Multi-lepton events at HERA

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Events containing high-P_T multi-leptons were sought at HERA by the H1 and ZEUS collaborations. Experimental data were compared to simulations of $\gamma\gamma \to l^+l^-$ processes, and H1 extracted the total and differential cross sections of the processes.

The doubly-charged Higgs, which decays into lepton pairs, was analysed by H1 as a possible source of the multi-electron events, which have been observed at high invariant masses.

1 Introduction

The high centre-of-mass energy of HERA (around 300 GeV) offers the possibility of producing events with two (or more) leptons at high transverse energy (E_T). The production rate of these events can be accurately predicted within the Standard Model (SM). The H1 and ZEUS collaborations compared the data collected by their detectors [1, 2] to the SM, in order to detect any deviation.

2 Lepton-pair production at HERA

At HERA the dominant process which produces high-E_T lepton pairs is the non-resonant electroweak process $\gamma\gamma \to l^+l^-$ (Fig. 1, left). Processes beyond the Standard Model may contribute to lepton pair production; the supersymmetric left-right models (SUSYLR, [3]) predict the existence of a doubly-charged Higgs ($H^{\pm\pm}$), which can decay into a pair of like-sign charged leptons (Fig. 1, right).

The $\gamma\gamma$ process was simulated using the GRAPE Monte Carlo [4], whereas the $H^{\pm\pm}$ signal was generated by CompHEP [5].

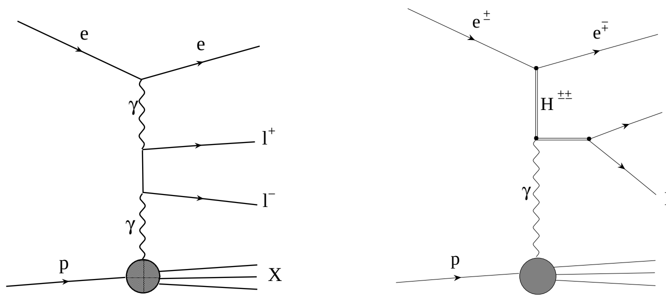

Figure 1: Lepton pair production via the $\gamma\gamma$ process (left); this is the major contribution to the l^+l^- production. Production of $H^{\pm\pm}$ (right) and its subsequent decay into two like-sign leptons; only one of the possible diagrams is shown.

3 Search for di-muon events

At H1, muon candidates were selected from tracks measured in the central tracker, which were linked to tracks found by the muon detector, or to a minimal ionising particle (MIP) deposit in the calorimeter (for low momentum tracks).

The search for di-muons [6] was carried out in the phase space defined by: $M_{\mu,\mu} > 5$ GeV, $P_T^{\mu 1} > 2.0$ GeV, $P_T^{\mu 2} > 1.75$ GeV, $20^\circ < \theta_\mu < 160^\circ$, $D^\mu_{\mathrm{Track,Jet}} > 1$ (or $D^\mu_{\mathrm{Track,Jet}} > 0.5$ if $P_T^\mu > 10$ GeV) [1].

GRAPE was found to describe well all data distributions. The total cross section measured by H1 is $\sigma = 46.5 \pm 1.3 \pm 4.7$ pb (46.2 pb expected from SM); the inelastic component was extracted by tagging the proton remnant X in the forward detectors [7]: $\sigma_{\mathrm{inel}} = 20.8 \pm 0.9 \pm 3.3$ pb (21.5 predicted by SM).

At ZEUS, muon candidates were selected requiring a track in the central tracker (CTD) pointing to a MIP in the calorimeter (CAL). In its analysis [8], the ZEUS collaboration required two isolated, energetic ($P_T^\mu > 5$ GeV) muons in the central region ($20^\circ < \theta_\mu < 160^\circ$) separated by an angle $\Omega < 174.2^\circ$; a comparison of the data to the GRAPE Monte Carlo shows a reasonable agreement (see Tab. 1).

[1] $D^\mu_{\mathrm{Track,Jet}}$ is the distance of the muon to the nearest track or jet in the pseudorapidity-azimuth-plane.

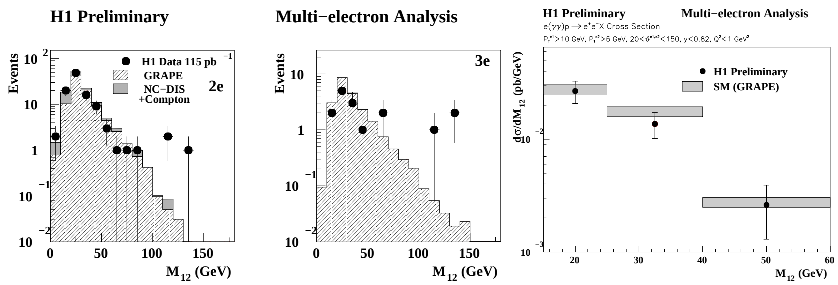

Figure 2: Invariant mass M_{12} for "2e" (left) and "3e" (centre) samples at H1. Differential cross section $\mathrm{d}\sigma/\mathrm{d}M_{12}$ (right) from $\gamma\gamma$ sample.

4 Search for multi-electron events

H1 performed an electron identification of clusters detected in the electromagnetic calorimeter; for candidates in the central region [2] a track matched in momentum and position was required.

In the H1 analysis [9] all electrons were asked to be isolated ($D^e_{\mathrm{Track}} > 0.5$) and energetic: $E_e > 5$ GeV (central and rear regions) or $E_e > 10$ GeV (forward). The electrons were sorted in transverse energy: $E_T^{e1} > E_T^{e2}$. At least two central electrons were required, one with $E_T > 10$ GeV and one with $E_T > 5$ GeV.

The events were classified as "2e" (two observed electrons) or "3e". The $\gamma\gamma$ sample was defined as: "2e", opposite-sign electrons and $E - P_z < 45$ GeV (so that only events where the scattered electron is lost in the beam pipe are kept). Fig.2, left and centre, shows the distribution of invariant mass of the highest E_T di-electrons, M_{12}. On the right the differential cross section $\mathrm{d}\sigma/\mathrm{d}M_{12}$ extracted from the $\gamma\gamma$ sample is shown. Good agreement is found between data and SM at low M_{12} (see also Tab. 1), an excess is observed at high mass: 3 events in "2e" sample (0.25 ± 0.05 expected) and 3 events in "3e" (0.23 ± 0.04 expected).

The doubly-charged Higgs was analysed by H1 [10] as a possible explanation of this excess; further cuts were applied to the sample, in order to optimize the sensitivity to $H^{\pm\pm}$. Only one event survived the cuts, although the efficiency

[2] In H1 analysis electrons were classified, depending on their polar angle, as forward ($5^\circ < \theta_e < 20^\circ$), central ($20^\circ < \theta_e < 150^\circ$) or backward ($150^\circ < \theta_e < 175^\circ$).

on the signal is quite high (20-45%). Therefore the 6 events observed by H1 are unlikely to originate from $H^{\pm\pm}$ production, and limits were set on this process; assuming a coupling $h_{ee} = 0.3$ and a branching ratio $BR(H^{\pm\pm} \to e^{\pm}e^{\pm}) = 1/3$, a doubly-charged Higgs with $M_H^{\pm\pm} < 102$ GeV was excluded.

At ZEUS electron candidates were selected by an algorithm which combines CTD information with electromagnetic clusters measured by the CAL; for candidates in the central region an energetic ($P > 5$ GeV) track matched in position was required.

In the ZEUS analysis [8], all electrons were asked to be isolated and energetic: $E_e > 10$ GeV (forward region [3]) or $E_e > 5$ GeV (central-rear regions). The events were accepted if they contain at least 2 central electrons, one with $E_T > 10$ GeV. The SM describes well the data (Fig. 3 and Table 1). No excess was observed for $M_{12} > 100$ GeV: 2 events were found with "2e" topology (0.77 ± 0.08 predicted by SM) and 0 in "3e" sample (0.37 ± 0.04 in SM).

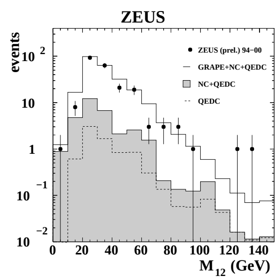

Figure 3: Invariant mass distribution of multi-electron events at ZEUS.

5 Conclusions

HERA collisions were analysed by H1 and ZEUS in the search for multi-lepton events. Data are well described by the simulation of $\gamma\gamma \to l^+l^-$ process, except for the high-mass region in multi-electron events at H1, where an excess is observed. The doubly-charged Higgs, decaying into di-leptons, was investigated as a possible source of the excess, and found to be unable to explain it.

[3] Electrons were classified by ZEUS, depending on their polar angle, as forward ($5^\circ < \theta_e < 17^\circ$), central ($17^\circ < \theta_e < 164^\circ$) or backward ($164^\circ < \theta_e < 175^\circ$).

Search	**Period**	**Lumi** [$\mathbf{pb}^{-1}$]	**Evts. in DATA (MC)**
H1, di-muons	1999-00	70.9	—
ZEUS, di-muons	1997-00	105.2	200 (213 ± 11)
H1, "2e" H1, "3e"	1994-97	115.2	105 (118.2 ± 12.8) 16 (21.6 ± 3.0)
ZEUS, "2e" ZEUS, "3e"	1994-00	130.5	191 (213 ± 4) 26 (34.7 ± 0.5)

Table 1: Summary of the various analyses presented in this review. The data taking period, the integrated luminosity and the number of events (detected and expected) is shown.

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