

Study of Rare Exclusive Electroweak Processes at HERA

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Results on multi-lepton events at high transverse momenta, isolated lepton events with large missing transverse energy and single W production reported to this conference are based for the first time on the full data samples taken by two colliding experiments, H1 and ZEUS, at HERA. The data correspond to an integrated luminosity of about 1 fb^{-1} from both experiments.

1. INTRODUCTION

The data taking at HERA, where electrons or positrons of 27.5 GeV collided with protons of up to 920 GeV, ended in June 2007. Each of the H1 and ZEUS experiments collected around 0.5 fb^{-1} data from the whole running period 1992-2007. The largest samples are from the second data taking period 2003-2007 (HERA-2). In comparison with HERA-1, the integrated luminosity of the e^+p and e^-p samples has a 2- and 10-fold increase, respectively. In addition, the e^+ and e^- beams at HERA-2 were longitudinally polarised. These data samples have made possible both the study of rare exclusive electroweak processes with cross section values down to 1 pb and the search for new physics phenomena.

This talk covers eight abstracts submitted to this conference from H1 and ZEUS on three main topics listed in the abstract. The results presented at the conference are briefly summarised here in the following sections.

2. MULTI-LEPTON EVENTS AT HIGH TRANSVERSE MOMENTA

An excess of multi-lepton events at high P_T at HERA was first reported in [1] by H1 based on HERA-1 data. The dominant Standard Model (SM) processes are from the lepton pair production in photon-photon interactions, $\gamma\gamma \rightarrow l^+l^-$, where the photons are radiated from incident beam particles. The background contributions are mainly from neutral current deep inelastic scattering (DIS) and QED compton processes where in addition to genuine electrons, hadrons or radiated photons are misidentified as electrons or muons. Beyond the SM, the production of a doubly charged Higgs boson [2] or processes involving generic bosons carrying two units of lepton number (bi-leptons) [3] could lead to multi-leptons events of large invariant mass.

The analyses are performed in a model independent way with the following main selection cuts. Take H1 [4] as an example, each event has to have at least two central ($20^\circ < \theta < 150^\circ$) electron or muon candidates with the leading lepton $P_T^1 > 10 \text{ GeV}$, the other lepton $P_T^2 > 5 \text{ GeV}$ and additional electrons in an extended angular region $5^\circ < \theta < 175^\circ$ and additional muons in $20^\circ < \theta < 160^\circ$ and $P_T > 2 \text{ GeV}$.

H1 has analysed seven topologies in ee , $\mu\mu$, $e\mu$, eee , $e\mu\mu$, $ee\mu$ and $eeee$. In all the topologies, the observed event yields are found in good agreement with the predicted ones [4]. However, when the comparison is made for the invariant mass of two highest P_T leptons $M_{12} > 100 \text{ GeV}$, excesses are observed in most of the topologies (Table I) although the number of observed events remains statistically limited. Also shown in Table I are preliminary results from ZEUS on di-electron and tri-electron samples [5]. In both samples no excess has been observed.

H1 has also compared the distributions of the scalar sum of the transverse momentum ($\sum P_T$) (see e.g. Fig. 1(left) for the e^+p data). At $\sum P_T > 100 \text{ GeV}$, 5 events have been observed in the e^+p sample with 0.96 ± 0.12 expected. None has been observed in the e^-p sample, however, while 0.64 ± 0.09 events are expected. Therefore the excess is only shown in the e^+p data sample.

Differential cross sections as a function of the leading transverse momentum P_T^1 for electron and muon pair production are measured by H1 [4] in a restricted phase space dominated by photon-photon interactions ($P_T^1 > 10 \text{ GeV}$, $P_T^2 > 5 \text{ GeV}$, $20^\circ < \theta < 150^\circ$, the inelasticity variable $y < 0.82$ and the four-momentum transfer squared

Table I: The number of observed events and SM expectations in different multi-lepton topologies for $M_{12} > 100$ GeV. The numbers shown in parentheses correspond to the contribution from the dominant pair production in $\gamma\gamma$ interactions.

Topology	H1		ZEUS	
	Data	SM (pair)	Data	SM (pair)
ee	3	$1.34 \pm 0.20(0.83)$	2	$1.7 \pm 0.2(0.9)$
$e\mu$	1	$0.59 \pm 0.06(0.59)$		
eee	3	$0.66 \pm 0.09(0.66)$	2	$1.0 \pm 0.1(1.0)$
$\mu\mu$	1	$0.17 \pm 0.07(0.17)$		
$e\mu\mu$	2	$0.16 \pm 0.20(0.83)$		

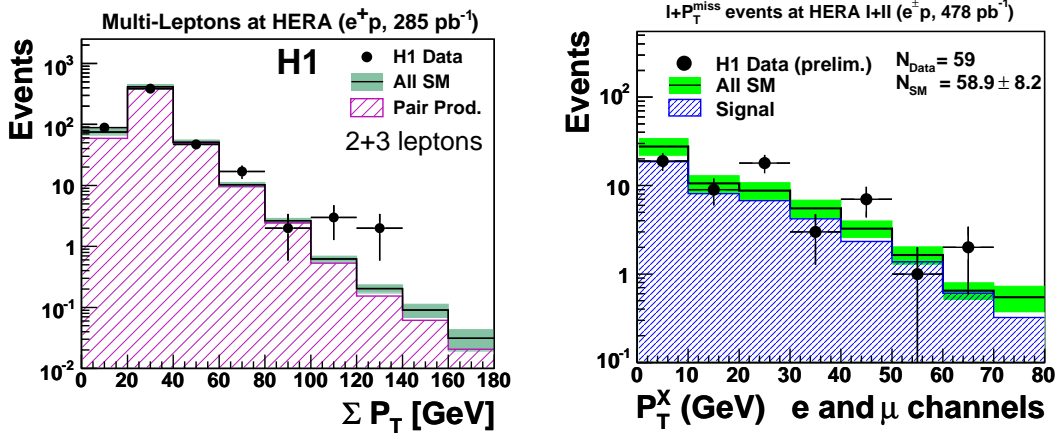


Figure 1: Left: The distribution of the scalar sum of the transverse momenta $\sum P_T$ for di-lepton and tri-lepton event samples for e^+p is compared to the total SM expectation and the dominant pair production. Right: The hadronic transverse momentum distribution in the isolated electron and muon channels combined is compared to the total SM expectation and dominant real W production.

$Q^2 < 1 \text{ GeV}^2$). ZEUS has released their preliminary results [6] for this conference in di-muon channel with a slightly different phase space cut ($P_T > 5 \text{ GeV}$). Both H1 and ZEUS measure steeply falling cross sections in good agreement with the SM expectations.

3. ISOLATED LEPTON EVENTS WITH LARGE MISSING ENERGY

The first isolated muon event with large missing transverse energy was reported by H1 in 1994 [7]. Since then several searches have been performed by H1 and ZEUS for different types of isolated lepton (e , μ , τ) and with increasingly large data samples [8]. The results [9, 10] reported to this conference with the full HERA data are summarised in Table II. The H1 excess in the e and μ channels (Fig. 1(right)) is not confirmed by ZEUS. ZEUS has, however, observed 2 isolated τ lepton events with a hadronic final state at large transverse momentum ($P_T^X > 25 \text{ GeV}$) for 0.20 ± 0.05 expected based on the HERA-1 data, of which 49% is contributed by the SM signal events from single W production with genuine isolated τ and missing transverse momentum in the final state. This number reflects thus the purity of the selection. The corresponding signal contribution (purity) for the e and μ channels is also shown in Table II. The rest is considered as background due to misidentification or mismeasurement. This latter contribution includes neutral and charged current DIS events, lepton pair production and photoproduction of jets.

The study of isolated lepton events with large missing transverse energy is interesting as it allows constraints to be placed on anomalous single top production [11] and bosonic stop decays [12] at HERA.

Table II: The number of observed events and expected contributions for three types of isolated lepton in $e^\pm p$ data samples for $P_T^X > 25$ GeV. The SM signal (dominated by W production) is shown in percentage in parentheses.

Dataset	Lepton	H1 [9]		ZEUS [10]	
		Data	Exp (signal)	Data	Exp (signal)
$e^+ p$	e	11	$4.7 \pm 0.9(75\%)$	3	$4.0 \pm 0.6(77\%)$
	μ	10	$4.2 \pm 0.7(85\%)$	3	$3.4 \pm 0.5(81\%)$
	τ	0	$0.5 \pm 0.1(72\%)$		
$e^- p$	e	3	$3.8 \pm 0.6(61\%)$	3	$3.2 \pm 0.5(69\%)$
	μ	0	$3.1 \pm 0.5(74\%)$	2	$2.3 \pm 0.4(85\%)$
	τ	1	$1.0 \pm 0.1(63\%)$		

4. W BOSON PRODUCTION CROSS SECTION

Within the SM, events with an isolated electron or muon and large missing transverse energy arise dominantly from the real W production. The W production cross section can thus be determined. The results from ZEUS [10] and H1 [13] are $\sigma(ep \rightarrow lWX) = (0.89_{-0.22}^{+0.25} \pm 0.10)$ pb and $\sigma(ep \rightarrow lWX) = (1.23 \pm 0.25 \pm 0.22)$ pb quoted at a center-of-mass energy of 316 GeV and 320 GeV, respectively. The first error is statistical and the second systematic. Both measurements reach a significance of about 5σ . They are in good agreement with the corresponding SM expectations of 1.2 pb and 1.3 pb with an uncertainty of 15% from the next-to-leading order calculations.

To further test the compatibility of the observed W decays with the SM, a measurement of the W boson polarisation is performed for the first time by H1 [13]. The measurement makes use of the angular distribution of the W boson production. For W^+ bosons, this reads:

$$\frac{dN}{d \cos \theta^*} \propto F_+ \cdot \frac{3}{8}(1 + \cos \theta^*)^2 + F_0 \cdot \frac{3}{4}(1 - \cos^2 \theta^*) + F_- \cdot \frac{3}{8}(1 - \cos \theta^*)^2 \quad (1)$$

where θ^* is defined as the angle between the W boson momentum in the lab frame and that of the charged decay lepton in the W boson rest frame, F_+ , F_0 and F_- stand respectively for the right-handed polarisation fraction, the longitudinal and left-handed one with $F_+ + F_0 + F_- = 1$. For W^- bosons, the $\cos \theta^*$ distributions have opposite values.

The measured differential cross section is compared with the SM expectation in Fig. 2(left). A fit to the distribution allows F_- and F_0 being simultaneously extracted. The results are shown in Fig. 2(right) and found to be in good agreement with the SM and compatible with anomalous single top production via flavour changing neutral current.

5. SUMMARY

Previously observed excesses in multi-lepton events at high transverse momenta and isolated lepton events with large missing transverse energy by H1 remain true with the full HERA data sample. The largest excess is up to about 3 standard deviations and is however not confirmed by ZEUS. Attempts in combining the H1 and ZEUS data have started and are being pursued [14]. As the HERA data taking has ended, it is unlikely that a definitive conclusion can be drawn with the combined data. Future experiments will eventually tell us whether the excess is a purely statistical fluctuation or a first sign of new physics.

References

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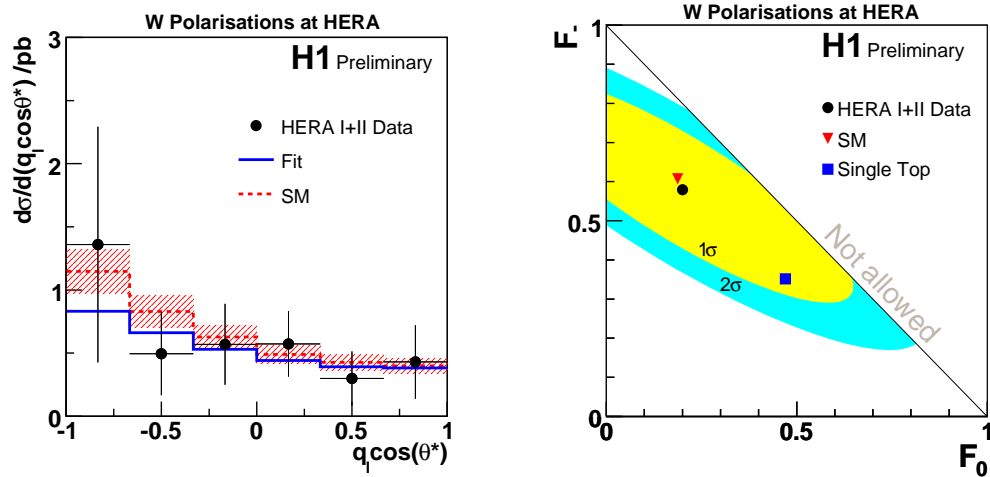


Figure 2: Left: Measured differential cross section shown with the statistical error bars in comparison with the SM prediction and the result of the fit. Right: The fitted F_- and F_0 at 1 and 2 σ contours in comparison with the SM prediction and anomalous single top production.

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