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Search for Events with Isolated Leptons and Missing Transverse Momentum with H1 at HERA

H1 Collaboration

Abstract

The search for events containing isolated leptons (electrons or muons) and missing transverse momentum produced in $e^{\pm}p$ collisions is performed with the H1 detector at HERA in the period 1994–2007. The analysed data sample corresponds to an integrated luminosity of 478 pb^{-1}, which includes 189 pb^{-1} of $e^{+}p$ data and 170 pb^{-1} of $e^{-}p$ data from the new HERA II phase. A total of 59 events are observed in the complete HERA data, compared to a Standard Model (SM) prediction of 58.9 $\pm$ 8.2. At large hadronic transverse momentum $P_T^X > 25$ GeV, a total of 24 events are observed compared to a SM prediction of 15.8 $\pm$ 2.5. In this region, 21 events are observed in the $e^{+}p$ data compared to a SM prediction of 8.9 $\pm$ 1.5, whereas in the $e^{-}p$ data 3 events are observed compared to a SM prediction of 6.9 $\pm$ 1.0.

1 Introduction

Events containing a high P_T isolated electron or muon associated with missing transverse momentum have been observed at HERA [1–4]. An excess of HERA I (1994–2000) data events compared to the Standard Model (SM) prediction at large hadronic transverse momentum P_T^X was reported by the H1 Collaboration [2]. In the HERA I data, luminosity 118 pb^{-1}, 11 electron events and 8 muon events are observed compared to a SM expectation of 11.5 $\pm$ 1.5 and 2.9 $\pm$ 0.5 respectively. At large hadronic transverse momentum $P_T^X > 25$ GeV, 5 electron events and 6 muon events are observed compared to a SM expectation of 1.8 $\pm$ 0.3 and 1.7 $\pm$ 0.3 respectively. The dominant SM contribution is from the production of real W bosons. Presented here is an update of the published H1 analysis, including the complete $e^{\pm}p$ high energy data sample accumulated at HERA (1994-2007), which corresponds to an integrated luminosity of 478 pb^{-1}.

2 Standard Model Processes

Signal events are defined as those that contain a prominent high P_T isolated lepton accompanied by genuine, large missing transverse momentum. The main SM process that may produce events with this topology is the production of real W bosons via photoproduction with subsequent leptonic decay: $ep \rightarrow eW^{\pm}(\rightarrow l\nu)X$. Additional, smaller contributions arise from the production of W bosons via the charged current process $ep \rightarrow \nu W^{\pm}(\rightarrow l\nu)X$ and the production of Z^0 bosons with subsequent decay to neutrinos $ep \rightarrow eZ^0(\rightarrow \nu\bar{\nu})X$, which only contributes to the electron channel.

The main SM background to events containing isolated electrons arises from neutral current (NC) events, where fake missing transverse momentum is produced by a fluctuation in the detector response, and from charged current (CC) events, where a particle in the hadronic final state or a radiated photon is interpreted as the isolated electron. For events containing an isolated muon the main SM background arises from lepton pair (LP) events, where one muon escapes detection and mismeasurement causes the apparent missing transverse momentum, and from CC events where, similarly to the electron channel, a particle in the hadronic final state is interpreted as the isolated muon.

3 Event Selection

The HERA II event selection is identical to that used in the HERA I analysis and is detailed in table 1.The main selection requirements are as follows: The lepton should have high transverse momentum P_T^l, be observed in the central region of the detector, defined by the polar angle θ_l and be isolated with respect to jets and other tracks in the event. The isolation of the lepton is quantified using the distances in $\eta - \phi$ space to the nearest jet $D_{\rm jet}$ and nearest track $D_{\rm track}$. The event should contain a large transverse momentum imbalance, both measured in the calorimeter, $P_T^{\rm calo}$ and over the complete event, $P_T^{\rm miss}$.

Variable	Electron	Muon
θ_l	$5° < \theta_l$ <140°	
P_T^l	> 10 GeV	
$P_T^{\rm calo}$	> 12 GeV	
$P_T^{\rm miss}$	> 12 GeV	
P_T^X	–	> 12 GeV
$D_{\rm jet}$	> 1.0	
$D_{\rm track}$	> 0.5 for $\theta_e \geq 45°$	> 0.5
ζ_l^2	> 5000 GeV^2 for $P_T^{\rm calo} < 25$ GeV	–
$\frac{V_{ap}}{V_p}$	< 0.5 (< 0.15 for $P_T^e < 25$ GeV)	< 0.5 (< 0.15 for $P_T^{\rm calo} < 25$ GeV)
$\Delta\phi_{l-X}$	$< 160°$	$< 170°$
# isolated μ	0	1
$\delta_{\rm miss}$	> 5 GeV †	–

† *if only one e candidate is detected, which has the same charge as the beam lepton.*

Table 1: Selection requirements for the electron and muon channels in the search for events with isolated leptons and missing transverse momentum.

In order to reduce background contributions, further cuts are then applied using variables sensitive to the presence of high energy undetected particles in the event: The azimuthal balance of the event $\frac{V_{ap}}{V_p}$, the difference in azimuthal angle between the lepton and the hadronic system, $\Delta\phi_{l-X}$ and the longitudinal momentum imbalance $\delta_{\rm miss}$. Additionally, muon events are required to have a minimum P_T^X and electron events with low values of $P_T^{\rm calo}$ are required to have large ζ_l^2, which is equivalent to the four momentum transfer squared Q^2 in NC events. To ensure that the two lepton channels are exclusive, electron events must contain no isolated muons. Further details on these variables and the event selection can be found in [2].

4 Results

The analysis of the HERA II e^+p data ($\mathcal{L} = 189$ pb^{-1}), which was collected between October 2003 and March 2007, yields 16 electron events and 7 muon events compared to an expectation of 17.5 $\pm$ 2.5 and 4.6 $\pm$ 0.7 respectively. The SM prediction is dominated by signal processes, where the majority is due to real W production. An excess of events is observed in the data compared to the SM prediction at $P_T^X > 25$ GeV, where 11 events are observed compared to an expectation of 6.0 $\pm$ 1.0. The results of the e^+p data are summarised in table 2. Figure 1 displays one of the HERA II e^+p electron events. It shows a high P_T electron and large missing transverse momentum. The absence of any reconstructed hadronic system X makes this event a candidate for elastic W production. Figure 2 shows a HERA II e^+p electron event with high P_T^X. The same features are visible as in figure 1, a high P_T electron and large missing transverse momentum. However, also present in this event is a prominent hadronic jet, giving rise to the large P_T^X. Figure 3 similarly displays a muon event in the HERA II e^+p data also containing a prominent hadronic jet.

The analysis of the HERA II e^-p data ($\mathcal{L} = 170$ pb^{-1}), which was collected between December 2004 and June 2006, yields 15 electron events and 2 muon events compared to an expectation of 17.7 $\pm$ 2.5 and 4.7 $\pm$ 0.7 respectively. Figure 4 shows a HERA II e^-p muon event with high P_T^X. As for the HERA II e^+p data the SM prediction is dominated by signal processes, where the majority is due to real W production. The results of the e^-p data are summarised in table 3.

Table 4 shows a summary of the analysis results for the H1 e^+p data ($\mathcal{L} = 294$ pb^{-1}), H1 e^-p data ($\mathcal{L} = 184$ pb^{-1}) and the full HERA H1 $e^{\pm}p$ data set ($\mathcal{L} = 478$ pb^{-1}). In all data samples the SM expectation is dominated by the signal contribution, the main contribution arising from real W production proceeeding via photoproduction. The signal contribution is observed to be lower in the e^-p data, due to the higher SM background arising from CC events.

In the H1 e^+p data, 26 electron events and 15 muon events are observed compared to SM predictions of 27.3 $\pm$ 3.8 and 7.2 $\pm$ 1.1 respectively. Figure 5 shows the P_T^X spectrum of the e^+p data for the combined electron and muon channels. In the H1 e^-p data, 16 electron events and 2 muon events are observed compared to SM predictions of 19.4 $\pm$ 2.7 and 5.1 $\pm$ 0.7 respectively. Figure 6 shows the P_T^X spectrum of the e^-p data for the combined electron and muon channels.

In the complete H1 HERA data set, 42 electron events and 17 muon events are observed compared to SM predictions of 46.7 $\pm$ 6.5 and 12.2 $\pm$ 1.8 respectively. Figure 7 shows the P_T^X spectrum of the $e^{\pm}p$ data for the combined electron and muon channels. In 13 of the electron events the lepton charge is measured as positive, in 8 events negative and is unmeasured in the remaining 21 events. In 6 of the muon events the lepton charge is measured as positive, in 8 events negative and is unmeasured in the remaining 3 events. The main signal process is expected to produce approximately two thirds positively charged leptons. All background processes are expected to produce approximately similar yields for both lepton charges except neutral current DIS, which produces leptons with the same charge as the lepton beam.

5 Summary

The search for events containing isolated electrons or muons and large missing transverse momentum produced in $e^{\pm}p$ collisions is performed with the H1 detector at HERA in the period 1994–2007. The full H1 high energy data sample is analysed, corresponding to an integrated luminosity of 478 pb^{-1}. A total of 59 events are observed in the data, compared to a SM prediction of 58.9 $\pm$ 8.2.

At large hadronic transverse momentum $P_T^X > 25$ GeV, a total of 24 events are observed compared to a SM prediction of 15.8 $\pm$ 2.5. In 11 events the lepton charge is positive, in 6 events negative and unmeasured in the remaining 7 events. The probability for the SM expectation to fluctuate to the observed number of events or more in the high P_T^X domain for all data is 0.0592. For just the e^+p data this probability is 0.0014, equivalent to an excess of data over SM of order 3σ. For the HERA I e^+p data alone this probability is 0.0015.

References

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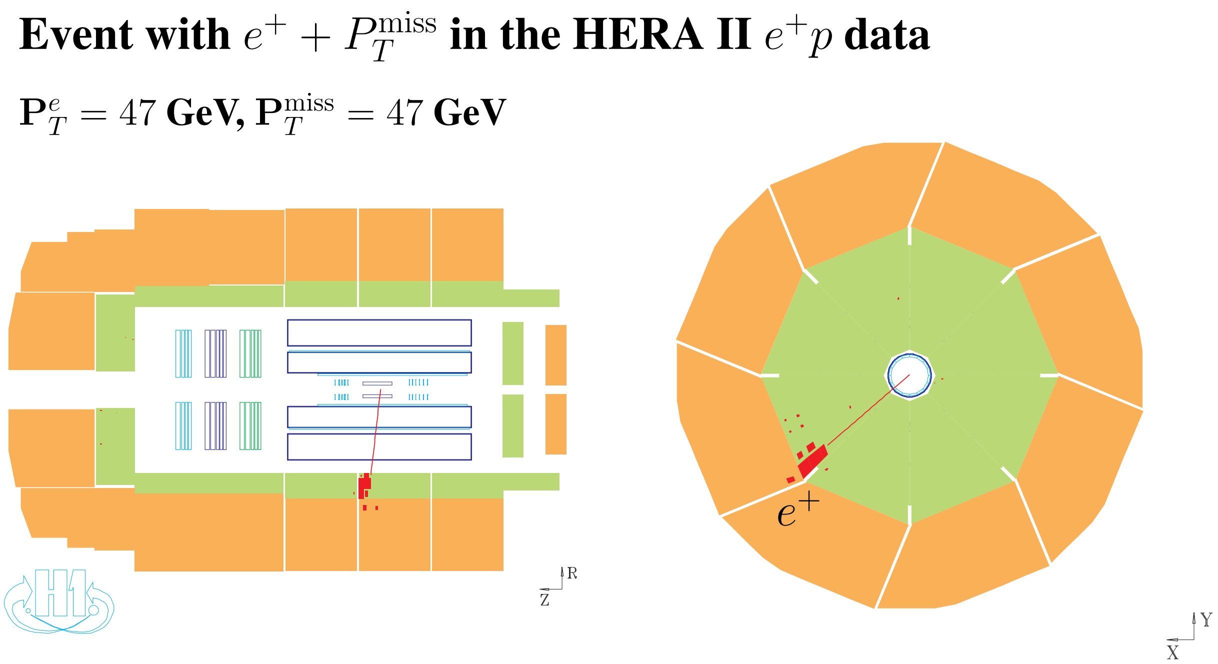

Figure 1: Display of an event with an isolated electron and missing transverse momentum: a candidate for elastic W production in the HERA II e^+p data.

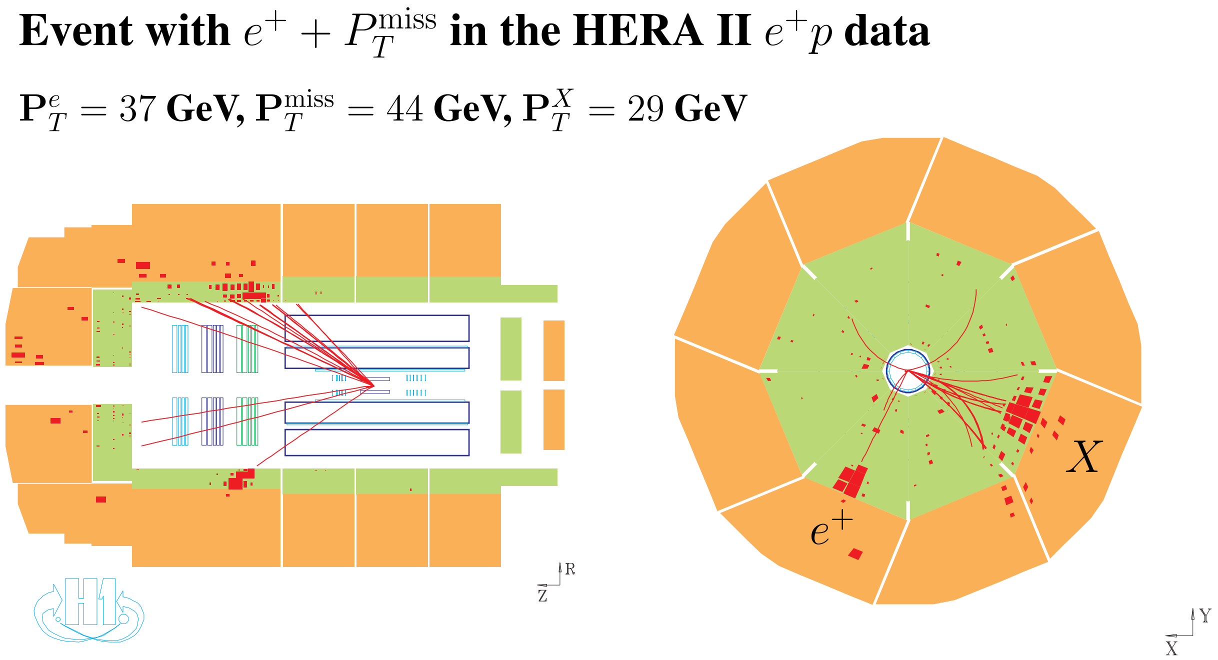

Figure 2: Display of an event with an isolated electron, missing transverse momentum and a prominent hadronic jet in the HERA II e^+p data.

Event with $\mu^- + P_T^{\rm miss}$ in the HERA II e^+p data

$\mathbf{P}_T^{\mu} = 51$ **GeV,** $\mathbf{P}_T^{\rm miss} = 39$ **GeV,** $\mathbf{P}_T^{X} = 48$ **GeV**

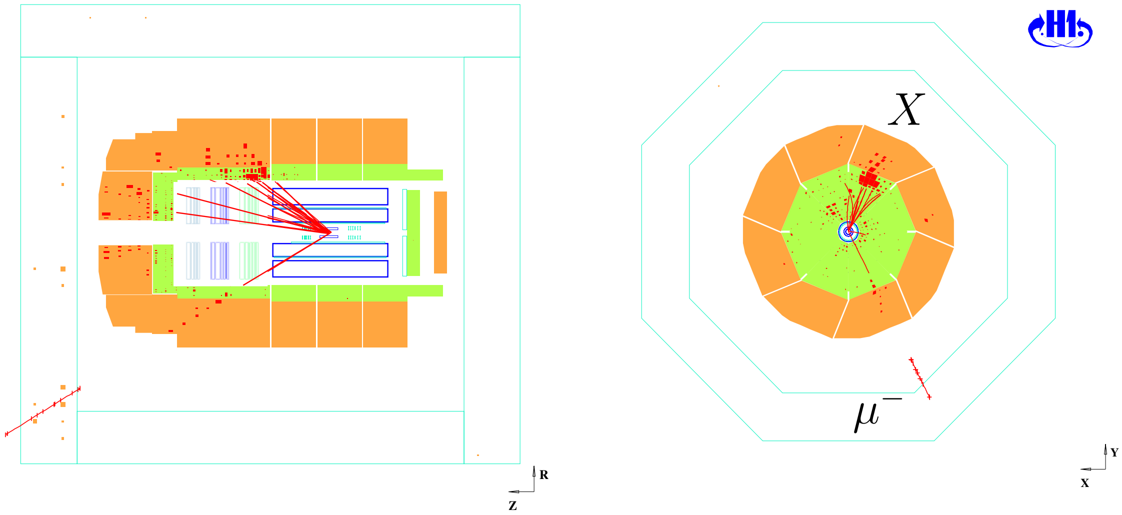

Figure 3: Display of an event with an isolated muon, missing transverse momentum and a prominent hadronic jet in the HERA II e^+p data.

Event with $\mu^- + P_T^{\rm miss}$ in the HERA II e^-p data

$\mathbf{P}_T^{\mu} = 38$ **GeV,** $\mathbf{P}_T^{\rm miss} = 51$ **GeV,** $\mathbf{P}_T^{X} = 24.7$ **GeV**

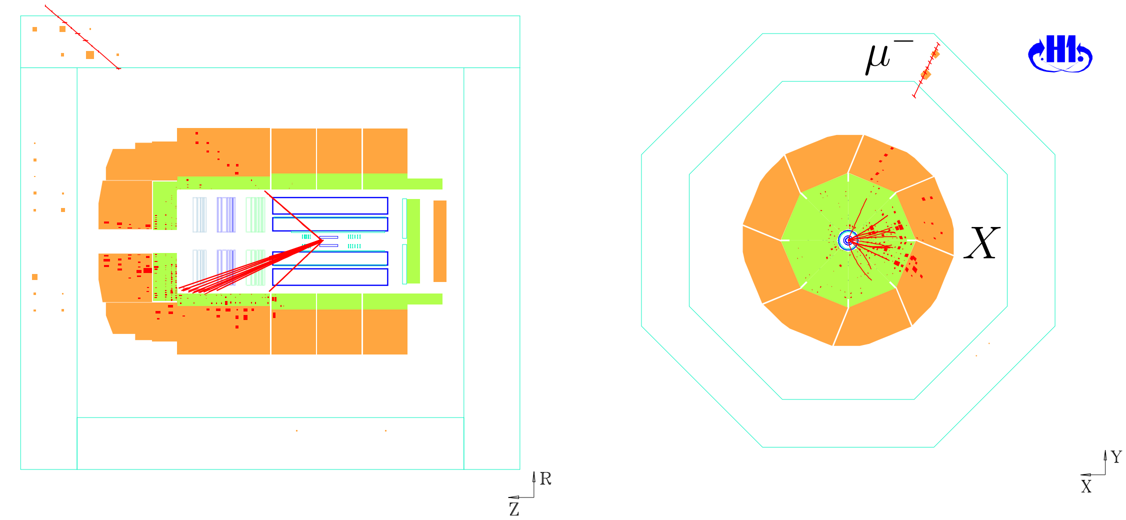

Figure 4: Display of an event with an isolated muon, missing transverse momentum and a prominent hadronic jet in the HERA II e^-p data.

H1 Preliminary, HERA II e^+p (189 pb^{-1})

Electron	H1 Data	SM Expectation	SM Signal
Full Sample	16	17.5 $\pm$ 2.5	12.3 $\pm$ 2.0
P_T^X >25 GeV	7	3.2 $\pm$ 0.6	2.3 $\pm$ 0.4
Muon	**H1 Data**	**SM Expectation**	**SM Signal**
Full Sample	7	4.6 $\pm$ 0.7	3.9 $\pm$ 0.6
P_T^X >25 GeV	4	2.8 $\pm$ 0.4	2.3 $\pm$ 0.4
Combined	**H1 Data**	**SM Expectation**	**SM Signal**
Full Sample	23	22.1 $\pm$ 3.1	16.2 $\pm$ 2.6
P_T^X >25 GeV	11	6.0 $\pm$ 1.0	4.6 $\pm$ 0.7

Table 2: The results of the search for events with isolated electrons or muons and missing transverse momentum in the HERA II e^+p data (189 pb^{-1}): observed and predicted numbers of events in the electron channel, the muon channel and the sum of electron and muon channels. The signal component of the SM expectation, dominated by real W production, is also given. The quoted errors contain statistical and systematic uncertainties added in quadrature.

H1 Preliminary, HERA II e^-p (170 pb^{-1})

Electron	H1 Data	SM Expectation	SM Signal
Full Sample	15	17.7 ± 2.5	11.7 ± 1.9
P_T^X >25 GeV	2	3.5 ± 0.6	2.1 ± 0.4
Muon	**H1 Data**	**SM Expectation**	**SM Signal**
Full Sample	2	4.7 ± 0.7	3.7 ± 0.6
P_T^X >25 GeV	0	2.9 ± 0.4	2.1 ± 0.4
Combined	**H1 Data**	**SM Expectation**	**SM Signal**
Full Sample	17	22.4 ± 3.1	15.3 ± 2.4
P_T^X >25 GeV	2	6.4 ± 1.0	4.2 ± 0.7

Table 3: The results of the search for events with isolated electrons or muons and missing transverse momentum in the HERA II e^-p data (170 pb^{-1}): observed and predicted numbers of events in the electron channel, the muon channel and the sum of electron and muon channels. The signal component of the SM expectation, dominated by real W production, is also given. The quoted errors contain statistical and systematic uncertainties added in quadrature.

H1 Preliminary l+P_T^{miss} events at HERA I+II		Electron obs./exp. (Signal contribution)	Muon obs./exp. (Signal contribution)	Combined obs./exp. (Signal contribution)
e^+p	Full Sample	26 / 27.3 $\pm$ 3.8 (71%)	15 / 7.2 $\pm$ 1.1 (85%)	41 / 34.5 $\pm$ 4.8 (74%)
294 pb^{-1}	P_T^X $>$ 25 GeV	11 / 4.7 $\pm$ 0.9 (75%)	10 / 4.2 $\pm$ 0.7 (85%)	21 / 8.9 $\pm$ 1.5 (80%)
e^-p	Full Sample	16 / 19.4 $\pm$ 2.7 (65%)	2 / 5.1 $\pm$ 0.7 (78%)	18 / 24.4 $\pm$ 3.4 (68%)
184 pb^{-1}	P_T^X $>$ 25 GeV	3 / 3.8 $\pm$ 0.6 (61%)	0 / 3.1 $\pm$ 0.5 (74%)	3 / 6.9 $\pm$ 1.0 (67%)
$e^{\pm}p$	Full Sample	42 / 46.7 $\pm$ 6.5 (69%)	17 / 12.2 $\pm$ 1.8 (82%)	59 / 58.9 $\pm$ 8.2 (72%)
478 pb^{-1}	P_T^X $>$ 25 GeV	14 / 8.5 $\pm$ 1.5 (68%)	10 / 7.3 $\pm$ 1.2 (79%)	24 / 15.8 $\pm$ 2.5 (73%)

Table 4: 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 $P_T^X > 25$ 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.

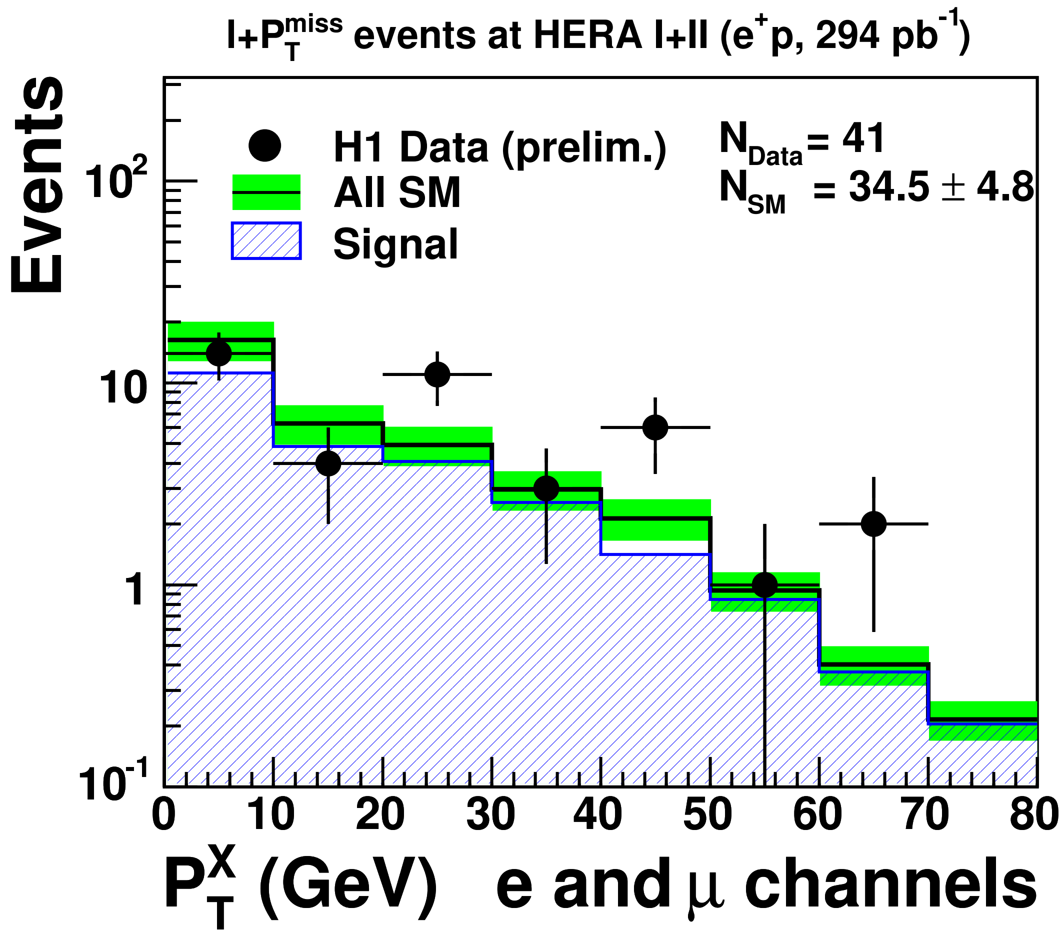

Figure 5: The hadronic transverse momentum distribution in the electron and muon channels combined: data (HERA I+II e^+p, 294 pb^{-1}) is compared to the SM expectation (open histogram). The signal component of the SM expectation, dominated by real W production, is given by the hatched histogram. $\mathrm{N_{Data}}$ is the total number of data events observed, $\mathrm{N_{SM}}$ is the total SM expectation. The total error on the SM expectation is given by the shaded band.

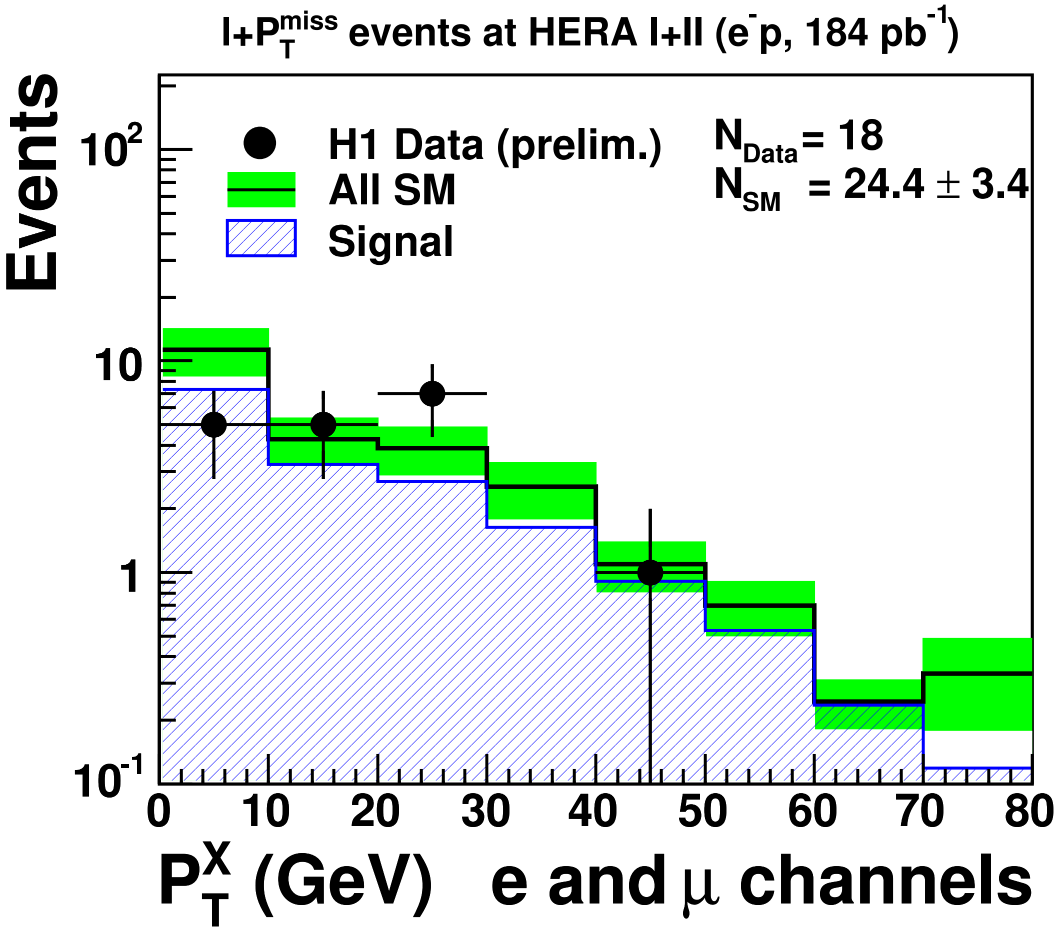

Figure 6: The hadronic transverse momentum distribution in the electron and muon channels combined: data (HERA I+II e^-p, 184 pb^{-1}) is compared to the SM expectation (open histogram). The signal component of the SM expectation, dominated by real W production, is given by the hatched histogram. $\mathrm{N_{Data}}$ is the total number of data events observed, $\mathrm{N_{SM}}$ is the total SM expectation. The total error on the SM expectation is given by the shaded band.

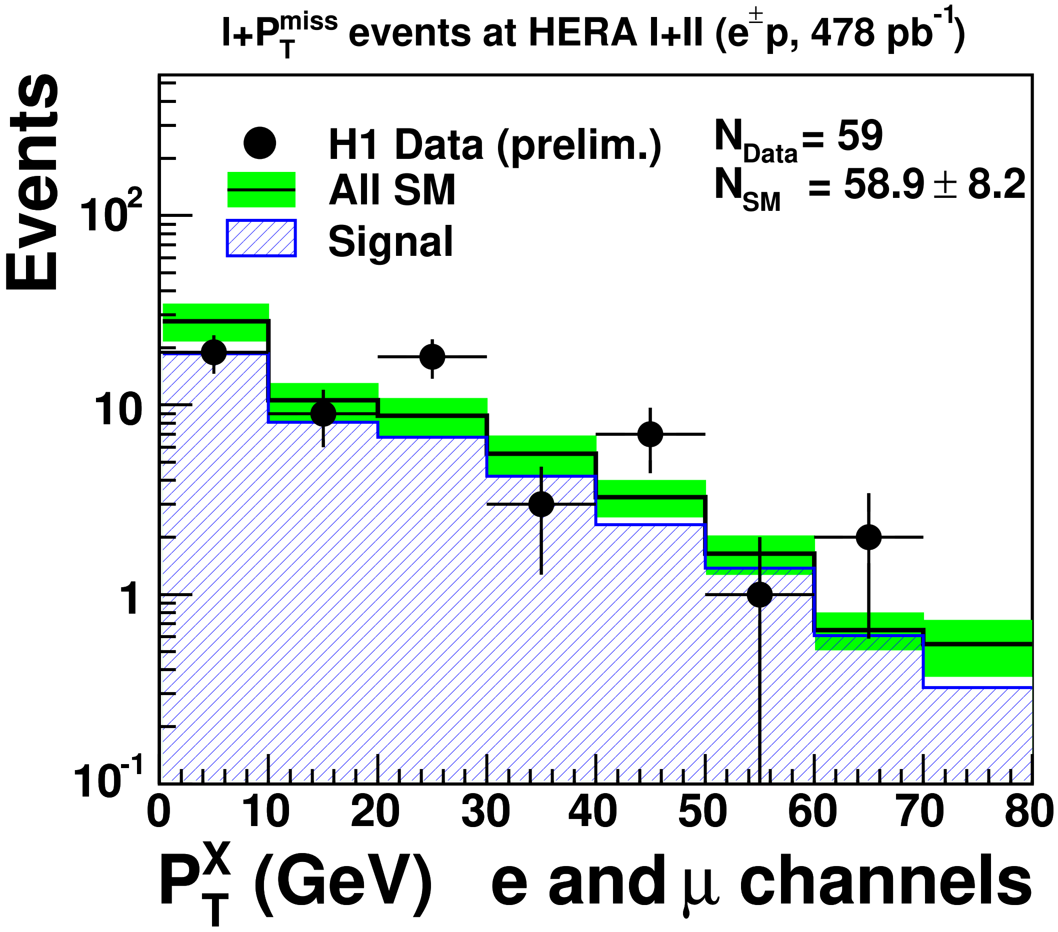

Figure 7: The hadronic transverse momentum distribution in the electron and muon channels combined: data (HERA I+II $e^{\pm}p$, 478 pb^{-1}) is compared to the SM expectation (open histogram). The signal component of the SM expectation, dominated by real W production, is given by the hatched histogram. $\mathrm{N_{Data}}$ is the total number of data events observed, $\mathrm{N_{SM}}$ is the total SM expectation. The total error on the SM expectation is given by the shaded band.