Events with Isolated Charged Leptons and Missing Momentum observed at the e^+p Collider HERA

D. Haidt[a]

[a]DESY
D-22603 Hamburg, Germany

Ten events observed by H1 and ZEUS are presented and discussed

1. Introduction

In the history of high energy physics *leptons* and *missing momentum* have proved to be powerful tools in searches for new phenomena.

The e^+p Collider HERA is operated with positrons of 27.5 GeV and protons of 820 GeV providing final states with invariant masses up to 300 GeV. Due to the large transverse momentum of the final state lepton the value of the quantity $\sum \vec{p}_T$, the vectorial sum over the transverse momenta of all observed final state particles, is a simple and efficient discriminator between the two inclusive processes $e^+p \to e^+ + anything$ (NC) and $e^+p \to \overline{\nu} + anything$ (CC), being small in the first and large in the latter case. During the year 1994 the H1 collaboration [1] observed in their study of events with *large missing momentum*, namely $|\sum \vec{p}_T| > 25$ GeV, an outstanding event (see figure 1) consisting of an isolated μ^+ with large transverse momentum and a hadron jet. In the meantime the available luminosity has increased by an order of magnitude and the two collaborations H1 and ZEUS have performed searches for events with the two signatures *missing momentum* and *isolated lepton* following complementary approaches :

- H1 selecting events with missing momentum and searching for isolated charged particles
- ZEUS selecting events with isolated charged leptons and looking for large transverse momentum imbalance in the final state.

The H1 analysis [2] based on 36.5 pb^{-1} is final, while the ZEUS analysis [3] based on 47 pb^{-1} is preliminary.

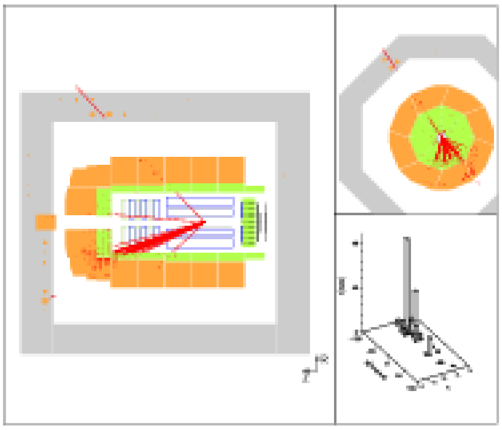

Figure 1. *The 1994 H1-event*

2. The two searches

The major steps in the analysis by H1 [2] are :

- Two independent requirements :
  1. Missing calorimetric momentum : $|\sum \vec{p}_T| > 25$ GeV
  2. Charged particle : $p_T > 10$ GeV and polar angle : $\Theta > 10^0$
- Reject $e^+p \to e^+ + anything$, if event balanced in azimuth or $E - p_L$

The resulting sample contains 124 events and is dominated by $e^+p \to \bar{\nu} + anything$. Are there events with *isolated* high-p_T charged particles ? This question is answered by introducing a distance measure between two points $(\eta, \phi)_i$ on the LEGO plot :

$$D_{12} = \sqrt{(\eta_1 - \eta_2)^2 + (\phi_1 - \phi_2)^2} \quad (1)$$

For any chosen high-p_T track the distance of closest approach is determined with respect to a jet (D_{jet}) and any other track (D_{track}). Jets are reconstructed by a cone algorithm with $R = 1$ and $E_T > 5$ GeV. As a matter of fact, every event has a jet. Tracks are accepted in the polar range $5^0 < \theta < 153^0$.

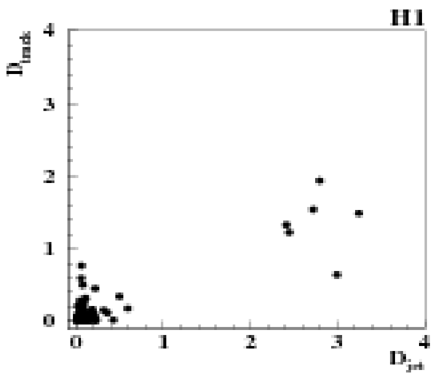

Figure 2. *Isolation plot*

Figure 2 shows, as expected, the majority of the events in the left lower corner in contrast to 6 completely isolated charged particles, which are uniquely identified as leptons. None of the events has an isolated charged hadron, nor are there events with 2 high-p_T particles. The lepton flavor in each of the 6 events (1 e^-, 2 μ^+, 2 μ^-, 1 $\mu^\pm$) differs from the one of the initial state e^+.

The major steps in the analysis by ZEUS [3] are :

- Isolated charged lepton:
  High p_T-track within $15^0 < \theta < 164^0$
  $E_e > 15$ GeV resp. $p_T^\mu > 5$ GeV
  Matching track with distance of closest approach < 10 (e) and 20 cm(μ)
  Isolation : no other track within cone of R=0.5 and accompanying energy in cone of R=1 smaller than 5 GeV
  Lepton identification
- Missing transverse momentum :
  p_T(calo) > 19 GeV (e), > 18 GeV (μ)
  p_T(calo+μ) > 18 GeV
- Suppress NC events : candidate with isolated e must have $\theta_e < 1.3$ rad and $\theta_{aco} > 0.3$ rad (if $p_T^{had} > 4$ GeV).

The final sample consists of 4 events, each with a e^+. Figure 3 displays their second event.

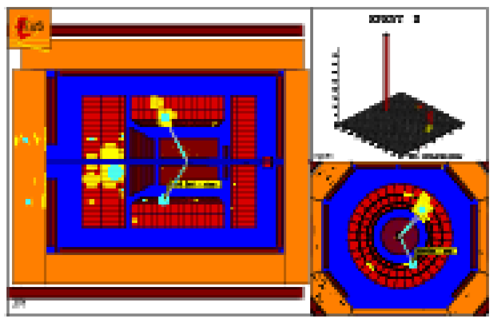

Figure 3. *The second ZEUS event*

3. Discussion

The kinematic properties of the two event samples are summarized in table 1. An examination of the relevant observables exhibits similar characteristics.

For the understanding of the signal various Standard Model processes have been considered as listed in the 2 tables below.

	ELECTRON	MUON-1	MUON-2	MUON-3 *)	MUON-4	MUON-5
The isolated high-P_T lepton						
Charge	Neg.(5σ)	Pos.(4σ)	Pos.(4σ)	Neg.(4σ)	Neg.(2σ)	unmeasured
P_T^l	$37.6^{+1.3}_{-1.3}$	$23.4^{+7.5}_{-5.5}$	$28.0^{+8.7}_{-5.4}$	$38.6^{+12.0}_{-7.4}$	$81.5^{+75.2}_{-25.4}$	> 44
θ^l	27.3 ± 0.2	46.2 ± 0.1	28.9 ± 0.1	35.5 ± 0.1	28.5 ± 0.1	31.0 ± 0.1
The hadronic system						
P_T^X	8.0 ± 0.8	42.2 ± 3.8	67.4 ± 5.4	27.4 ± 2.7	59.3 ± 5.9	30.0 ± 3.0
$P_\parallel^X$	-7.2 ± 0.8	-42.1 ± 3.8	-61.9 ± 4.9	-12.5 ± 2.1	-57.0 ± 5.5	-28.6 ± 3.1
$P_\perp^X$	-3.4 ± 0.9	-2.7 ± 1.8	26.8 ± 2.7	-24.3 ± 2.5	-16.3 ± 3.2	-9.1 ± 2.3
P_z^X	79.9 ± 4.4	153.1 ± 9.1	247.0 ± 18.9	183.7 ± 13.6	118.9 ± 12.1	145.4 ± 8.2
E^X	81.1 ± 4.5	162.0 ± 10.0	256.9 ± 19.5	186.8 ± 14.0	141.7 ± 13.7	154.8 ± 9.1
Global properties						
P_T^{miss}	30.6 ± 1.5	$18.9^{+6.6}_{-8.3}$	$43.2^{+6.1}_{-7.7}$	$42.1^{+10.1}_{-5.9}$	$29.4^{+71.8}_{-13.9}$	> 18
δ	10.4 ± 0.7	$18.9^{+3.6}_{-3.2}$	$17.1^{+2.5}_{-1.7}$	$26.9^{+4.2}_{-2.9}$	$43.5^{+19.3}_{-7.2}$	> 22
$M_T^{l\nu}$	67.7 ± 2.7	$3.0^{+1.5}_{-0.9}$	$22.8^{+6.7}_{-4.2}$	$75.8^{+23.0}_{-14.0}$	94^{+157}_{-54}	> 54
*) Positron in MUON-3 : $P_T^e = 6.7 \pm 0.4$, $P_\parallel^e = 6.1 \pm 0.4$, $P_\perp^e = -2.8 \pm 0.2$; $P_z^e = -3.7 \pm 0.2$						

Candidate	1	2	3	4
Year	96	97	97	97
Corrected Electron p_T (GeV)	24.7 ± 1.2	47.64 ± 1.9	44.4 ± 1.9	36.8 ± 1.6
Electron Polar Angle	37°	58°	70°	54°
Corrected Hadronic p_T (GeV)	0.4 ± 0.2	18.9 ± 2.7	24.6 ± 1.5	18.6 ± 2.4
Corrected Missing p_T (GeV)	24.3 ± 1.2	33.8 ± 2.4	22.7 ± 2.1	32.6 ± 1.4
Corrected Transverse Mass (GeV)	49.0 ± 1.6	79.2 ± 3.3	62.3 ± 3.3	67.8 ± 2.2
Matching Track p_T (GeV/c)	$22.3^{+6.6}_{-4.2}$	$44.1^{+33.0}_{-13.1}$	$42.9^{+17.4}_{-6.7}$	$35.9^{+13.8}_{-7.8}$
Track Charge	+1	+1	+1	+1

Table 1
Kinematic properties of the 6 H1 and the 4 ZEUS events

H1	Electron Channel	Muon Channel
Data	0 e^+,1 e^-	5
W prod.	1.65 ± 0.47	0.53 ± 0.11
Z prod.	0.01 ± 0.01	0.01 ± 0.01
CC	0.02 ± 0.01	0.01 ± 0.01
NC : e^+	0.51 ± 0.10	0.09 ± 0.06
NC : e^-	0.02 ± 0.01	
γ prod.	< 0.02	< 0.02
Heavy q	< 0.04	< 0.04
$\gamma\gamma$ e^+	0.09 ± 0.03	$0.14^{+0.14}_{-0.07}$
$\gamma\gamma$ e^-	0.04 ± 0.01	

ZEUS	Electron Channel	Muon Channel
Data	4 e^+,0 e^-	0
W prod.	2.22 ± 0.02	0.46 ± 0.02
CC	0.65 ± 0.17	0.37 ± 0.13
NC	0.32 ± 0.14	< 0.03
$\gamma\gamma(e)$	0.27 ± 0.27	
$\gamma\gamma(\mu)$		0.41 ± 0.18
$\gamma\gamma(\tau)$	< 0.06	0.06 ± 0.06

The most prominent contribution is W-production with subsequent leptonic decay. This hypothesis explains naturally the flavor properties of the final state lepton and the large imbalance in transverse momentum. Both collaborations have used the leading order calculation of Baur, Vermaseren and Zeppenfeld [4] to predict the distributions of various observables such as transverse mass (Jacobian peak), missing momentum, transverse momentum of the charged lepton and the hadron system (see figure 4; equivalent figures exist also for the ZEUS analysis). The most prominent event is displayed in figure 5.

Other processes do not contribute significantly to the signal. The smallness of several contributions reflects directly the severe selection criteria. The events with μ observed only by H1 attract some attention, as they occur more frequently than expected with the Standard Model.

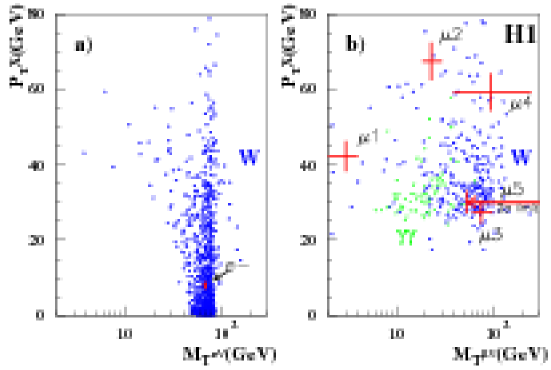

Figure 4. *Comparison of the 6 H1 events (crosses) with the W-hypothesis (dots) and the $\gamma\gamma$ (circles) background ; the simulation is based on a luminosity of 500 pb^{-1}; the asymmetry between the e-channel (a) and the μ-channel (b) originates from the fact that the e contributes to the calorimetric p_T, while the μ does not.*

4. Conclusions

The two collaborations H1 and ZEUS have reported 10 outstanding events with isolated high-p_T lepton and missing transverse momentum corresponding to a visible cross section of about 0.1 pb.

A definitive comparison of the two analyses is not yet possible, since the ZEUS results are preliminary and in addition the selection criteria are different. On the other hand, the two analyses are sufficiently similar to allow for a qualitative comparison, which is the author's assessment. Within the presently small statistics the event samples are compatible in size with each other and so are the background estimates. The flavor composition may be compared as follows : (a) given the 4 ZEUS e^+ events H1 should expect 1.6, while 0 observed (but 1 e^-); (b) given the 5 H1 μ-events ZEUS should expect 3.2, while none is observed. Future HERA running will ascertain the nature of the events with μ.

There is evidence for $e^+p \to W + anything$. It is rewarding to observe W-production finally

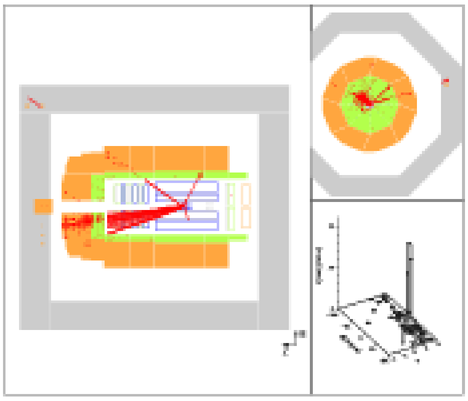

Figure 5. *Display of H1-event MUON-3 as candidate for the process $e^+p \to e^+W^- + jet$: the final state e^+ taken as the scattered e^+ fixes the kinematics of the event; the μ^- together with the missing momentum combine to an invariant mass compatible with the W mass.*

in lepton-nucleon scattering, where the search started - 35 years ago - in the first neutrino experiments [5]. All events satisfy the W-kinematics, though in some cases the probablity is quite low. For the time being, the program used to simulate W-production, both for the total rate and the differential distributions, is based on lowest-order only, since no higher order calculation is yet available.

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REFERENCES

1. H1-Collaboration : DESY 94-248 (1994)
2. H1-Collaboration : C. Adloff et al., Eur.Phys.J. **C**: DOI 10.1007/s100529800973 and DESY-98-063 (May 1998).
3. ZEUS-Collaboration : I. Negri : Talk given at *Lake Louise Winter Institute* February 1998, see http://www-zeus.desy.de/conferences98/
U. Schneekloth : Talk given at *Moriond Electroweak* March 1998, see http://www-zeus.desy.de/conferences98/ and DESY report 98-060
4. U. Baur, J.A.M Vermaseren and D. Zeppenfeld, Nucl. Phys. **B375** (1992) 3
5. D. Perkins : contribution to *Proceedings of the Siena International Conference on Elementary Particles*, 1963, p.555;
F. Ferrero : ibidem, p.571.