# THE $W$ CROSS SECTION AND LEPTON PRODUCTION WITH MISSING $P_T$ AT HERA

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The H1 and ZEUS Collaborations have performed searches for events with high energy leptons and missing transverse momentum in the positron-proton collisions collected at $\sqrt{s} = 300\ GeV$ between 1994 and 1997. Altogether 9 candidates were found, of which 4 $e^{\pm}$ and 2 $\mu^{\pm}$ events behave as expected from exclusive $W$-boson production, whereas 3 $\mu^{\pm}$ events show kinematic properties atypical of all Standard Model processes considered. These results are summarized and discussed within the Standard Model and its possible extensions.

## 1 Analysis Strategies

The analysis procedures used by ZEUS and H1 are described in detail in [1] and [2]. At HERA the main Standard Model (SM) processes expected to yield isolated leptons with high transverse momentum ($P_T^l$) are Neutral Current interactions (NC), photon-photon interactions ($\gamma\gamma$) and exclusive $W$-boson production with subsequent leptonic decay. The corresponding cross sections are o(100 pb), o(1 pb) and o(0.1 pb) respectively.

High-$P_T$ leptons ($P_T^e \geq 10\ GeV$, $P_T^{\mu} \geq 10\ GeV$ (H1) or $5\ GeV$ (ZEUS)) are identified from the match of a high-$P_T$ track with a calorimetric electromagnetic shower ($e$) or minimum ionizing particle pattern ($\mu$). H1 $\mu$ candidates must in addition have a significant signal in the muon detector. Lepton isolation is quantified in the pseudo rapidity-azimuth $(\eta, \phi)$ plane by the distance of the lepton from the closest track ($\geq 0.5$ radian) and either the distance of the lepton from the closest hadronic jet ($\geq 1$ radian, H1) or the calorimetric energy measured in the vicinity of the lepton ($\leq 4\ GeV$, ZEUS). Once an isolated lepton is identified, a hypothetical transverse neutrino is reconstructed from the calorimetric missing transverse momentum ($e$-channel) or the transverse momentum imbalance between the $\mu$ track and complementary calorimetric deposits ($\mu$-channel).

The kinematic cuts are designed to suppress NC and $\gamma\gamma$ contributions compared to $W$ production. The calorimetric missing transverse momentum $P_T^{calo}$ must exceed $25\ GeV$ (H1), $20\ GeV$ ($e$-channel, ZEUS) or $15\ GeV$ ($\mu$-channel, ZEUS). Note that $P_T^{calo}$ is equal to the reconstructed neutrino transverse mo-

Table 1: Comparison of the observed event yields with SM expectations.

| | $e$-channel | | $\mu$-channel | |
|---|---|---|---|---|
| | ZEUS | H1 | ZEUS | H1 |
| DATA | 3 | 1 | 0 | 5 |
| $W$ | 2.0 | $1.7 \pm 0.5$ | 0.6 | $0.5 \pm 0.1$ |
| OTHERS | $1.0 \pm 0.5$ | $0.7 \pm 0.1$ | $0.6 \pm 0.2$ | $0.3 \pm 0.2$ |

mentum $P_T^\nu$ in the $e$-channel and approximately equal to the recoil hadronic transverse momentum $P_T^X$ in the $\mu$-channel. In the $e$-channel the NC contribution is further reduced by requiring an azimuthal acoplanarity between the identified $e$ and the hadronic system ($\Delta\phi_{e-X}$) larger than $5^o$ (H1) or $17^o$ (ZEUS). In the $\mu$-channel ZEUS compensate their lower $P_T^{calo}$ threshold by an additional cut at 15 $GeV$ in $P_T^\nu$.

## 2 Results

The above selection applied to the ZEUS (integrated luminosity L = 47 $pb^{-1}$) and the H1 (L = 37 $pb^{-1}$) samples yields 3 $e^+$ events for ZEUS and 1 $e^-$, 2 $\mu^+$, 2 $\mu^-$ plus 1 $\mu$ of undetermined sign for H1. The distribution of the high-$P_T$ track isolation variables made by H1 [1] prior to lepton identification shows that the candidates are well separated from the bulk of events with calorimetric missing transverse momentum, mostly due to Charged Current interactions. Table 1 compares the observed yields to the SM predictions. The most important SM process is $W$ production, followed by NC interactions in the $e$-channel and $\gamma\gamma$ processes in the $\mu$-channel. Contributions from lepton mis-identification or hadron punch-through are small compared to genuine lepton production. The detailed kinematic parameters of the observed events are given in [1] and [2]. Some of them are compared to the expectations from dominant SM processes in figures 1 and 2 .

In the $e$-channel all candidates have a small or moderate $P_T^X$, and a lepton-neutrino transverse mass $M_T^{e\nu}$ close to the $W$ mass as expected from $W$ production. Given this agreement of their $e^+$ candidates properties with SM expectations, ZEUS derive [2] a total cross section for exclusive $W$ production:

$\sigma(e^+p \rightarrow e^+W^\pm X) = 1.0^{+1.0}_{-0.7}$ (stat) $\pm$ 0.3 (syst) pb

compatible with the SM estimation of 0.94 pb. The corresponding upper limit on abnormal $W$ boson production can be translated into the following limits on anomalous $WW\gamma$ couplings: $-7.6 \leq \Delta\kappa \leq 3.9$ (95 % CL, $\lambda = 0$).

In the $\mu$-channel, it is remarkable that despite the fact that no explicit cut is made on these variables in the H1 selection scheme, the $\mu$-events show both

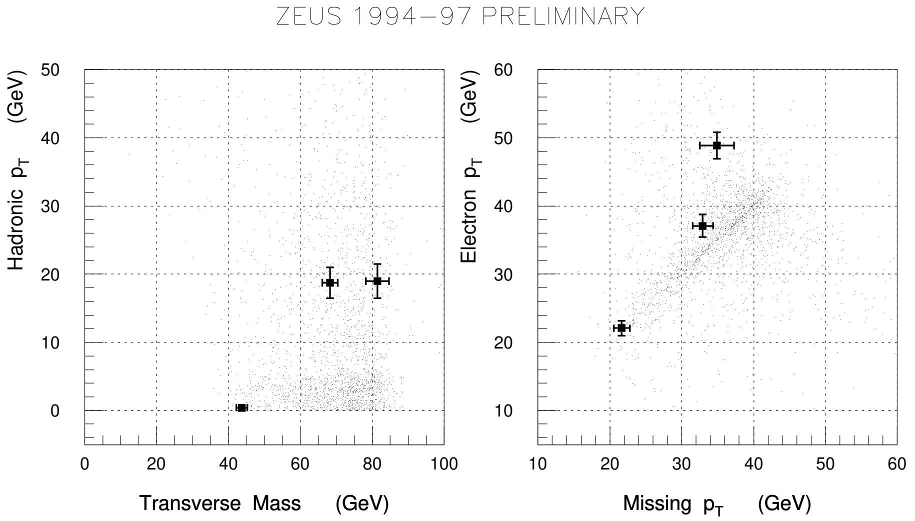


Figure 1: Kinematics of the 3 ZEUS $e^+$ candidates compared to the distributions expected from $W$ production, for an integrated luminosity 1000 times higher than in the data.

a non-zero $P_T^\nu$ and (except $\mu1$) a significant acoplanarity $\Delta\phi_{\mu-X}$ as additional evidence for undetected high-$P_T$ particles. Events $\mu3$ and $\mu5$ lie at moderate $P_T^X$ and show $M_T^{\mu\nu}$ values compatible (within 2 standard deviations for $\mu5$) with the $W$ mass. Thanks to the observation of the scattered positron, $\mu3$ can have its full $\mu$-$\nu$ mass reconstructed and found to be equal to $82^{+19}_{-12}\,GeV$. Event $\mu5$ however shows the unexpected features of a very stiff $\mu$ track and a neutral hadronic jet [1]. The other 3 $\mu$-events show either a lower $M_T^{\mu\nu}$ or a higher $P_T^X$ than expected from most $W$ events or $\gamma\gamma$ interactions. The indication of a rate excess in the $\mu$ channel therefore corresponds to events with properties not typical of SM processes.

## 3 Discussion of H1 atypical Muon Events

### *3.1 H1-ZEUS Compatibility*

For a more direct comparison of their data with H1, ZEUS have redone their analysis using similar kinematic cuts as H1 [2,3]. They still find no event with a high-$P_T$ $\mu$ associated to a hadronic system of $P_T^X \geq 30\ GeV$. Assuming the same acceptance as for $W$-production they set an upper limit of 0.17 pb (95 % CL) for the production cross section in this kinematic domain. Taking into

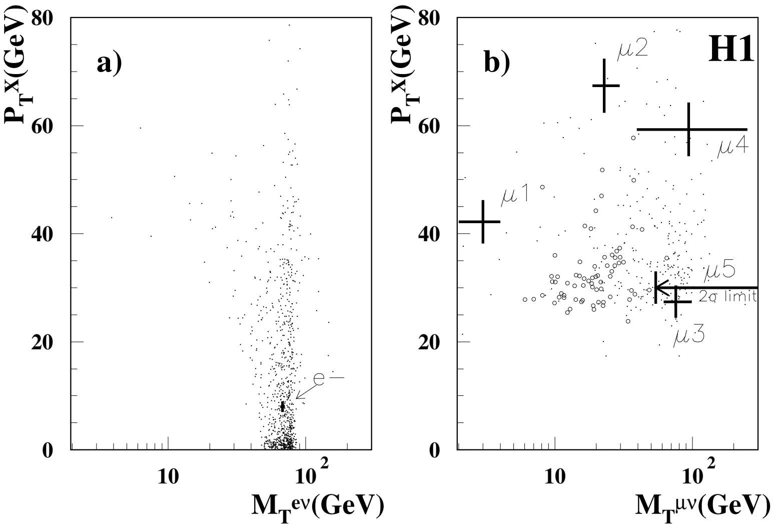


Figure 2: Kinematics of the H1 $e^-$ (a) and $\mu$ (b) candidates compared to the distributions expected from $W$ production (dots) and $\gamma\gamma$ interactions (circles), for an integrated luminosity 500 times higher than in the data.

account the H1 integrated luminosity and selection efficiency, this translates into an upper limit of 3.2 events to be compared to the 4 events measured by H1 at $P_T^X \geq 30\ GeV$. The difference between the $\mu$-event yields observed by H1 and ZEUS is therefore at the level of 2 standard deviations only.

Similarly the apparent asymmetry between the $e$ and $\mu$ results at high $P_T^X$ has a statistical significance of order 2 standard deviations.

### *3.2 W Interpretation*

The interpretation of all muon events as SM $W$ production can be further questionned when considering the measured kinematic properties of the candidates in addition to the indication of a rate excess. For example reconstructing the neutrino using the $W$ mass constraint yields for event $\mu 2$ a very high $x_{Bjorken}$ value, which together with the high $P_T^X$ value makes this event particularly unlikely as a SM $W$.

However when dealing with $W$-production it must be remembered that the predictions mentioned here were computed at leading order only [4]. Higher order QCD terms might enhance $W$-boson production at high $P_T^X$. NLO calculations were recently made available [5] for $W$ production sub-processes induced by resolved photon interactions, but the experimental conditions make the $\mu$-channel measurements only sensitive to the high-$P_T^X$ part of the cross section, which is dominated by direct photon interactions. In this domain no NLO calculation is available yet. Full NLO computations [6] made for the similar (apart for the $W$ mass) process of prompt photon production predict an increase of the cross section of order 10 % at high $P_T^X$.

### *3.3 Interpretations beyond the Standard Model*

Considering the low probability of the observed signal within the SM, it is worthwhile investigating which processes beyond the SM could explain the measured events. These can range from anomalous 3-boson couplings to decays of new heavy resonances of various types.

It has been argued [7] that anomalous $WW\gamma$ couplings could enhance $W$-production in $ep$ collisions preferentially at high $P_T^X$. Combining the ZEUS and H1 results in the $e$ and $\mu$ channels, the observed excess of events at $P_T^X \geq 25\ GeV$ is about a factor 2. In this interpretation this would correspond to an anomalous coupling $\Delta\kappa$ which has almost been excluded by the Tevatron experiments [8].

A lepto-quark produced by positron-quark fusion and decaying into a muon-quark system can be discarded from the measured event kinematics, which is incompatible with 2-body decays [9].

In the hypothesis of a resonance decaying into a quark and a $W$, the escaping neutrino can be fully reconstructed using the $W$ mass constraint in addition to transverse momentum conservation. The resulting $\mu$-$\nu$-$X$ masses of events $\mu 2$ and $\mu 4$ are found (within measurement errors of $\approx 15\ GeV$) to be compatible with each other and with the top mass. Exclusive top quark production is expected to be completely negligible at HERA in the SM, but could be significantly enhanced in dynamic models for fermion mass generation [10], provided a significant amount of intrinsic charm is present in the proton.

Another possible source of events with high-$P_T$ jets, leptons and missing transverse momentum is the production of squarks in Supersymmetry models with $R$-parity violation. A favoured process is the fusion of the incident positron and a $d$ quark into a $\tilde{t}$ squark, decaying into either a $\tilde{b}$ squark and a $W$ [11], or a $b$ quark and a chargino [3]. In the latter case the $\tilde{t}$ and $\tilde{\chi}$ masses can be reconstructed from the hadron jet parameters using 2 independent events only. Taking $\mu 2$ and $\mu 4$ the mass ranges required to acommodate this interpretation are found to be $\approx 200-300$ $GeV$ and $\approx 100-200$ $GeV$ for the $\tilde{t}$ and $\tilde{\chi}$ respectively.

## 4 Outlook

Since 1998 the HERA Collider has been operating in $e^-p$ mode and should produce by the end 1999 an integrated luminosity comparable to that delivered in the $e^+p$ runs. These new data will provide complementary information on the processes discussed here. The question of the origin of the $e^+p$ muon events will also be addressed with higher precision once a significantly larger $e^+p$ data sample has been accumulated, which is foreseen after the HERA luminosity upgrade starting in the year 2000.


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## References


1. C.Adloff et al. (H1 Collaboration) Eur. Phys. J. 5 (1998) 575.
2. ZEUS Collaboration, contributed paper 756 to ICHEP98, Vancouver, Canada, July 1998.
3. C.Diaconu et al., hep-ph/9901335, to appear in the proceedings of the $3^{rd}$ UK Phenomenology Workshop on HERA Physics, Durham, UK, September 1998.
4. U.Baur et al., Nucl. Phys. B375 (1992) 3.
5. P.Nason et al., hep-ph/9902296, contribution to the $3^{rd}$ UK Phenomenology Workshop on HERA Physics, Durham, UK, September 1998.
6. L.E.Gordon and J.K.Storrow, Z. Phys. C 63 (1994) 581.
7. M.N.Dubimin and H.S.Song, hep-ph/9708259.
8. S.Abachi et al. (D0 Collaboration), Phys. Rev. Lett. 78 (1997) 3634.
9. H1 Collaboration, contributed paper 579 to ICHEP98, Vancouver, Canada, July 1998.
10. H.Fritzsch and D.Holtmannspötter, hep-ph/9901411.
11. T.Kon et al., Phys. Lett. B 376 (1996) 227, and hep-ph/9707355.