variate methods. For the extraction of the results a discriminator based on a phasespace density estimator with a range-search algorithm is chosen. Distributions of the discriminator output for the electron and muon channels are shown in figure 2 for the signal and background MCs. Also shown are the data events as classified by the algorithm.

4 Cross Sections and Limits

Limits on the signal cross section were extracted from the discriminator spectra using a maximum likelihood method. The number of signal events S_{fit} was fit by constructing a likelihood assuming a Poisson-distributed background with a signal component of which only the shape is known. The normalisation of this signal component was determined from the minimum of the negative double log-likelihood function $-2\log\mathcal{L}$. The number of signal events is converted to the cross section

$$\sigma_{ep->etX} = \frac{S_{fit}}{\epsilon_{top} \cdot Br \cdot \mathcal{L}}$$

where ϵ_{top} is the efficiency to select single top production estimated with the single top MC, Br is the branching ratio product $\mathcal{B}_{t\to bW} \cdot \mathcal{B}_{t\to\ell\nu}$ and $\mathcal{L}$ the integrated luminosity. Correction factors for NLO contributions and different centre-of-mass energies are applied to the cross section [14].

Likelihood functions are calculated for the electron and muon channel separately. The channels are combined by adding their $-2\log\mathcal{L}$ functions. The likelihood function for the hadronic channel was taken from the HERA I analysis and included in the sum. The 95% confidence limits on the cross-section are then taken directly from the zero-suppressed log-likelihood function by interpreting it as a χ^2 function. An upper bound on the cross–section of

$$\sigma_{ep\to etX} < 0.16\ \mathrm{pb}$$

at the 95% confidence level is found, which is translated into an upper bound on the coupling

$$\kappa_{tu\gamma} < 0.14.$$

Figure 3 represents the current status of constraints on the couplings $\kappa_{tu\gamma}$ and v_{tuZ}. The top mass is assumed to be $m_t = 175$ GeV in order to compare with previous results. The new preliminary results presented here extend the bounds on $\kappa_{tu\gamma}$ into a region so far uncovered by current colliders. The most strict bound on v_{tuZ} is set by the L3 experiment at LEP [15]. Also shown are results from the CDF experiment at the Tevatron [16] and results from the ZEUS experiment using the HERA I data [17].

5 Summary

Limits on anomalous single top production in ep collisions were set using the full HERA I+II data set recorded by the H1 detector. Preliminary results presented here extend the bounds on the coupling $\kappa_{tu\gamma}$ into a region so far uncovered by current colliders.

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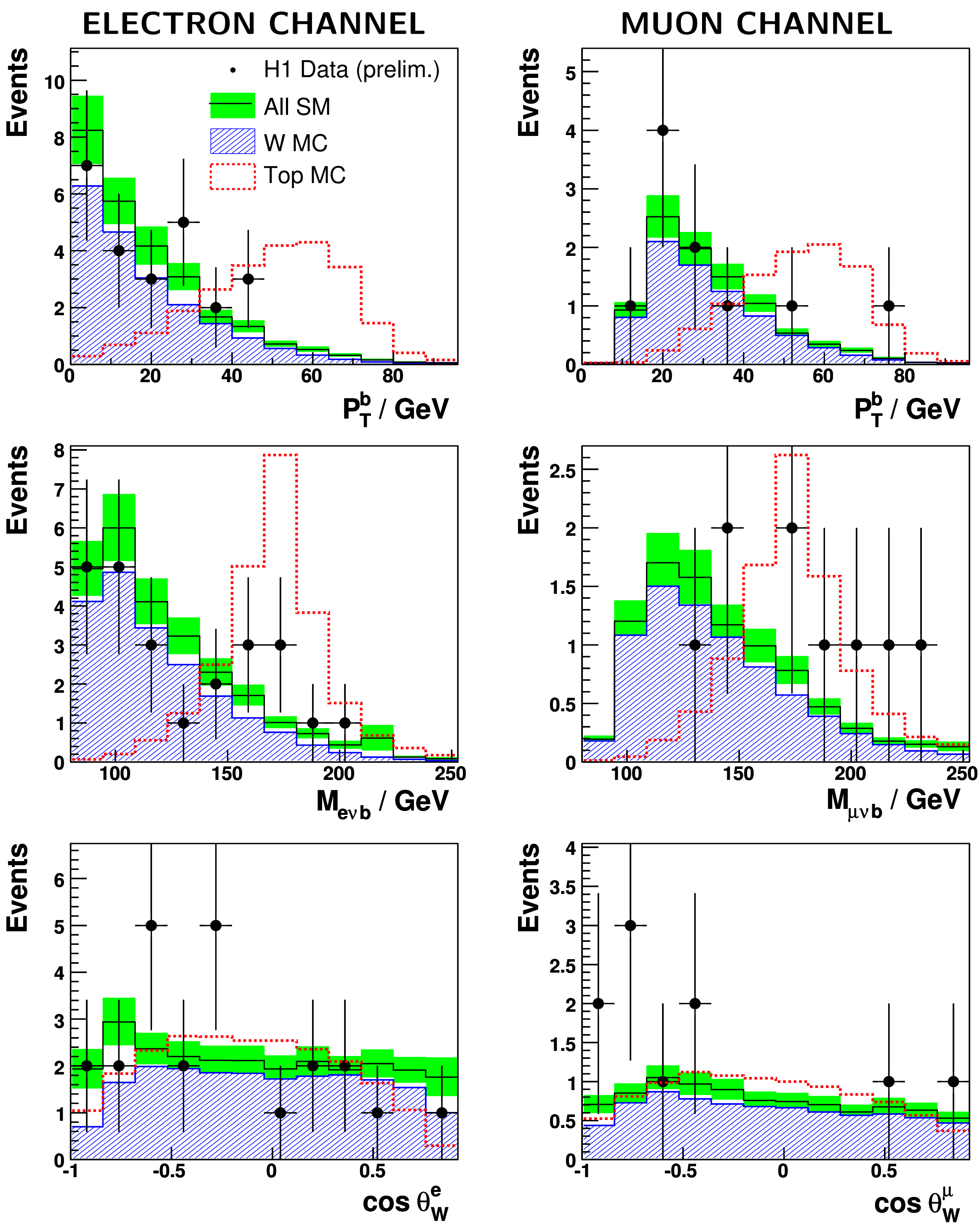

Figure 1: Control distributions of observables used to differentiate anomalous single top production from SM background processes in the top preselection. Show are the transverse momentum of the reconstructed b quark P_T^b, the reconstructed top mass $M_{\ell\nu b}$ and the W decay angle $\cos\theta_W^\ell$ for the electron channel (left column) and muon channel (right column). The data are shown as points, the total SM expectation as open histogram with systematical and statistical errors added in quadrature in green. The W production component used to train the multi-variate discriminators is shown in blue and the shape of the top signal MC is shown in red.

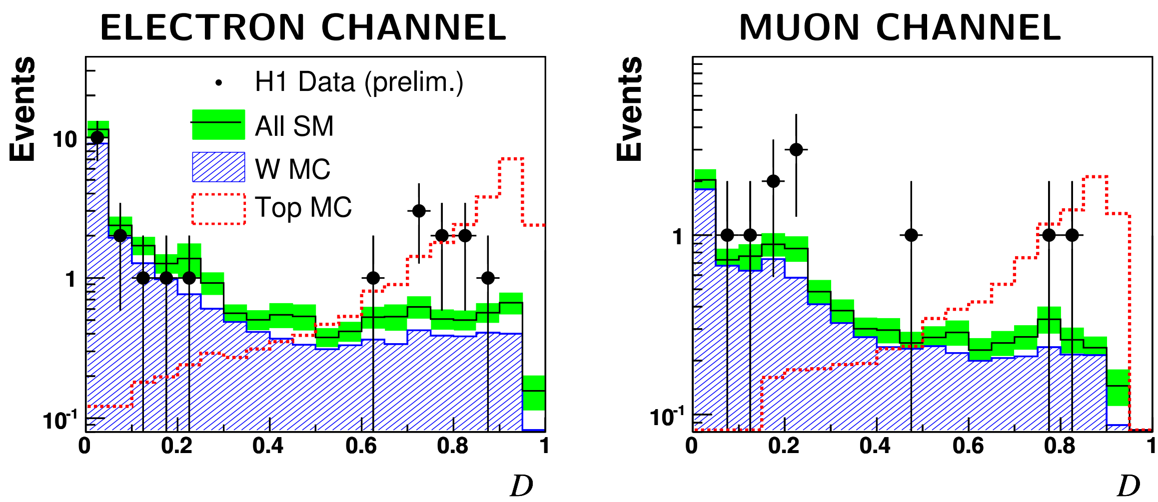

Figure 2: Discriminator output distributions for the electron channel (left) and muon channel (right) from a phase space density estimator using a range search algorithm. The data are shown as points, and the total SM expectation as open histogram with systematical and statistical errors added in quadrature in green. The W production component used to train the multi-variate discriminators is shown in blue and the shape of the top signal MC is shown in red.

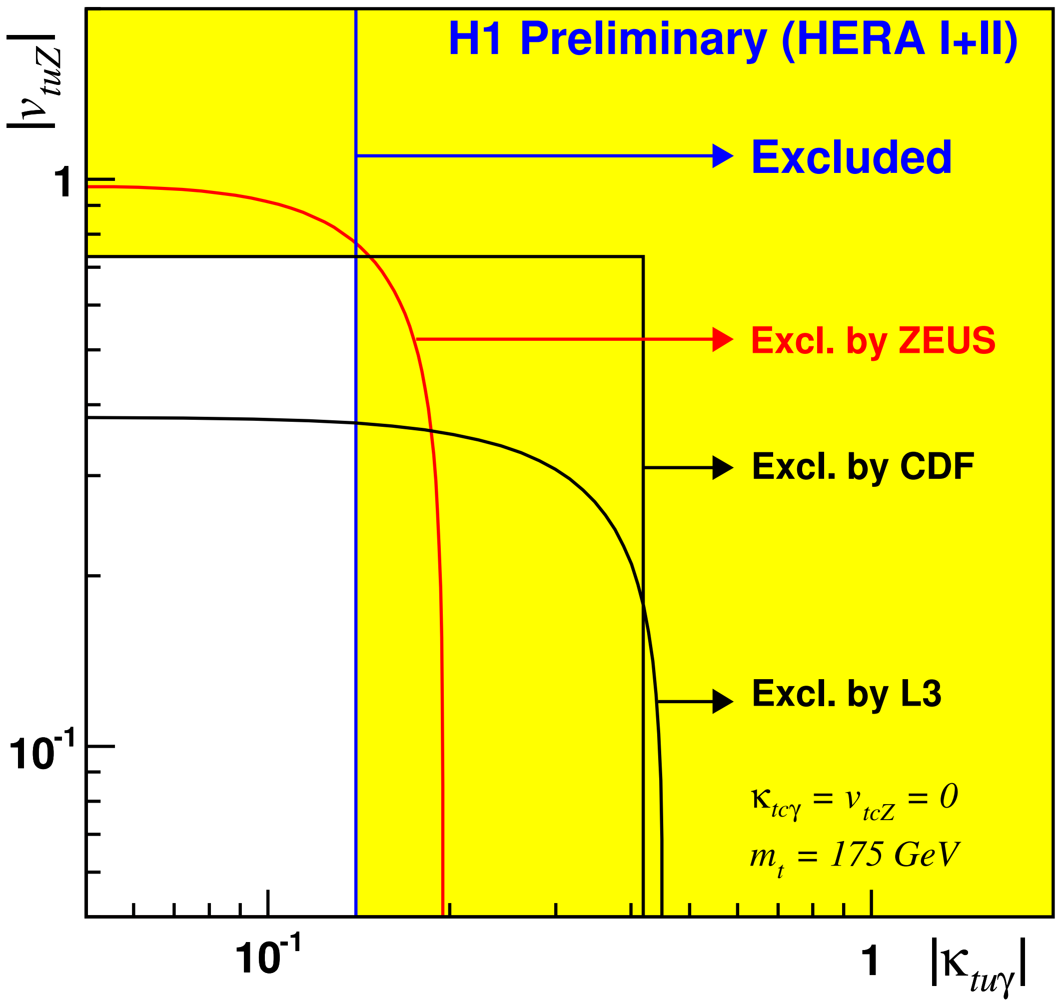

Figure 3: Exclusion limits at the 95% confidence level on the anomalous $\kappa_{tu\gamma}$ and v_{tuZ} couplings obtained at the TeVatron (CDF experiment), LEP (L3 experiment) and HERA (H1 and ZEUS experiments). Anomalous couplings of the charm quark are neglected $\kappa_{tc\gamma} = v_{tuZ} = 0$. Limits are shown assuming a top mass $m_t = 175$ GeV.