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SEARCHES FOR LFV AND FCNC AT HERA

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This report presents a search in ep collisions at HERA for events with isolated leptons and large missing p_T. The rate of such events could be enhanced, respect to the Standard Model expectations, by new interactions involving flavor changing neutral current or lepton-flavor violation. The results have been obtained using data collected by the ZEUS detector at $\sqrt{s} \sim 300$ GeV during 1994-2000 and corresponding to an integrated luminosity of ~ 130 pb^{-1}.

1 Introduction

The study of processes induced by flavor changing neutral current (FCNC) or lepton-flavor violation (LFV) is one of the fundamental tools to investigate possible effects due to physics beyond the Standard Model (SM). Such processes are strongly suppressed in the SM picture (strictly forbidden at the tree level and only allowed via loops) and can produce spectacular final states with high-p_T leptons and large missing p_T.
This report will review the searches for these processes [1,2,3,4,5,6,7] performed by the ZEUS Collaboration at the HERA ep collider (center of mass energy, $\sqrt{s} \sim 300$ GeV) using the data collected in 1994-2000 and corresponding to an integrated luminosity $\mathcal{L} \sim 130$ pb^{-1}.

2 Flavor changing neutral current

FCNC in the quark sector could lead to single-top production at HERA via an up-top transition mediated by a γ or a Z via an anomalous FCNC coupling. The subsequent decay $t \to bW$ leads, via the leptonic decay of the W, to final states with a high-p_T isolated lepton, large missing p_T (due to νs) and large p_T of the hadronic state (P_T^{had}). The event selection required an isolated track with transverse momentum $p_T > 5$ GeV identified either as electron, muon or tau (see below for a description of the tau finder); a calorimeter transverse momentum $P_T^{CAL} > 20$ GeV; at least one jet with transverse energy $E_T > 5$ GeV within the range $-1.0 < \eta < 2.5$. Events with identified electrons and a topology characteristic of neutral current (NC) DIS events were rejected.
Table 1 summarizes the ZEUS results for all the leptonic channels and for different P_T^{had} cut. The electron and muon channel [1,2] exhibit a good agreement with the SM predictions while for the tau [3] a slight excess has been found. The H1 Collaboration reported an excess of events in the electron and muon channel with

ZEUS 1994-2000 $e^{\pm}p$ $\mathcal{L} = 130.1\ \mathrm{pb}^{-1}$	Electron obs./exp. ($W^{\pm}$ contribution)	Muon obs./exp. ($W^{\pm}$ contribution)	Tau obs./exp. ($W^{\pm}$ contribution)
$P_T^{had} > 25$ GeV	2 / 2.90 $^{+0.59}_{-0.32}$ (45%)	5 / 2.75 $^{+0.21}_{-0.21}$ (50%)	2 / 0.20 $^{+0.05}_{-0.05}$ (49%)
$P_T^{had} > 40$ GeV	0 / 0.94 $^{+0.11}_{-0.10}$ (61%)	0 / 0.95 $^{+0.14}_{-0.10}$ (61%)	1 / 0.07 $^{+0.02}_{-0.02}$ (71%)

Table 1. Summary of the results of searches for events with isolated leptons, missing transverse momentum and large P_T^{had}. The number of observed events is compared to the SM prediction. The $W^{\pm}$ component is given in parentheses in percent. The statistical and systematic uncertainties added in quadrature are also indicated.

respect to SM expectation [8,9]. A recent review of the high-p_T leptons searches at HERA can be found in [11]. The results of the electron and muon channel have been converted to limits on the anomalous coupling mediating single top production (also the hadronic W decay was considered in the limit setting). Figure 1 shows the 95% confidence level limits from HERA, LEP and TEVATRON experiments, in the $k_\gamma - V_Z$ plane, where k_γ and V_Z are the FCNC anomalous couplings at the photon vertex and the vector coupling at the Z vertex, respectively. HERA experiments have larger sensitivity to k_γ; for low values of V_Z HERA results improve on LEP and TEVATRON limits.

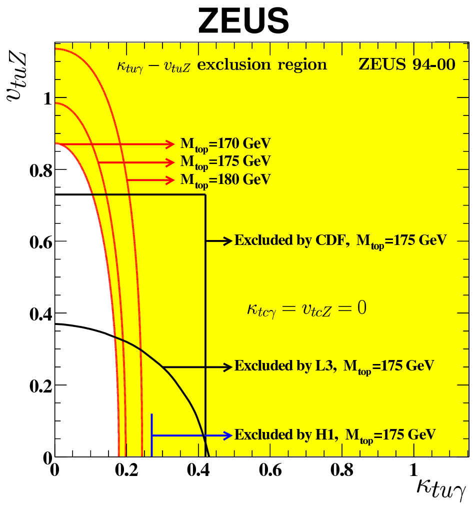

Figure 1. Limits at 95% confidence in the $k_\gamma - V_Z$ plane. The LEP and TEVATRON results are also shown. The H1 limit was obtained assuming a vanishing V_Z, the result is in any case conservative for $V_Z > 0$.

The search for τ leptons is based on their hadronic decays, with one charged particle detected in the central tracking detector. In order to distinguish the narrow τ jets with low charged-multiplicity from quark- and gluon-induced jets, the internal jet structure was parameterized using variables related to the jet shape [10]. The separation between signal and background was studied using Monte Carlo (MC) events, $W \to \tau\nu_\tau$ for the signal and charged current (CC) DIS for the background. In order to separate signal from background the jet-shape variables were combined to form a discriminant D used to select τ-candidates (see [3] for details). Three events fullfilled the τ-candidate criteria while 0.40 ± 0.13 are expected from the SM. Figure 2 shows the hadronic transverse momentum (P_T^{had}) distributions of the data and MC events that survived the τ selections. The final cuts were designed using

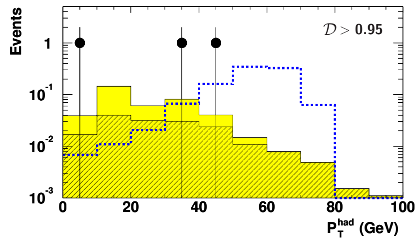

Figure 2. Distribution of the hadronic transverse momentum, P_T^{had}. The data (points) are compared to the SM expectations (shaded histogram). The dashed histogram represents the contribution from W production. The dashed line represents the single-top signal MC normalized to an integral of one event.

the single-top MC as a template. A cut at $P_T^{had} > 25$ GeV gave the best expected upper limit assuming no signal. Two events remained in the data, while 0.20 ± 0.05 are expected from the SM, mainly from direct W production. The observed excess cannot be explained by single-top production, since this process is already strongly constrained by the electron and the muon channel results which have a much higher sensitivity.

3 Lepton-flavor violation

The recent experimental results on neutrino oscillation suggest that lepton-flavor violation does occur. Minimal modification to the SM to accomodate neutrino oscillations and masses predict no detectable rate, in collider experiments, for LFV in the charged lepton sector. However, many extension of the SM involve LFV at a fundamental level. In this section ZEUS searches for the process $ep \to \ell X$, where ℓ is a μ or a τ and X the hadronic final state, are presented. Such process can be mediated by leptoquarks (LQ), bosons which carry both lepton (L) and baryon (B) numbers and have lepton-quark Yukawa coupling. Both s- and u-channel reactions contribute to the process. Here we consider only LQ which have two different couplings λ_{eq_α} to an electron and a quark q_α and $\lambda_{\ell q_\beta}$ to a μ or a τ and a quark q_β (α and β are generation indices).

Indirect searches for such reactions have yielded strong constraints when q_α and q_β are light quarks. When heavy quarks are involved and especially for $\ell = \tau$, HERA sensitivity, in some cases, extends beyond existing limits.

The Buchmüller Rückl Weyler (BRW) model [12], which assumes the most general Lagrangian with $SU(3)_C \times SU(2)_L \times U(1)_Y$ invariant couplings of a LQ to a lepton and a quark is used to classify LQ species. In addition we also assumed that members of each $SU(2)$ multiplet are degenerate in mass, that LQs couple to either left-handed and right-handed leptons, but not both and that one LQ species dominates the production. There are 14 LQs species under this assumptions which are characterized by the spin ($J = 0, 1$), the weak isospin ($T = 0, 1/2, 1$) and the fermion number ($F = L + 3B = 0, \pm 2$, L and B being lepton and baryon number, respectively). Following the Aachen notation [13] scalar (vector) LQs are named S_T^χ (V_T^χ) where $\chi = L, R$ denotes the chirality of the leptons which couple to the LQ. When two different hypercharge states are allowed one is distinguished with a $\tilde{}$. In SUSY models with R parity violation, LFV processes can be mediated by squarks ($\tilde{u}$, $\tilde{d}$).

The distinctive signature of LFV processes mediated by LQs or squarks is a high p_T μ or τ balanced by a jet in the transverse plane. The selection criteria required a missing p_T cut in the range $12 - 20$ GeV (depending on the decay channel) and the requirement that the final state lepton be isolated and aligned with the missing p_T. The τ was searched for both in its leptonic and hadronic decay channels; for the hadronic channel the method described in the Section 2 was used. ZEUS limits in some cases improve on low energy constraints, especially for the τ-channel when higher generation quarks are involved. Table 2 [7] shows the limits for $F = 0$ LQs with masses larger than $\sqrt{s}$ coupling to e and τ, obtained using the e^+p data collected in 1999-2000 and corresponding to $\mathcal{L} = 65.5\text{pb}^{-1}$. The limits from low energy experiments are also reported. In many cases, flagged by boxes, ZEUS constraints are the most stringent to date. The H1 collaboration published similar results [14].

4 Conclusions

A review was presented of the searches for high-pt isolated leptons with the ZEUS detector at HERA. The results have been used to improve the constraints on single-top production and lepton-flavor violation. The observations are in good agreement with the SM expectations except for a slight excess of 2 τ events while only 0.2 are expected. The next years of data taking allowing a significant increase of the integrated luminosity, will clarify the picture.

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$e \to \tau$	HERA I (prel.) e^+p (1999-2000 65 pb^{-1})						$F = 0$
ij	$S^L_{1/2}$ $e^-\bar{u}$ e^+u	$S^R_{1/2}$ $e^-(\bar{u}+\bar{d})$ $e^+(u+d)$	$\tilde{S}^L_{1/2}$ $e^-\bar{d}$ e^+d	V^L_0 $e^-\bar{d}$ e^+d	V^R_0 $e^-\bar{d}$ e^+d	$\tilde{V}^R_0$ $e^-\bar{u}$ e^+u	V^L_1 $e^-(\sqrt{2}\bar{u}+\bar{d})$ $e^+(\sqrt{2}u+d)$
1 1	$\tau \to \pi e$ 0.4 **2.2**	$\tau \to \pi e$ 0.2 **1.8**	$\tau \to \pi e$ 0.4 **3.2**	$\tau \to \pi e$ 0.2 **2.3**	$\tau \to \pi e$ 0.2 **2.3**	$\tau \to \pi e$ 0.2 **1.7**	$\tau \to \pi e$ 0.06 **0.8**
1 2	$\boxed{\mathbf{2.2}}$	$\tau \to Ke$ 6.3 $\boxed{\mathbf{1.9}}$	$K \to \pi\nu\bar{\nu}$ 5.8×10^{-4} **3.4**	$\tau \to Ke$ 3.2 $\boxed{\mathbf{2.6}}$	$\tau \to Ke$ 3.2 $\boxed{\mathbf{2.6}}$	$\boxed{\mathbf{1.9}}$	$K \to \pi\nu\bar{\nu}$ 1.5×10^{-4} **0.9**
1 3	*	$B \to \tau\bar{e}$ 0.6 **3.8**	$B \to \tau\bar{e}$ 0.6 **3.8**	$B \to \tau\bar{e}$ 0.3 **3.2**	$B \to \tau\bar{e}$ 0.3 **3.2**	*	$B \to \tau\bar{e}$ 0.3 **3.2**
2 1	$\boxed{\mathbf{11}}$	$\tau \to Ke$ 6.3 **6.4**	$K \to \pi\nu\bar{\nu}$ 5.8×10^{-4} **7.8**	$\tau \to Ke$ 3.2 **3.5**	$\tau \to Ke$ 3.2 **3.5**	$\boxed{\mathbf{4.6}}$	$K \to \pi\nu\bar{\nu}$ 1.5×10^{-4} **1.9**
2 2	$\tau \to 3e$ 5 **13**	$\tau \to 3e$ 8 $\boxed{\mathbf{7.3}}$	$\tau \to 3e$ 17 $\boxed{\mathbf{8.9}}$	$\tau \to 3e$ 9 $\boxed{\mathbf{4.4}}$	$\tau \to 3e$ 9 $\boxed{\mathbf{4.4}}$	$\tau \to 3e$ 3 **7.1**	$\tau \to 3e$ 1.6 **2.7**
2 3	*	$B \to \tau\bar{e}X$ 14 $\boxed{\mathbf{11}}$	$B \to \tau\bar{e}X$ 14 $\boxed{\mathbf{11}}$	$B \to \tau\bar{e}X$ 7.2 $\boxed{\mathbf{6.8}}$	$B \to \tau\bar{e}X$ 7.2 $\boxed{\mathbf{6.8}}$	*	$B \to \tau\bar{e}X$ 7.2 $\boxed{\mathbf{6.8}}$
3 1	*	$B \to \tau\bar{e}$ 0.6 **11**	$B \to \tau\bar{e}$ 0.6 **11**	V_{ub} 0.12 **4.0**	$B \to \tau\bar{e}$ 0.3 **4.0**	*	V_{ub} 0.12 **4.0**
3 2	*	$B \to \tau\bar{e}X$ 14 **14**	$B \to \tau\bar{e}X$ 14 **14**	$B \to \tau\bar{e}X$ 7.2 $\boxed{\mathbf{5.2}}$	$B \to \tau\bar{e}X$ 7.2 $\boxed{\mathbf{5.2}}$	*	$B \to \tau\bar{e}X$ 7.2 $\boxed{\mathbf{5.2}}$
3 3	*	$\tau \to 3e$ 8 **19**	$\tau \to 3e$ 17 **19**	$\tau \to 3e$ 9 **10**	$\tau \to 3e$ 9 **10**	*	$\tau \to 3e$ 1.6 **10**

Table 2. *Rejection limits at 95% C.L. on $\frac{\lambda_{1i}\lambda_{3j}}{M^2_{LQ}}$ for $F = 0$ LQs, in units of TeV^{-2}. The first column indicates the quark generations coupling to $LQ - e$ and $LQ - \tau$, respectively. The HERA preliminary results are reported in the third line (bold) of each cell. The low energy process providing the most stringent constraint and the corresponding limit are shown in the first and second lines. The HERA limits are enclosed in a box if better than the low energy constraints (or if no constraint is available). In cases marked with * only a top quark would have been involved. Only part of the HERA I data set was used for these results. The most stringent limits reported in this table come from the 99-00 e^+p data set (integrated luminosity 65 pb^{-1}).*

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