SEARCH FOR SINGLE-TOP PRODUCTION WITH THE ZEUS DETECTOR AT HERA*

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A search for anomalous single-top production, $ep \to etX$, $t \to Wb$, has been made with the ZEUS detector at HERA using an integrated luminosity of 130 pb^{-1}. No evidence for top-quark production was found in either the leptonic or the hadronic decay channel of the W boson. The resulting constraints on single-top production via quark-flavour changing neutral current (FCNC) transitions exclude a substantial region in the FCNC $tu\gamma$ coupling not ruled out by other experiments.

1 Single-top production at HERA

In the Standard Model (SM), flavour changing neutral current (FCNC) interactions are suppressed by the GIM mechanism [1]. Due to the large mass of the top-quark, close to the electroweak symmetry breaking scale, deviations from the SM are expected to be observed first in the top sector.

At the HERA ep collider, with its maximum centre-of-mass energy of $\sqrt{s} =$ 318 GeV, top quarks can only be singly produced. At tree level, the production proceeds through the charged current (CC) reaction $ep \to \nu t\bar{b}X$. Since the SM cross section for single-top production is less than 1 fb, any observed single-top event in the present data would be a clear sign of physics beyond the SM. The FCNC coupling, tuV or tcV, would induce the neutral current (NC) reaction $ep \to etX$ [2, 3], in which the incoming lepton exchanges a γ or Z^0 with an up-type quark in the proton, yielding a top quark in the final state (see Fig. 1). The Z^0 exchange is suppressed by the large propagator mass. Furthermore, large values of $x \gtrsim 0.3$, where x denotes the fraction of the proton momentum carried by the struck quark, are needed to produce a top quark. Since the

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u-quark density of the proton is much higher than the c-quark density, the production of single top quarks is most sensitive to a coupling of the type $tu\gamma$.

The search for single-top quark production [4] reported in the following sections was based on the complete HERA I dataset of 130 pb^{-1}.

2 Single-top signatures

The SM decay, $t \to bW$, with subsequent leptonic decay of the W boson, $W \to e\nu_e, \mu\nu_\mu$ (11% branching ratio per channel), leads to the presence of an isolated high-energy lepton, significant missing transverse momentum arising from the undetected neutrino and a large value of the hadronic transverse momentum, p_T^{had}, stemming from the b-quark decay. Production of single W bosons with subsequent leptonic decay is the only SM process with a measurable cross section (about 1 pb, evaluated including QCD corrections $\mathcal{O}(\alpha^2\alpha_s)$ [5]), which leads, at HERA, to events with an isolated lepton and missing transverse momentum in the final state. However a steeply falling p_T^{had}-spectrum is expected for events from single W production.

In the hadronic decay channel of the W boson, $W \to q\bar{q}'$ (68 % branching ratio), three jets are expected in the final state, with the dijet invariant-mass distribution for the correct pair of jets peaking at the mass of the W boson, M_W, and the three-jet invariant-mass distribution peaking at the mass of the top quark, M_{top}. QCD multijet events are the main SM background in the hadronic channel.

Anomalous FCNC couplings could lead to the decays $t \to u\gamma$ and $t \to uZ^0$, resulting in multi-jet signatures with lepton pairs from the decay of the gauge boson.

3 Leptonic channel

The main selection requirements for the search in the leptonic decay channels of the W boson were large missing transverse momentum as measured with the calorimeter, $p_T^{\text{CAL}} > 20$ GeV, and the presence of an isolated track, which had to be identified as either electron or muon. The events had to contain at least one jet. Events with an electron candidate in a back-to-back configuration with the hadronic system were rejected, thus reducing background from neutral current deep inelastic scattering (NC DIS) events.

The selected data sample contained 24 (12) electron (muon) candidate events, in good agreement with $20.6^{+1.7}_{-4.6}$ ($11.9^{+0.6}_{-0.7}$) events expected from SM processes. The SM expectation in the electron channel is dominated by badly reconstructed NC DIS events, while in the muon channel the main contribution is from Bethe-Heitler muon pair production, where only one of the two muons is detected and the missing transverse momentum is due to mismeasurement.

A subsequent final selection for single-top candidates was applied to the preselection of isolated lepton events. The cuts were optimised using simulations of both the SM background and the expected single-top signal. In the electron channel, NC DIS background was further reduced based on the energy-momentum balance. In the muon channel, a cut on the missing transverse momentum, after correcting for the muon-track momentum, was applied to reduce background from Bethe-Heitler muon pair production. In both channels, a large value of the hadronic transverse momentum, $p_T^{\rm had} > 40$ GeV, was required. After applying these additional cuts, no events remained in the data sample, while $0.94^{+0.11}_{-0.10}$ ($0.95^{+0.14}_{-0.10}$) electron (muon) events were expected from SM processes, mainly from single W production. The efficiency for single-top production was 34% (33%) in the electron (muon) channel. Table 1 summarizes the observed and expected events for different stages of the single-top search.

Leptonic channel	Electron channel obs./expected (W)	Muon channel obs./expected (W)
Preselection	24 / $20.6^{+1.7}_{-4.6}$ (17%)	12 / $11.9^{+0.6}_{-0.7}$ (16%)
Final sel. ($p_T^{\rm had} > 25$ GeV)	2 / $2.90^{+0.59}_{-0.32}$ (45%)	5 / $2.75^{+0.21}_{-0.21}$ (50%)
Final sel. ($p_T^{\rm had} > 40$ GeV)	0 / $0.94^{+0.11}_{-0.10}$ (61%)	0 / $0.95^{+0.14}_{-0.10}$ (61%)

Table 1: Number of observed events at different selection stages of the single-top search, compared to the SM expectations. The percentage of single-W production included in the expectation is indicated in parentheses. The statistical and systematic uncertainties added in quadrature are also indicated.

4 Hadronic channel

The event selection in the hadronic decay channel of the W boson required three jets with $p_T^{\text{jet1}} > 40$ GeV, $p_T^{\text{jet2}} > 25$ GeV and $p_T^{\text{jet3}} > 14$ GeV. The photoproduction background was reduced by requiring one of the 2-jet masses and the 3-jet mass to be compatible with the W boson mass and the top mass, respectively. Events from NC DIS processes were suppressed by rejecting events with identified electron candidates.

The normalisation uncertainties of the photoproduction background, which was only evaluated in leading order of QCD, were reduced by normalising the simulated event rates to those observed in the low-mass domain. There were 14 events observed in the data, while $17.6^{+1.8}_{-1.2}$ events were expected from SM background. The signal efficiency was 24% for the hadronic decays of the W boson.

5 Exclusion limits on FCNC couplings

The results from the searches in both the leptonic and hadronic W decay channels were combined to constrain the production of single-top quarks through FCNC. The 95% confidence level (CL) limit for $\kappa_{tu\gamma}$, evaluated assuming $v_{tuZ} = 0$ and $M_{\text{top}} = 175$ GeV, is $\kappa_{tu\gamma} < 0.174$. Next to leading order (NLO) QCD corrections to the single-top production cross section [3] have been taken into account. In addition, the effect of a non-vanishing v_{tuZ} coupling was considered. In this case a leading order cross section was used. The LEP [6] and Tevatron [7] experiments have performed similar searches for single-top production and rare top decays, respectively. They are sensitive to anomalous top-quark couplings to u and c quarks through both the photon and the Z^0 boson. The results of these searches are compared to the ZEUS limits in Fig. 2. The ZEUS limits are shown for three different values of M_{top}, since the uncertainty on the top mass is the dominating systematic uncertainty. It is evident that HERA is competitive in searches for FCNC couplings through photon interactions.

References

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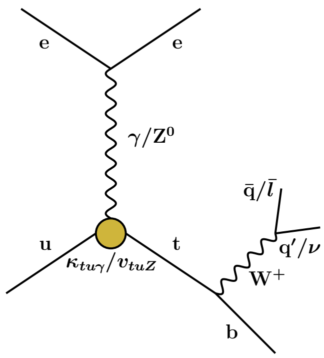

Figure 1: Single top-quark production via FCNC transitions at HERA.

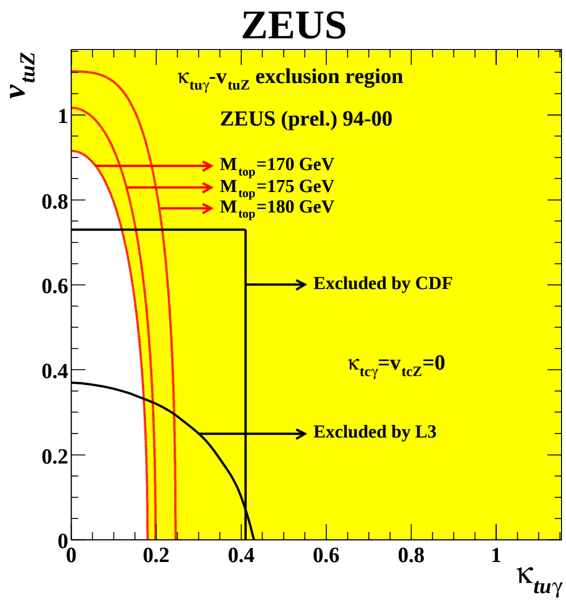

Figure 2: Exclusion regions at 95% C.L. in the $\kappa_{tu\gamma}$-v_{tuZ}-plane from L3, CDF and ZEUS.

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