A GENERAL SEARCH FOR NEW PHENOMENA IN E^-P SCATTERING AT HERA

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A model-independent search for deviations from the Standard Model prediction is performed in e^-p collisions at HERA II using H1 data recorded during the years 2005 and 2006, corresponding to an integrated luminosity of 159 pb^{-1}. All event topologies involving isolated electrons, photons, muons, neutrinos and jets with high transverse momenta are investigated in a single analysis. Events are assigned to exclusive classes according to their final state. A statistical algorithm is used to search for deviations from the Standard Model in the distributions of the scalar sum of transverse momenta or invariant mass of final state particles and to quantify their significance. A good agreement with the Standard Model prediction is observed in most of the event classes. No significant deviation is found in the phase–space and event topologies covered by this analysis.

1 Introduction

At HERA electrons [a] and protons collide at a centre-of-mass energy of up to 319 GeV. These high-energy electron-proton interactions provide a testing ground for the Standard Model (SM) complementary to e^+e^- and $p\overline{p}$ scattering.
The approach described in this paper [1] closely follows the strategy of the previously published H1 analysis using HERA I data [2]. It consists of a comprehensive and generic search for deviations from the SM prediction at large transverse momenta. The analysis covers phase–space regions where the SM prediction is sufficiently precise to detect anomalies and does not rely on assumptions concerning the characteristics of any SM extension. Using the complete HERA II e^-p data sample, this is the first general search performed on a large data set from electron-proton collisions.

[a] In this paper "electrons" refers to both electrons and positrons, if not otherwise stated.

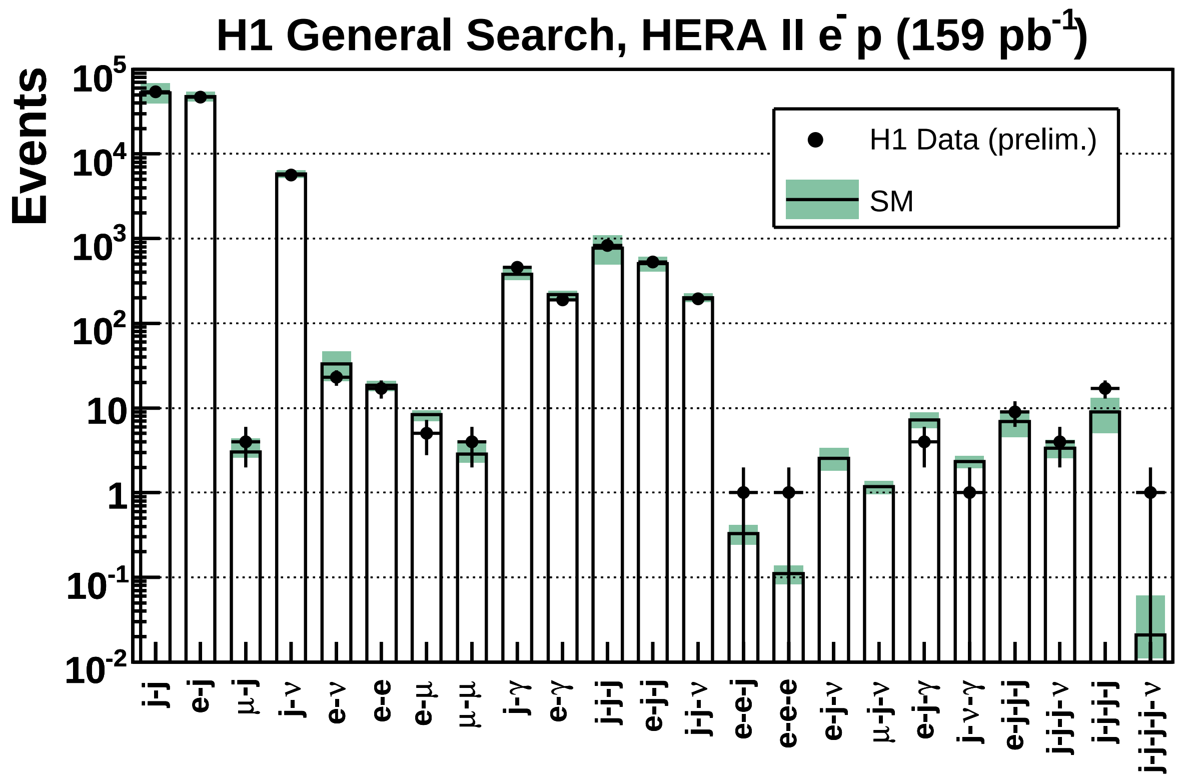

Figure 1: The data and the SM expectation for all event classes with observed data events or a SM expectation greater than 1 event. The analysed data sample corresponds to an integrated luminosity of 159 pb^{-1}. The error bands on the predictions include model uncertainties and experimental systematic errors added in quadrature.

2 Data analysis

The event sample studied consists of the full 2005–2006 HERA II e^-p data set, corresponding to an integrated luminosity of 159 pb^{-1}. All final states with at least two objects with $P_T > 20$ GeV in the polar angle range $10^\circ < \theta < 140^\circ$ are investigated. Considered objects are electrons (e), photons (γ), muons (μ), jets (j) and neutrinos (ν) (or non-interacting particles). The identification criteria for each type of object are similar to those applied in the published HERA I analysis, ensuring an unambiguous identification while keeping high efficiencies. All objects are required to be isolated from each other by a minimum distance R of 1 unit in the $\eta - \phi$ plane. The events are classified into exclusive event classes according to the number and types of objects. This exclusive classification ensures a clear separation of the final states and allows an unambiguous statistical interpretation.
As this analysis investigates all final state topologies of ep interactions at high transverse momentum, a precise and reliable estimate of all relevant HERA processes is needed. Hence, several Monte Carlo generators are used to generate a large number of events in all event classes, carefully avoiding double-counting of processes. The simulation contains the order α_S matrix elements for QCD processes, while second order α matrix elements are used to calculate QED processes. Additional jets are modelled using leading logarithmic parton showers as representation of higher order QCD radiation. All processes are generated with a luminosity significantly higher than that of the data.

The results of the data analysis are summarised in figure 1, which presents the event yields subdivided into event classes for the data and SM expectation. All event classes with observed

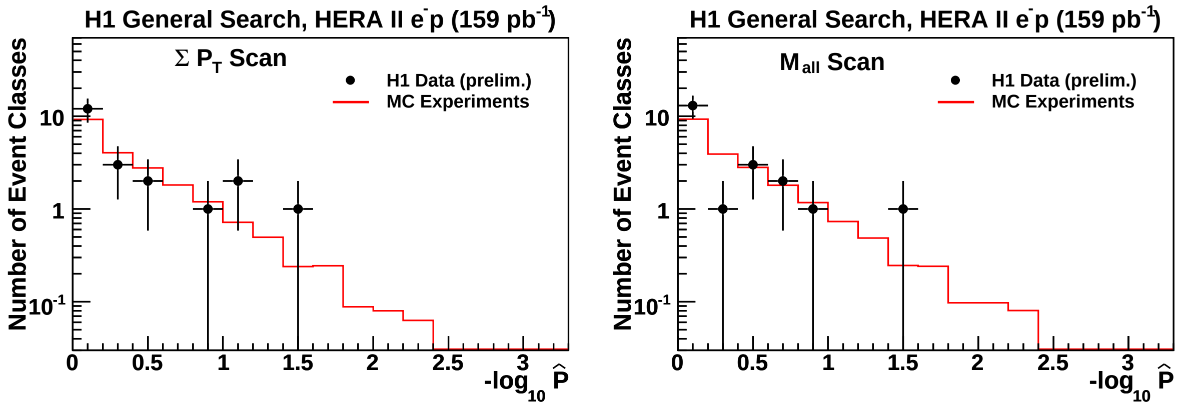

Figure 2: The $-\log \hat{P}$ values for the data event classes and the expected distribution from MC experiments as derived by investigating the $\sum P_T$ distributions (left) and M_{all} distributions (right) with the search algorithm.

data events or a SM prediction greater than 1 event are shown[b]. In each class, a good agreement between the number of observed data events and the SM prediction is seen.
No data events are observed in the event classes μ-j-ν and e-j-ν where the largest discrepancy between the data and the SM prediction was found in the analysis of the HERA I data (see section 4). Those classes correspond mainly to high P_T W production with subsequent leptonic decay, where deviations in the e^+p data continue to be observed[3]. The total SM expectation amounts to 1.2 ± 0.2 and 2.5 ± 0.8 in the μ-j-ν and e-j-ν classes, respectively.

3 Search for deviations

In order to quantify the level of agreement between the data and SM expectation and to identify regions of possible deviations, the invariant mass M_{all} and sum of transverse momenta $\sum P_T$ distributions of all reliable event classes are systematically investigated using the same search algorithm as developed for the previous publication. A region is defined as a sample of connected histogram bins, which have at least the size of twice the resolution of the observable. A statistical estimator p is defined to determine the region of most interest by calculating the probability that the SM expectation fluctuates upwards or downwards to the data. This estimator is derived from the convolution of a Poisson probability density function (pdf) to account for statistical errors with a Gaussian pdf to include systematic uncertainties. A possible sign of new physics is found if the expectation significantly disagrees with the data, and thus the region of most interest (greatest deviation) is given by the region having the smallest p-value, p_{min}. This method finds narrow resonances and single outstanding events, as well as signals spread over large regions of phase–space in distributions of any shape.
The fact that somewhere in the distribution a fluctuation with a value p_{min} might occur is taken into account by calculating the probability $\hat{P}$ to observe a deviation with a p-value p_{min} at any position in the distribution. Thus $\hat{P}$ is the central measure of significance of the deviation found. To determine $\hat{P}$, hypothetical data histograms are diced according to the pdf of the expectation. The value of $\hat{P}$ is then defined as the fraction of hypothetical data histograms with a p_{min}-value smaller than the p_{min}-value obtained from the data, and consequently the event class of most interest for a search is the one with the smallest $\hat{P}$-value.
The overall level of agreement between the data and SM expectation can be quantified further by taking into account the large number of event classes studied in this analysis. Among all

[b] The $\mu - \nu$ event class is discarded from the present analysis. It is dominated by events in which a poorly reconstructed muon gives rise to missing transverse momentum, faking the neutrino signature.

classes, there is some chance that small $\hat{P}$ values occur. This probability can be calculated by replacing all data distributions by hypothetical Monte Carlo (MC) distributions based on the SM expectation. The complete statistical algorithm is applied on this MC experiment, representing a single HERA experiment with an integrated luminosity of 159 pb^{-1}. The expectation for the $\hat{P}$ values of the data is then given by the distribution of $\hat{P}_{SM}$ values derived from many MC experiments. In the case that deviations arise from statistical or systematical fluctuations only, the distribution of $\hat{P}$-values obtained from data and MC experiments are compatible.

The results of the search for deviations between data and SM expectation are summarised in figure 2. Shown is the negative base–10 logarithm of the $\hat{P}$ values obtained from the real data compared to the expectation derived from a large set of MC experiments. The comparison is presented separately for the scans of the M_{all} and $\sum P_T$ distributions. All $\hat{P}$ values range from 0.01 to 0.99, corresponding to event classes where no significant discrepancy between data and SM expectation is observed. These results are in good agreement with the expectation from MC experiments.

Although data events are observed in the j-j-j-j and j-j-j-j-ν event classes, no reliable $\hat{P}$ values can be calculated for these classes due to uncertainties of the SM prediction at highest M_{all} and $\sum P_T$ values [2]. These event classes are not considered to search for deviations from the SM in this extreme kinematic domain. Consequently, these event classes are not taken into account to determine the overall degree of agreement between the data and the SM.

4 Comparison with HERA I results

While good agreement in all event classes is observed between the data and the SM prediction in the present HERA II analysis, some discrepancy is found in the previously published general search on the HERA I data. Complementary to the pure e^-p event sample studied here, the HERA I data set is largely dominated by positron-proton collisions. There the most significant deviation is found in the μ-j-ν event class with $\hat{P}$ values of 0.01 and 0.001 for the scan of the M_{all} and $\sum P_T$ distributions, respectively. The global probability to find at least one event class with a $\hat{P}$ value smaller than that of the μ-j-ν class in the HERA I data amounts to 28% for the M_{all} and 3% for the $\sum P_T$ distributions.

5 Conclusions

The data collected with the H1 experiment during the years 2005–2006 (HERA II) have been investigated for deviations from the SM prediction at high transverse momentum. All event topologies involving isolated electrons, photons, muons, neutrinos and jets are investigated in a single analysis. This is the first general search performed on a large set of data from electron–proton collisions. A good agreement between data and SM expectation is found in most event classes. In each event class the invariant mass and sum of transverse momenta distributions of particles have been systematically searched for deviations using a statistical algorithm. No significant deviation from the SM is observed in the phase–space and event topologies covered by this analysis.

References

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