W and Anomalous Single Top Production at HERA

Eram Rizvi

Queen Mary, University of London - Dept of Physics
Mile End Rd, London, E1 4NS - UK

The analysis of W production and the search for anomalous single top production is performed with the H1 detector at HERA with an integrated luminosity of 0.5 fb⁻¹, consisting of the complete high energy data from the HERA programme. Production cross section measurements of single W production, as well as W polarisation fractions in events containing isolated leptons and missing transverse momentum are also presented. In the context of a search for single top production an upper limit on the top production cross section \( \sigma_{ep \rightarrow etX} < 0.16 \) pb is established at the 95% confidence level, corresponding to an upper bound on the anomalous magnetic coupling \( \kappa_{t\gamma} < 0.14 \).

1 Events with Isolated Leptons and \( P_T^{\text{miss}} \)

Events containing a high \( P_T \) isolated electron or muon and associated with missing transverse momentum have been observed at HERA [1,2]. An excess of HERA I data events (1994–2000, mostly in \( e^+p \) collisions) compared to the SM prediction at large hadronic transverse momentum \( P_X^T \) was reported by the H1 Collaboration [2].

The main SM contribution is the production of real W bosons via photoproduction with subsequent leptonic decay \( ep \rightarrow eW^\pm (\rightarrow l\nu)X \), where the hadronic system \( X \) is typically of low \( P_T \).

The event selection employed by the H1 [4] analysis may be summarised as follows: The identified lepton should have high transverse momentum \( P_T^{l} > 10 \) GeV, be observed in the central region of the detector and be isolated with respect to jets and other tracks in the event. The event should also contain a large transverse momentum imbalance, \( P_T^{\text{miss}} > 12 \) GeV. Further cuts are then applied, which are designed to reduce SM background, whilst preserving a high level of signal purity.

The analysis has recently been performed on the electron and muon channels using the complete HERA I+II data sets, which corresponds to 478 pb⁻¹ [4]. A total of 59 events are observed in the data, compared to a SM prediction of 58.9 ± 8.2. For \( P_X^T > 25 \) GeV, a total of 24 events are observed compared to a SM prediction of 15.8 ± 2.5, of which 21 events are observed in the \( e^+p \)

*On behalf of the H1 Collaboration

DIS 2008
data compared to a SM prediction of $8.9 \pm 1.5$. The observed data excess in the HERA I $e^+p$ data thus remains at the 3.0$\sigma$ level for the complete H1 $e^+p$ dataset. The results of the analysis are summarised in Table 1.

Figure 1 shows the $P_T^X$ distribution of the $e^+p$ data for the combined electron and muon channels. The signal contribution, dominated by real $W$ production, is seen to dominate the total SM expectation in all data samples. Overall there is good agreement with the SM expectation. A possible contribution from anomalous single top production would be expected to contribute at high $P_T^X$.

2 Cross Sections and $W$ Polarisation Fractions

The selection results described in section 1 are used to calculate production cross sections for events with an energetic isolated lepton and missing transverse momentum ($\sigma_{\ell+P_{\text{miss}}}$) and for single $W$ boson production ($\sigma_W$), for which the branching ratio for leptonic $W$ decay is taken into account [7]. The results are shown below with statistical (stat) and systematic (sys) uncertainties compared to the SM prediction, quoted with a theoretical systematic error (th.sys) of 15%.

| H1 | HERA I+II Data       | SM     |
|----|----------------------|--------|
| $\sigma_{\ell+P_{\text{miss}}}$ | $0.24 \pm 0.05 \text{(stat)} \pm 0.05 \text{(sys)}$ | $0.26 \pm 0.04 \text{(th.sys)}$ |
| $\sigma_W$ | $1.23 \pm 0.25 \text{(stat)} \pm 0.22 \text{(sys)}$ | $1.31 \pm 0.20 \text{(th.sys)}$ |

A measurement of the $W$ polarisation fractions is also performed since new physics may modify the SM polarisation fractions of $W$s from single top decays [6] and is described in [7]. Additional selection criteria are applied to ensure good reconstruction of the $W$ and the missing $\nu$. Using a 2D fit, optimal values of the left-handed ($F_L$) and longitudinal ($F_0$) fractions are extracted, as shown in figure 2 (left) compared to the SM and a FCNC single top model [8]. The data are in agreement with the SM expectation albeit within large experimental uncertainties.

3 Search for Single Top Quark Production

The excess of events at high $P_T^X$ may be interpreted in terms of anomalous single top production via flavour changing neutral currents with coupling $\kappa_{tu\gamma}$ between $t$ and $u$ quarks and the exchange photon. Such a search has been reported by H1 previously [9] [10].

In this analysis, 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 studied. Therefore a top preselection is applied by requiring good top mass reconstruction and a lepton charge compatible top production.

A multivariate analysis is then performed to discriminate top from SM background (dominated by real $W$ production) using the transverse momentum of the reconstructed $b$ quark candidate $P_T^b$, the reconstructed top mass $M_{\ell b}$, and the $W$ decay angle $\cos \theta_W^\ell$ calculated as the angle between the lepton momentum in the $W$ rest frame and the $W$ direction in the top quark rest frame. A multivariate discriminator is trained using ANOTOP [8] as the signal model and EPVEC [11] as the background model. The discriminator is based on a phase space density estimator using a range search algorithm [12].

DIS 2008
The observed data distributions of these quantities agree well with the SM expectation within the uncertainties. No evidence for single top production is observed. Using a maximum likelihood method an upper limit on the anomalous top production cross section of $\sigma_{ep\rightarrow etX} < 0.16$ pb is established at 95% CL. The corresponding H1 limit on the coupling $r_{tu\gamma} < 0.14$ is shown in figure 2 (right) and is currently the best limit compared to those from other colliders 13-14.

References

[1] C. Adloff et al. [H1 Collaboration] 1998 Eur. Phys. J. C 5 575 (Preprint hep-ex/9806009)
[2] V. Andreev et al. [H1 Collaboration] 2003 Phys. Lett. B 561 241 (Preprint hep-ex/0301030)
[3] S. Chekanov et al. [ZEUS Collaboration] 2003 Phys. Lett. B 559 153 (Preprint hep-ex/0302010)
[4] H1 Collaboration, contributed paper to HEP-EPS 2007, Manchester, abstract 228, H1prelim-07-063
[5] H1 Collaboration, contributed paper to HEP-EPS 2007, Manchester, abstract 227, H1prelim-07-064
[6] K. Hagiwara, R. D. Peccei, D. Zeppenfeld and K. Hikasa Nucl. Phys.B 2821987253.
[7] H1 Collaboration, contributed paper to HEP-EPS 2007, Manchester, abstract 775, H1prelim-07-161
[8] E. Perez, unpublished.
[9] A. Aktas et al. [H1 Collaboration] 2004 Eur. Phys. J. C 33 9 (Preprint hep-ex/0310032)
[10] H1 Collaboration, contributed paper to HEP-EPS 2007, Manchester, abstract 776, H1prelim-07-163
[11] U. Baur, J. A. Vermaseren and D. Zeppenfeld, Nucl. Phys.B 375 1992 3.
[12] A. Höcker et al. TMVA Users Manual, [physics/0703039v4].
[13] P. Achard et al. [L3 Collaboration] 2002 Phys. Lett. B 549 290 (Preprint hep-ex/0210041)
[14] CDF Collaboration, CDF Public Note 9202, 2008
[15] CDF Collaboration, CDF Public Note 8888, 2007; Amnon Harel, et al.
| H1 Preliminary | Electron obs./exp. (Signal contribution) | Muon obs./exp. (Signal contribution) | Combined obs./exp. (Signal contribution) |
|----------------|-----------------------------------------|---------------------------------------|----------------------------------------|
| $e^+p$          | Full Sample                             | 26 / 27.3 ± 3.8 (71%)                 | 15 / 7.2 ± 1.1 (85%)                   | 41 / 34.5 ± 4.8 (74%)                 |
|                | $P_T > 25$ GeV                           | 11 / 4.7 ± 0.9 (75%)                  | 10 / 4.2 ± 0.7 (85%)                   | 21 / 8.9 ± 1.5 (80%)                 |
| $e^-p$          | Full Sample                             | 16 / 19.4 ± 2.7 (65%)                 | 2 / 5.1 ± 0.7 (78%)                    | 18 / 24.4 ± 3.4 (68%)                |
|                | $P_T > 25$ GeV                           | 3 / 3.8 ± 0.6 (61%)                   | 0 / 3.1 ± 0.5 (74%)                    | 3 / 6.9 ± 1.0 (67%)                  |
| $e^\pm p$       | Full Sample                             | 42 / 46.7 ± 6.5 (69%)                 | 17 / 12.2 ± 1.8 (82%)                  | 59 / 58.9 ± 8.2 (72%)                |
|                | $P_T > 25$ GeV                           | 14 / 8.5 ± 1.5 (68%)                  | 10 / 7.3 ± 1.2 (79%)                   | 24 / 15.8 ± 2.5 (73%)                |

Table 1: Summary of the H1 results of searches for events with isolated electrons or muons and missing transverse momentum for the $e^+p$ data (294 pb$^{-1}$), $e^-p$ data (184 pb$^{-1}$) and the full HERA I+II data set (478 pb$^{-1}$). The results are shown for the full selected sample and for the subsample at large $P_T > 25$ GeV. The number of observed events is compared to the SM prediction. The signal component of the SM expectation, dominated by real $W$ production, is given as a percentage in parentheses. The quoted errors contain statistical and systematic uncertainties added in quadrature.

Figure 2: Left: The fit result for the simultaneously extracted left handed ($F_-$) and longitudinal ($F_0$) $W$ boson polarisation fractions (point) at 1 and 2σ CL (contours). Also shown are the values for the SM prediction (triangle) and anomalous single top production via FCNC (square). Right: Exclusion limits at the 95% CL in the search for single top production on the anomalous $\kappa_{\gamma t\gamma}$ and $v_{tuZ}$ couplings obtained at LEP (L3 experiment [13]), the Tevatron (CDF experiment [14], the result shown is from [15]), and HERA (H1 [10] and ZEUS [3] experiments). Anomalous couplings of the charm quark are neglected $\kappa_{tc\gamma} = v_{tcZ} = 0$. Limits are shown assuming a top mass $m_t = 175$ GeV.