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GENERAL SEARCH FOR NEW PHENOMENA IN *EP* SCATTERING AT HERA

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A model-independent search for deviations from the Standard Model has been performed using the H1 data at HERA. All event topologies involving isolated electrons, photons, muons, neutrinos and jets with a transverse momentum above 20 GeV have been investigated. The largest deviation is found for the channel with a muon, a jet and a neutrino.

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 $p\bar{p}$ scattering. It is widely believed that the SM is incomplete and that new physics signals may appear below energies of 1 TeV. Many extensions to the SM have been constructed during the last decades predicting various phenomena which may be visible at high energies or large transverse momenta (P_T). HERA data have been used to test some of these models by analysing their anticipated experimental signatures and limits on their parameters have been derived [1].

The approach described in this paper consists of a comprehensive and generic search for deviations from the SM prediction at large transverse momenta. All high P_T final state configurations involving electrons (e), muons (μ), jets (j), photons (γ) or neutrinos (ν) are systematically investigated. 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. Such a model-independent approach might discover unexpected manifestations of new physics.

2 Event yields

All final states containing at least two objects (e, μ, j, γ, ν) with $P_T > 20$ GeV in the polar angle[b] range $10^\circ < \theta < 140^\circ$ are investigated. Additional requirements have been chosen to ensure an unambiguous identification of particles, whilst re-

[a] In this paper "electrons" refers to both electrons and positrons, if not otherwise stated.
[b] The origin of the H1 coordinate system is the nominal ep interaction point, with the direction of the proton beam defining the positive z-axis (forward region). The transverse momenta are measured in the xy plane. The pseudorapidity η is related to the polar angle θ by $\eta = -\ln\tan(\theta/2)$.

taining high efficiencies. Moreover, all objects are required to be isolated from each other by a minimum distance $\mathrm{R} = \sqrt{\Delta\eta^2 + \Delta\phi^2} > 1$ in the $\eta - \phi$ plane. The complete HERA I data sample (1994 – 2000) is used, corresponding to an integrated luminosity of 117 pb^{-1}. All selected events are classified into exclusive event classes according to the number and types of objects detected in the final state (e.g. e-j, μ-j-ν, j-j-j-j-j). These exclusive event classes ensure a clear separation of final states and allow an unambiguous statistical interpretation of the results.

Several Monte Carlo event generators are combined to simulate events for all SM processes which have large cross sections or are expected to be dominant for specific event classes , avoiding double-counting. All processes are generated with an integrated luminosity significantly higher than that of the data sample and Monte-Carlo events are passed through a full detector simulation. The simulation of these HERA processes is performed up to order α_s in QCD. QED processes are calculated to second order in α_{em}. Additional jets are generated using leading logarithmic parton showers as a representation of higher order QCD radiation.

All experimentally accessible combinations of objects have been studied. Data events or a SM expectation greater than 0.1 event are found in 25 classes. The results of the analysis are summarised in Fig. 1 left.

A good overall agreement between data and SM expectation is observed for most of the event classes. Many of them have been analysed here for the first time at HERA. Selection efficiencies have been derived to quantify the sensitivity in each class.

A discrepancy between data and SM expectation is observed in the μ-j-ν event class which corresponds to event topologies typical of W production. The deviation was already reported in [2] and will be further discussed in Sec. 3.

Excesses in 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 available Monte Carlo programs - only be produced via parton showers, these channels are discarded in the following statistical analysis.

3 Search for deviations

In order to quantify the level of agreement between the data and the SM expectation and to identify regions of possible deviations, a new search algorithm is developed. Detailed studies have shown that the invariant mass of all objects, M_{all} and the sum of their transverse momenta, $\sum P_T$ have a large sensitivity to new physics. The algorithm described in the following locates the region of largest deviation of the data from the SM in these distributions. The calculation of the significance of this deviation is inspired by [3].

A region is defined as a set of connected histogram bins, which have a size of at least 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 for each possible region. The estimator is derived from the convolution of a Poisson probability density function (p.d.f.) to account for statistical errors with a Gaussian p.d.f. to include the effect of non-negligible systematic uncertainties. The region of greatest deviation is the region having the smallest p-value, p_{min}. Such a method is able to find 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 the deviation could have occured at any point in the distribution 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. This $\hat{P}$ is the central measure of significance of the largest deviation in each distribution. To determine $\hat{P}$ hypothetical data histograms are diced according to the probability density function of the SM expectation. The value of $\hat{P}$ is the fraction of the hypothetical data histograms with a p_{min}-value smaller than the p_{min}-value measured in real data, and consequently, the event class of most interest for a search is the one with the smallest $\hat{P}$-value.

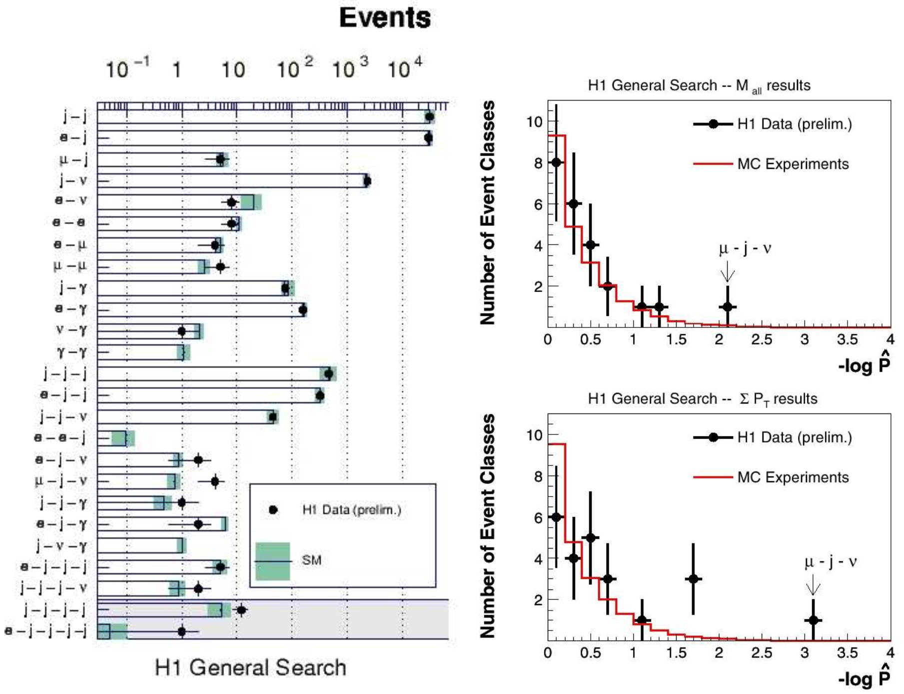

Figure 1. Left figure : The data and SM expectation for all events classes containing data events or a SM expectation greater than 0.1 event. The predictions for the *j-j-j-j* and *e-j-j-j-j* event classes (grey area) are less reliable, and these classes are therefore excluded from the statistical analysis. Right figures : The -log $\hat{P}$ values for the data event classes and the expected distribution from MC experiments for the search in M_{all} (upper) and in the ΣP_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

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. The probability to find a $\hat{P}$-value in at least one event class which is smaller than the minimum observed in the data can thus be calculated and quantifies the global significance of the observed deviation.

The results of the search for deviations between data and SM expectation are summarised in the Fig. 1 right.

Presented are the distributions of the negative 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 ΣP_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 ΣP_T region, respectively. This discrepancy was already reported in [2].

As this analysis studies a large number of event classes, small $\hat{P}$-values are expected in some cases. To quantify the overall significance of the deviations, the probability can be calculated, to observe a $\hat{P}$-value which is smaller than the lowest value found in the investigated M_{all} and ΣP_T distributions in any of the event classes. These values are found to be about 25% for the set of M_{all} distributions and about 2% for the ΣP_T distributions.

4 Conclusions

The data collected with the H1 experiment during the years 1994–2000 (HERA I) have been investigated in a search for deviations from the SM prediction at high transverse momentum. For the first time all event topologies involving isolated electrons, photons, muons, neutrinos and jets are investigated in a single analysis. A good agreement between the data and the SM expectation is found in most event classes. A better knowledge of rare processes may be required to search for deviations from the SM in final states with four or more jets at the highest invariant mass or transverse momentum. The distributions in the invariant mass and scalar sum of transverse momenta of the particles in each event class have been systematically searched for deviations using a novel statistical algorithm. The most significant deviation is found in the μ-j-ν event class, a topology where deviations have also been previously reported. No new significant deviation is found.

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