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General search for new phenomena in ep scattering at HERA

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Abstract. A model-independent search for deviations from the Standard Model prediction has been performed in e^+p and e^-p collisions at HERA using H1 data. All experimentally measurable event topologies involving isolated electrons, photons, muons, neutrinos and jets with high transverse momenta have been investigated. A good agreement with the Standard Model prediction is found in most of the event classes. A new algorithm has been developed to look for regions with large deviations from the Standard Model in the invariant mass and sum of transverse momenta distributions and to quantify the significance of the fluctuations observed. The largest deviation is found in topologies with an isolated muon, missing transverse momentum and a jet which confirms previous observations. About 2% of hypothetical Monte Carlo experiments would produce deviations more significant than the one observed in the corresponding distribution of sum of transverse momenta.

1 Introduction

At HERA electrons[1] and protons collide with a centre-of-mass energy of up to 319 GeV. The H1 experiment at HERA has accumulated data corresponding to more than 100 pb^{-1} of integrated luminosity in the first period (HERA I, 1994-2000) and provides therewith a complete and well understood data set. One important goal at HERA is the search for new physics beyond the Standard Model (SM), which is predicted by a large variety of extensions to the SM resulting in final state topologies at high energies or large transverse momenta. In various dedicated analyses the HERA I data have been searched for new physics signals, and upper limits on cross-sections of new processes have been derived. Some discrepancies between the analysed data and the SM prediction have been found [1,2].

The approach described in this analysis consists in an extensive search for deviations from the SM prediction at large transverse momentum P_T in all final state topologies with at least two objects. 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 specific models beyond the SM. An in this spirit so-called model-independent search might therefore be able to discover unexpected manifestations of new physics and give an answer to the important question if new physics signals might be hidden in the HERA I data.

[a] on behalf of the H1 Collaboration

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

2 Data analysis

The event sample studied consists of the full 1994-2000 HERA I data. Investigated are all final states with at least two objects with $P_T > 20$ GeV in the polar angle range $10° < \theta < 140°$. The considered objects are electron (e), muon (μ), photon (γ), jet (j) and neutrino (ν) (or non-interacting particle). The identification criteria for each type of particle are based on previous analyses on specific final states. Additional requirements have been chosen to ensure an unambiguous identification of particles, still keeping high efficiencies [3]. Moreover all objects are required to be isolated from each other by a minimum distance $R = \sqrt{\Delta\eta^2 + \Delta\phi^2} > 1$ in the $\eta - \phi$ plane. All events are then divided in exclusive event classes according to the number and type of the measured objects. This exclusive classification ensures a clear separation of the final states and an unambiguous statistical interpretation later on.

As this analysis investigates all final state topologies of ep interactions, 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 modeled using leading logarithmic parton showers as representation of higher order QCD radiation. All processes are generated with a luminosity at least 20 times higher than that of the data.

The results of the analysis are summarised in Fig. 1, which presents the event yields for the data and SM expectation subdivided in event classes. Shown are all event

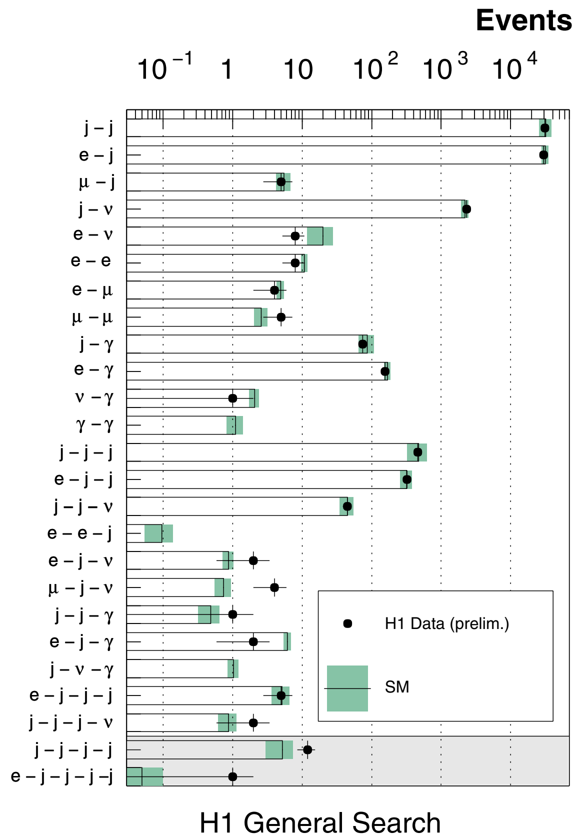

Fig. 1. The data and SM expectation for all event classes containing data events or a SM expectation greater than 0.1 event. The predictions for the *j-j-j-j* and *e-j-j-j-j* event class (grey area) are less reliable, and these classes are therefore not passed through the statistical analysis

classes containing data events or a SM expectation greater than 0.1 event[2].

A good overall agreement between data and SM expectation is observed for most of the event classes. Many of them have been analysed herein for the first time at HERA. Selection efficiencies have been derived to quantify the finding potential and can be used to set exclusion limits for new physics signals [3].

A discrepancy between data and SM expectation is observed in the μ-j-ν event class, which corresponds to typical event topologies arising from W production. The deviation was already reported in [1] and will be further discussed in Sect. 3.

Some discrepancies on the total event yields can also be observed in the *j-j-j-j* and *e-j-j-j-j* event classes, but since these spectacular events can – in the current Monte Carlo programs – only be produced via parton showers, it can not be ensured that the Monte Carlo prediction is reliable.

[2] The μ-ν event class was discarded from the analysis because of overwhelming background from low P_T photoproduction.

3 Search for deviations

To search for deviations between data and the SM expectation the invariant mass M_{all} and sum of transverse momenta $\sum P_T$ distributions of all reliable event classes are investigated. In order to quantitatively determine the level of agreement between data and SM expectation and to identify regions of possible deviations, a new search algorithm has been developed. 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 [3]. As in this ansatz a possible sign of new physics is found, if the expectation significantly disagrees with the data, the region of most interest (greatest deviation) is given by the region having the smallest p-value, $p_{\min}$. This method finds narrow resonances, single outstanding events as well as signals spread over large regions of phase space in distributions of any shape.

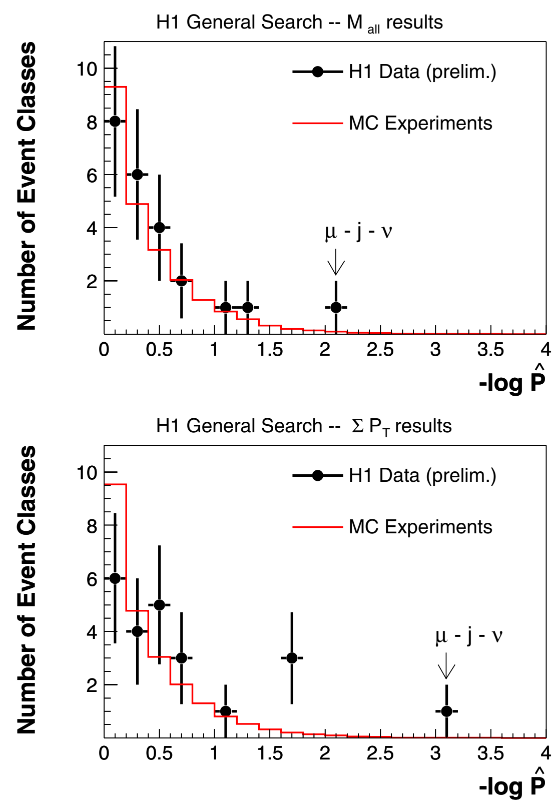

Fig. 2. The $-\log \hat{P}$ values for the data event classes and the expected distribution from MC experiments for the search in the M_{all} (upper) and in the $\sum P_T$ distributions (lower). All event classes with a SM expectation greater than 0.1 event, except the *j-j-j-j* and the *e-j-j-j-j* event class, are presented

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 found deviation. The calculation of the global significance of a deviation has been inspired by [4]. To determine $\hat{P}$ hypothetical data histograms are diced according to the probability density function 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 with the real data, and consequently the event class of most interest for a search is the one with the smallest $\hat{P}$-value.

To compare the obtained $\hat{P}$-values with an expectation, all data distributions are replaced by hypothetical Monte Carlo (MC) distributions. The complete algorithm is applied on these independent sets of MC experiments. In the case that deviations arise only from statistical or systematical fluctuations, 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 Fig. 2. Presented are the distributions of the negative decade logarithm of the final $\hat{P}$-values obtained from data compared to the expectation from MC experiments. The upper figure shows the distribution obtained from the search in the M_{all} distributions, while the result of the search in the $\sum P_T$ distributions is presented in the lower figure. Most $\hat{P}$-values range from 0.01 to 0.99, corresponding to event classes where no significant discrepancy between data and SM expectation is observed.

The largest deviation is observed in the μ-j-ν event class, where $\hat{P}$-values of 0.010 and 0.0008 are found corresponding to the high M_{all} and high $\sum P_T$ region. The corresponding distributions of M_{all} and $\sum P_T$ together with the regions selected by the algorithm are presented in Fig. 3. The invariant mass region contains 2 data events for an expectation of 0.05±0.02 events. In the chosen $\sum P_T$ region 3 data events are found while only 0.07±0.03 events are expected. This discrepancy was already reported in [1].

As this analysis studies a large number of event classes, there is some chance that small $\hat{P}$-values can arise. To quantify the significance of the deviations, the likeliness can be calculated, that the smallest $\hat{P}$-value found in the investigated M_{all} and $\sum P_T$ distributions occurs. These values are found to be about 25% for the set of M_{all} distributions and about 2% for the $\sum P_T$ distributions.

4 Conclusions

The data collected with the H1 experiment during the years 1994-2000 (HERA I) has been searched for deviations from the SM prediction. All possible event topologies have been investigated in a coherent and model-independent way. Many event classes are analysed herein for the first time at HERA. A good agreement between data and SM expectation has been found in most event classes, illustrating the good understanding of SM physics at HERA up to the edges of phase space. The invariant mass and sum of transverse momenta distributions of the event classes have been systematically searched for deviations with a novel algorithm. The most significant deviation is found in the μ-j-ν event class, a topology, where deviations have also been previously observed. No new significant deviation is found. With this work one of the most complete analysis of HEP data at high P_T has been presented and we are curiously looking forward to HERA II data taking.

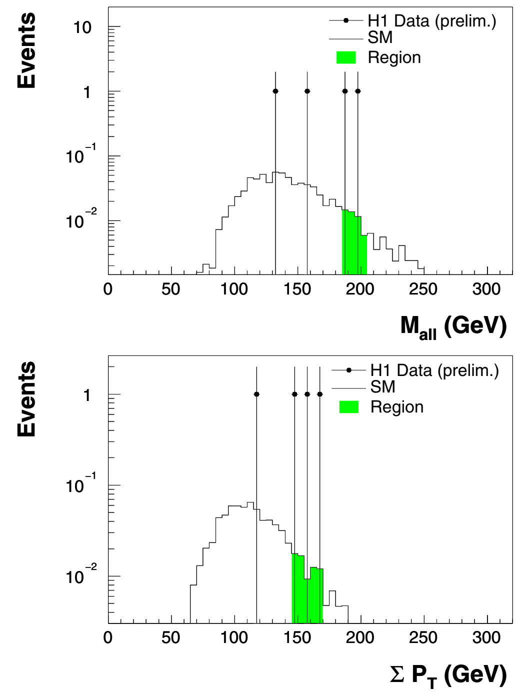

Fig. 3. The number of data events and the SM expectation for the μ-j-ν event class as a function of M_{all} (upper) and $\sum P_T$ (lower). The shaded area shows the region of greatest deviation chosen by the search algorithm

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