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Search for Events with Isolated Leptons and Missing Transverse Momentum

H1 Collaboration

This document presents an update of the previous preliminary results in the search for events with isolated leptons (electrons or muons) and missing transverse momentum in $e^{\pm}p$ collisions with the H1 detector at HERA in the period 1994–2005 [1]. The analysed data sample now corresponds to an integrated luminosity of 279 pb^{-1}, which includes 53 pb^{-1} of $e^{+}p$ data and 107 pb^{-1} of $e^{-}p$ data from the new HERA II phase. A total of 40 events are observed in the complete HERA data, compared to a Standard Model (SM) prediction of 34.3 $\pm$ 4.8.

At large hadronic transverse momentum $P_T^X > 25$ GeV, a total of 17 events are observed compared to a SM prediction of 9.0 $\pm$ 1.5. In this region, 15 events are observed in the $e^{+}p$ data compared to a SM prediction of 4.6 $\pm$ 0.8, whereas in the $e^{-}p$ data 2 events are observed compared to a SM prediction of 4.4 $\pm$ 0.7. Events with large transverse momentum are observed in both the HERA I and II $e^{+}p$ samples. Further details of the analysis may be found in [2].

1 Introduction

The H1 Collaboration has previously reported the observation of events with energetic isolated electrons or muons associated with missing transverse momentum [2]. The analysis includes the full HERA I data sample corresponding to an integrated luminosity of 118pb^{-1}. In the HERA I data, 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 contribution to the SM expectation arises from the production of real W bosons. Presented here is an update of the published analysis, including the new $e^{\pm}p$ data sample accumulated at HERA II from October 2003 to October 2005, corresponding to an integrated luminosity of 160 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, contributing only to the electron channel, the production of Z^0 bosons with subsequent decay to neutrinos $ep \rightarrow eZ^0(\rightarrow \nu\bar{\nu})X$.

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_{jet} and nearest track D_{track}. The event should contain a large transverse momentum imbalance, both measured in the calorimeter, P_T^{calo} and over the complete event, P_T^{miss}. In order to reduce background contributions, further cuts are then applied using variables sensitive to the presence of high energy undetected particles

Variable	Electron	Muon
θ_l	$5^\circ < \theta_l < 140^\circ$	
P_T^l	> 10 GeV	
$P_T^{\rm calo}$	> 12 GeV	
$P_T^{\rm miss}$	> 12 GeV	
P_T^X	–	> 12 GeV
D_{jet}	> 1.0	
D_{track}	> 0.5 for $\theta_e \geq 45^\circ$	> 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)
$\Delta\phi_{l-X}$	$< 160^\circ$	$< 170^\circ$
# 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 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 δ_{miss}. Additionally, muon events are required to have a minimum P_T^X and electron events with low values of P_T^{calo} are required to have large ζ_l^2, which is equivalent to the four momentum transfer squared Q^2 in NC events. So 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 ($\mathcal{L} = 53$ pb^{-1}), which was collected between October 2003 and August 2004, yields 9 electron events and 1 muon event compared to an expectation of 4.8 $\pm$ 0.8 and 1.3 $\pm$ 0.2 respectively. The SM prediction is dominated by signal processes, where the majority is due to real W production. In the electron channel an excess of events is observed in the data compared to the SM prediction at $P_T^X > 25$ GeV, where 5 events are observed compared to an expectation of 0.8 $\pm$ 0.2. The observation of 1 muon event in the data is in agreement with the SM event yield. 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.

The analysis of the HERA II e^-p data ($\mathcal{L} = 107$ pb^{-1}), which was collected between December 2004 and October 2005, yields 10 electron events and 1 muon event compared to an expectation of 10.9 $\pm$ 1.5 and 2.9 $\pm$ 0.4 respectively. 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. However, as expected from the SM, the CC background is observed to be higher. The data excess observed at high P_T^X in the HERA II e^+p electron channel is not present in the e^-p data, where 1 event is observed compared to an expectation of 2.1 $\pm$ 0.1.

Table 2 shows a summary of the analysis results for the H1 e^+p data ($\mathcal{L}$ = 158 pb^{-1}), H1 e^-p data ($\mathcal{L}$ = 121 pb^{-1}) and the full HERA H1 $e^\pm p$ data set ($\mathcal{L}$ = 279 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. At high P_T^X the signal contribution is observed to be higher than for the full sample.

In the H1 e^+p data, 19 electron events and 9 muon events are observed compared to SM predictions of 14.6 $\pm$ 2.0 and 3.9 $\pm$ 0.6 respectively. Figure 3 shows the P_T^X spectrum of the e^+p data for the combined electron and muon channels. In the H1 e^-p data, 11 electron events and 1 muon event are observed compared to SM predictions of 12.6 $\pm$ 1.8 and 3.3 $\pm$ 0.5 respectively. Figure 4 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, 30 electron events and 10 muon events are observed compared to SM predictions of 27.2 $\pm$ 3.8 and 7.2 $\pm$ 1.1 respectively. Figure 5 shows the P_T^X spectrum of the $e^\pm p$ data for the combined electron and muon channels. In 11 of the electron events the lepton charge is measured as positive, in 6 events negative and is unmeasured in the remaining 13 events. In 5 of the muon events the lepton charge is measured as positive, in 4 events negative and is unmeasured in the remaining event. 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 1994–2005. The analysed data sample corresponds to an integrated luminosity of 279 pb^{-1}. A total of 40 events are observed in the data, compared to a SM prediction of 34.3 $\pm$ 4.8. At large hadronic transverse momentum $P_T^X > 25$ GeV, a total of 17 events are observed compared to a SM prediction of 9.0 $\pm$ 1.5. In 9 events the lepton charge is positive, in 4 events negative and unmeasured in the remaining 4 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 0.0208 compared to 0.0015 for the HERA I data (the majority of which is e^+p data). For the complete e^+p data alone, this probability is 0.0003.

The continued increase in luminosity expected from the HERA II programme in the coming years will improve the precision of the measurement of events with isolated leptons and missing transverse energy and will hopefully clarify the excess observed in the e^+p data at large hadronic transverse momentum.

References

[1] H1 Collaboration; *Search for Events with Isolated Leptons and Missing Transverse Momentum at HERA*, contributed paper to *The International Europhysics Conference on High Energy Physics, EPS05*, Lisbon 2005, **Abstract 637**.

[2] V. Andreev *et al.* [H1 Collaboration], Phys. Lett. B **561** (2003) 241 [hep-ex/0301030].

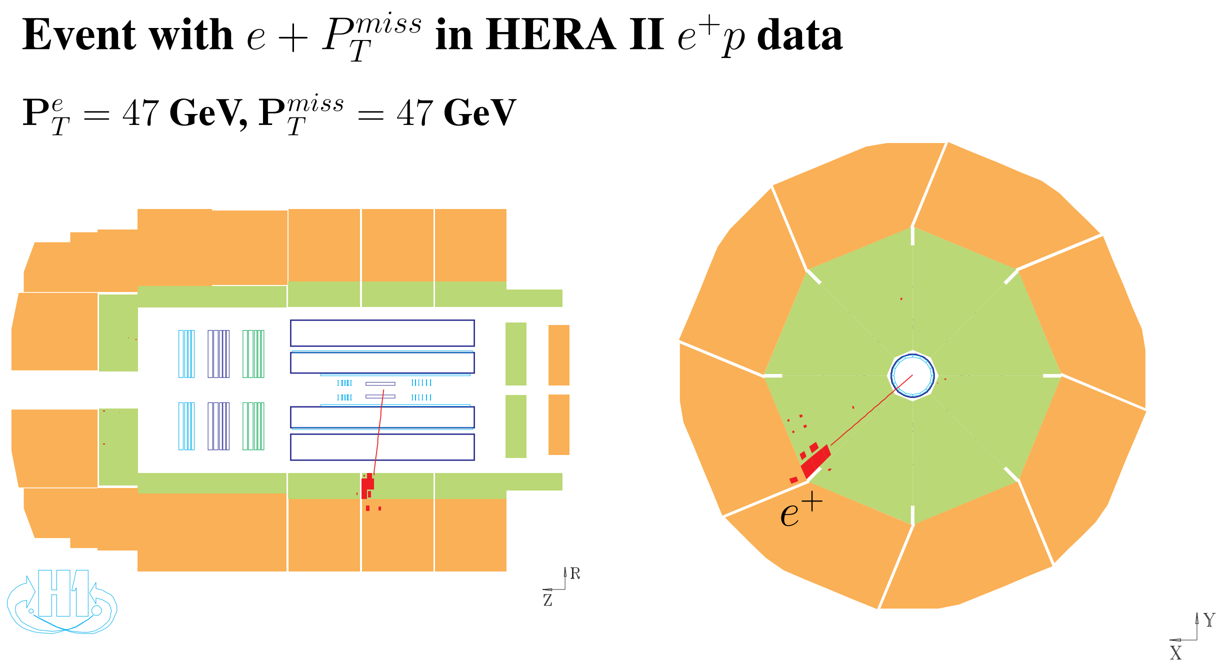

Figure 1: Display of an event with an isolated electron and missing transverse momentum: a candidate for elastic W production.

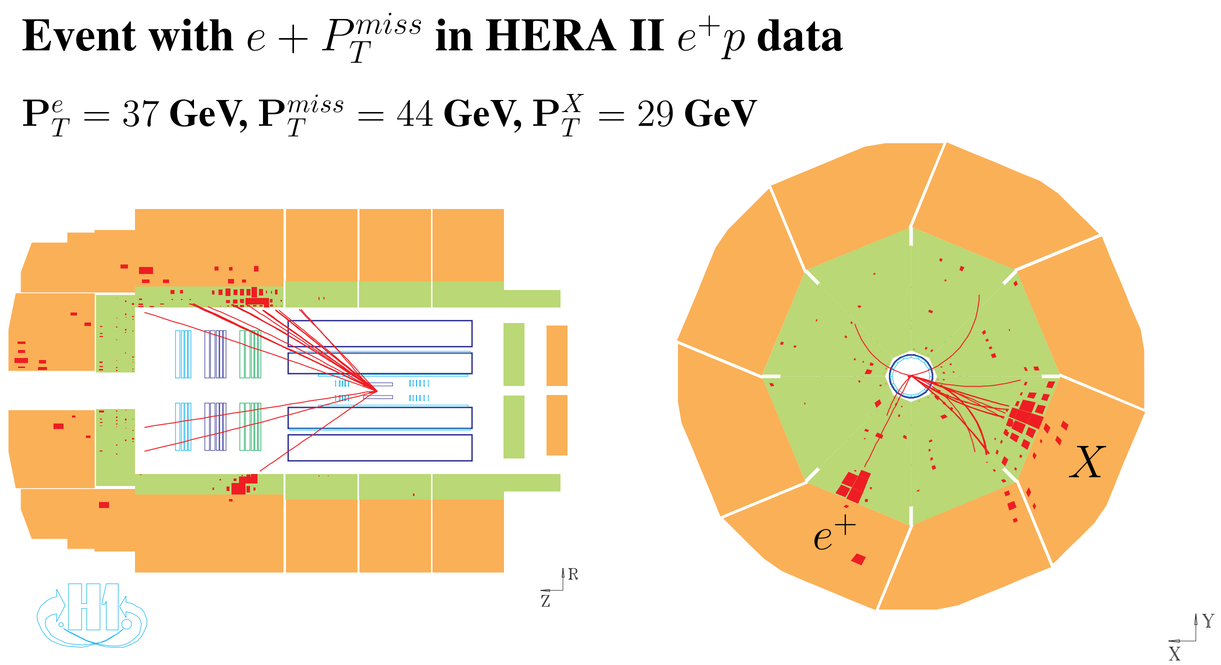

Figure 2: Display of an event with an isolated electron, missing transverse momentum and a prominent hadronic jet.

H1 Preliminary		Electron obs./exp. (Signal contribution)	Muon obs./exp. (Signal contribution)	Combined obs./exp. (Signal contribution)
1994-2004 e^+p 158 pb^{-1}	Full Sample	19 / 14.6 $\pm$ 2.0 (70%)	9 / 3.9 $\pm$ 0.6 (84%)	28 / 18.5 $\pm$ 2.6 (73%)
	$P_T^X > 25$ GeV	9 / 2.3 $\pm$ 0.4 (80%)	6 / 2.3 $\pm$ 0.4 (84%)	15 / 4.6 $\pm$ 0.8 (82%)
1998-2005 e^-p 121 pb^{-1}	Full Sample	11 / 12.6 $\pm$ 1.8 (66%)	1 / 3.3 $\pm$ 0.5 (79%)	12 / 15.8 $\pm$ 2.2 (68%)
	$P_T^X > 25$ GeV	2 / 2.4 $\pm$ 0.5 (62%)	0 / 2.0 $\pm$ 0.3 (76%)	2 / 4.4 $\pm$ 0.7 (68%)
1994-2005 $e^\pm p$ 279 pb^{-1}	Full Sample	30 / 27.2 $\pm$ 3.8 (68%)	10 / 7.2 $\pm$ 1.1 (81%)	40 / 34.3 $\pm$ 4.8 (71%)
	$P_T^X > 25$ GeV	11 / 4.7 $\pm$ 0.9 (69%)	6 / 4.3 $\pm$ 0.7 (78%)	17 / 9.0 $\pm$ 1.5 (73%)

Table 2: Summary of the H1 results of searches for events with isolated electrons or muons and missing transverse momentum for the e^+p data ($\mathcal{L}$=158 pb^{-1}), e^-p data ($\mathcal{L}$=121 pb^{-1}) and the full HERA data set ($\mathcal{L}$=279 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.

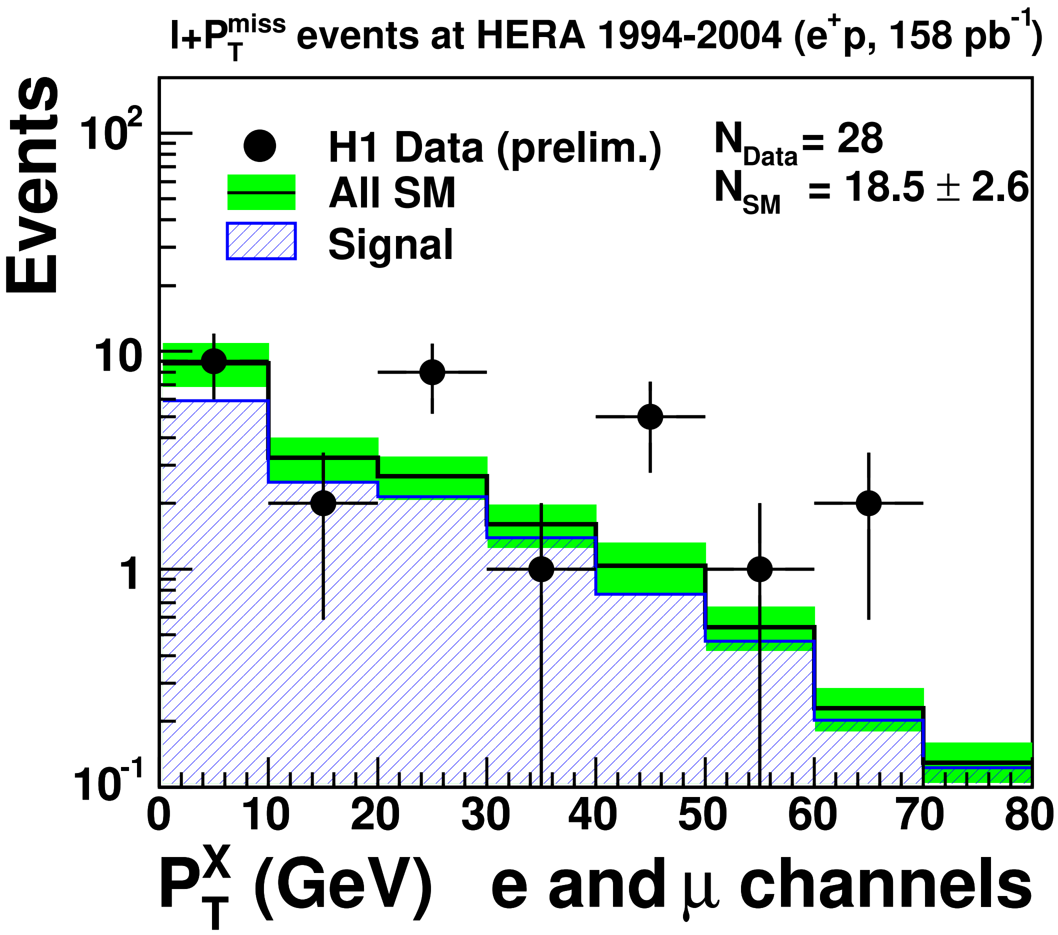

Figure 3: The hadronic transverse momentum distribution in the electron and muon channels combined: data (HERA e^+p, $\mathcal{L} = 158$ pb^{-1}) is compared to the SM expectation (open histogram). The signal component of the SM expectation, dominated by real W production, is given by the hatched histogram. $\mathrm{N_{Data}}$ 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.

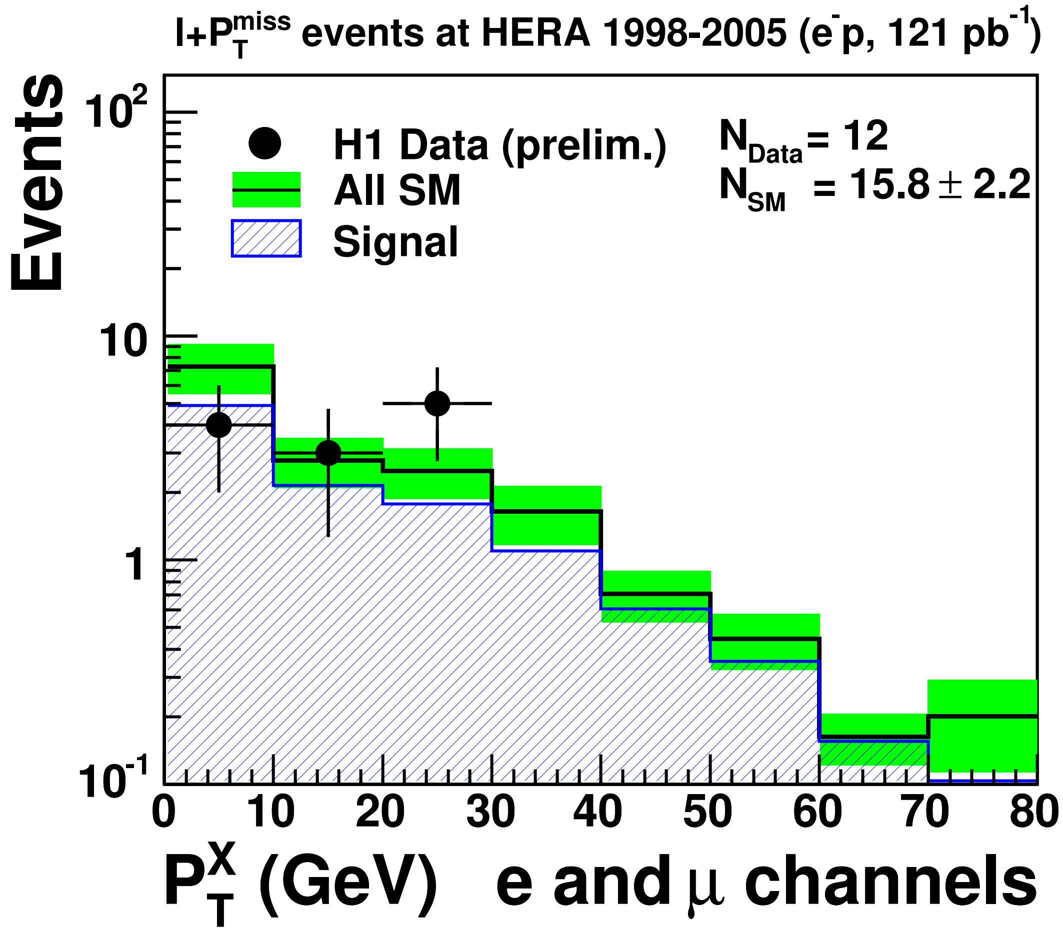

Figure 4: The hadronic transverse momentum distribution in the electron and muon channels combined: data (HERA e^-p, $\mathcal{L} = 121$ pb^{-1}) is compared to the SM expectation (open histogram). The signal component of the SM expectation, dominated by real W production, is given by the hatched histogram. $\mathrm{N}_{\mathrm{Data}}$ is the total number of data events observed, N_{SM} is the total SM expectation. The total error on the SM expectation is given by the shaded band.

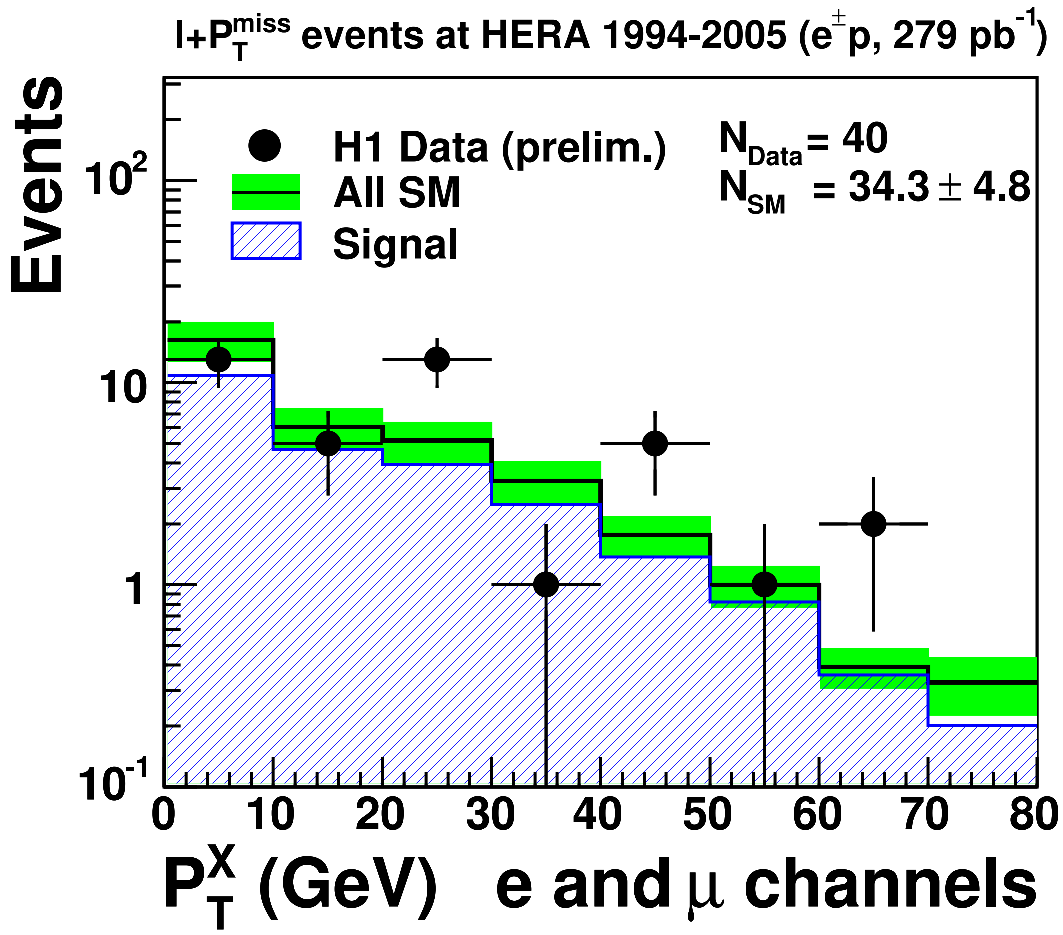

Figure 5: The hadronic transverse momentum distribution in the electron and muon channels combined: data (HERA $e^{\pm}p$, $\mathcal{L} = 279$ pb^{-1}) is compared to the SM expectation (open histogram). The signal component of the SM expectation, dominated by real W production, is given by the hatched 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.