Are the H1 and ZEUS “High $Q^2$ Anomalies” Consistent with Each Other?

Manuel Drees
APCTP, 207-43 Cheongryangri-dong, Tongdaemun-gu, Seoul 130-012, Korea

Abstract

Both ZEUS and H1 have recently reported an excess of events at high $Q^2$ and high Bjorken–$x$. However, the $x$ distributions differ considerably; moreover, H1 sees more events with lower luminosity. Taken separately, the $x$ distributions and the number of observed events are consistent between the two experiments at the few percent level. However, when combined it becomes clear that the results of H1 and ZEUS are as (in)compatible with each other as each is with the Standard Model.
Very recently both experiments at the \( ep \) collider HERA, H1 \cite{1} and ZEUS \cite{2}, announced an excess of events that look like deep-inelastic scattering (DIS) events with high squared 4-momentum \( Q^2 \) and high Bjorken\( -x \). Both experiments estimated the probability of getting such an excess from a fluctuation within the Standard Model (SM) to be somewhat less than 1\%. Naively the combination of both experiments therefore excludes the SM at the better than 99.99\% confidence level. This is causing a flurry of papers \cite{3–9} that attempt to explain the effect in terms of some “new physics”.

However, combining the results from the two experiments only makes sense if they are consistent with each other. In this note I argue that the level of consistency of the two experiments with each other is no better than the compatibility of each experiment by itself with the SM. The two results can therefore not be claimed to mutually reinforce each other.

In order to arrive at this conclusion, one has to examine two aspects of the data sets: The distributions in Bjorken-\( x \), and the number of excess events seen by H1 and ZEUS. Let me begin with the \( x \) distributions.

The fact that these distributions look different has been noted before \cite{3, 4, 5}; H1 seems to see a rather well-defined peak at \( M_e = \sqrt{x_e s} \approx 200 \) GeV, whereas the ZEUS events are broadly distributed around 220 GeV. Here \( s = 300 \) GeV is the \( ep \) centre-of-mass energy, and the subscript “e” indicates that the momentum of the outgoing positron has been used to determine \( x \). It has been argued \cite{3, 5} that comparing the two distributions might be misleading, since ZEUS uses a different method (the “double angle” method) to reconstruct \( x \). However, this is not entirely correct. While ZEUS prefers the double angle method, since it gives more precise results given the performance of their detector, they do also give results for \( x_e \). Table 1a,b lists the events seen by H1 and ZEUS, respectively, in the H1 search window, defined by \( M_e \geq 180 \) GeV, \( y_e > 0.4 \). (\( y \) is the scaled positron energy loss in the proton rest frame.)

\[
\begin{array}{|c|c|c|c|c|c|c|}
\hline
\# & 1 & 2 & 3 & 4 & 5 & 6 & 7 \\
\hline
M_e & 196 \pm 5 & 208 \pm 4 & 188 \pm 12 & 198 \pm 2 & 211 \pm 4 & 192 \pm 6 & 200 \pm 2 \\
\hline
\end{array}
\]

\[
\begin{array}{|c|c|c|c|}
\hline
\# & 1 & 2 & 3 & 4 \\
\hline
M_e & 218 \pm 10 & 220 \pm 10 & 234 \pm 12 & 200 \pm 14 \\
\hline
\end{array}
\]

\textbf{Table 1:} The \( M_e \) values in GeV of the events found by H1 (a) and ZEUS (b) in the region \( M_e \geq 180 \) GeV, \( y_e \geq 0.4 \).

As stated earlier, the ZEUS events seem to lie at higher values of \( M_e \). Specifically, the averages of the two distributions are:

\[
\overline{M_e}(\text{H1}) = (200.3 \pm 1.2) \text{ GeV}; \quad (1a)
\]

\[
\overline{M_e}(\text{ZEUS}) = (219.3 \pm 5.5) \text{ GeV}. \quad (1b)
\]
These two values seem to differ by 3.4 standard deviations! However, so far I have only included the errors that are uncorrelated from event to event. Both H1 and ZEUS quote an overall energy scale uncertainty of 3% for their electromagnetic calorimeters. Call $r$ the energy scale factor. Then

$$\frac{1}{M_e} \frac{dM_e}{dr} \bigg|_{r=1} = 1 + \frac{1 - 2y_e}{2y_e}$$

(2)

The second term can be neglected for $y_e$ near 0.5, where most of the events are; neglecting it for the few events at high $y_e$ is conservative, since it will overestimate the impact of the energy scale uncertainty on the determination of $M_e$. With this assumption, a 3% energy scale uncertainty simply gives a 3% uncertainty in $M_e$. Adding this systematic error in quadrature to the statistical errors in eqs. (1), and assuming that the H1 and ZEUS energy scale factors are independent of each other, one finds:

$$\overline{M}_e(ZEUS) - \overline{M}_e(H1) = (19.0 \pm 10.5) \text{ GeV},$$

(3)

which amounts to a difference of 1.8 “standard deviations”. Naively this means that the two distributions are compatible with each other at only the 8% level. However, since the error in eq.(3) is mostly due to systematic effects (the energy scale uncertainties of both experiments), no straightforward statistical interpretation can be given.

One can overcome the scale uncertainty by determining the variance $\sigma_{M_e}$ of the distributions (or, equivalently, their second moments). From table 1 one finds:

$$\sigma_{M_e}(H1) = (3.3 \pm 0.6) \text{ GeV};$$

(4a)

$$\sigma_{M_e}(ZEUS) = (9.1 \pm 4.1) \text{ GeV},$$

(4b)

which gives

$$\sigma_{M_e}(ZEUS) - \sigma_{M_e}(H1) = (5.8 \pm 4.2) \text{ GeV}.$$  

(5)

This only amounts to a 1.4 standard deviation “discrepancy”, due to the larger errors of ZEUS’ $M_e$ values, and the rather small number of events seen by ZEUS, which does not really suffice to determine the shape of the $M_e$ distribution.

This brings me to the second part of my argument, the discrepancy in the number of events seen by the two experiments. In the search region $M_e \geq 180$ GeV, $y_e \geq 0.4$ defined by H1, they find seven events, but ZEUS only finds four. This is in spite of the fact that ZEUS analyzed 30% more data ($\int L dt = 20.1 \text{ pb}^{-1}$, vs. $14.2 \text{ pb}^{-1}$ for H1), and used looser cuts that result in a higher efficiency. Comparing the number of events with $Q^2 \geq Q_{\text{min}}^2$ expected within the SM given by the two experiments (table 2 of [1] and table 6 of [2]), one concludes

$$c \equiv \frac{\langle n \rangle_{H1}}{\langle n \rangle_{ZEUS}} = 0.55 \text{ to } 0.60,$$

(6)

where $\langle n \rangle = \sigma \epsilon \int L dt$ is the expected number of events for given cross section $\sigma$, luminosity $\int L dt$ and efficiency $\epsilon$. Here I am assuming that the efficiency for putative non-SM events in the samples is the same as for SM DIS events at high $Q^2$. The authors of ref. [5] have checked that this is indeed the case for events due to the $s$–channel production of leptoquarks (or

*ZEUS lists a fifth excess event, at $y_e = 0.32$; however, ZEUS does not seem to have a well–defined search region. This fifth event has $M_e = (225 \pm 20)$ GeV; its inclusion would therefore make the discrepancy between the two $M_e$ distributions slightly worse.
squarks with appropriate R–parity breaking couplings, which amounts to the same thing in this context), which is the so far most popular interpretation of the excess [4–8]. Note also that the ratio $c$ for DIS events is [1, 2] essentially independent of $Q_{\text{min}}^2$ for $Q_{\text{min}}^2 \geq 5,000 \text{ GeV}^2$.

From eq.(3) one concludes that if $\langle n \rangle_{H1} = n_{H1} = 7$, then $\langle n \rangle_{ZEU} = 11$ to 13, compared to the actual $n_{ZEU} = 4$. This shows that the hypothesis $\langle n \rangle_{H1} = 7$ is excluded by the ZEUS data at the 99% (99.5%) c.l. for $c = 0.6$ (0.55). Simply taking [4] the number of excess events observed by H1 as a measure for any “new physics” cross section is therefore misleading.

However, this does not directly tell us how (in)compatible the number of events seen by the two groups are. In order to investigate this question one has to let $\langle n \rangle_{H1}$ or, equivalently, $\langle n \rangle_{ZEU}$ float, and compute the combined probability

$$P(\langle n \rangle_{ZEU}, c) = \frac{p(n_{H1} \geq 7) \cdot p(n_{ZEU} \leq 4)}{p_{\text{max}}},$$

where

$$p(n_{H1} \geq k) = 1 - \sum_{n=0}^{k-1} \frac{(c\langle n \rangle_{ZEU})^n}{n!} e^{-c\langle n \rangle_{ZEU}}; \quad (8a)$$

$$p(n_{ZEU} \leq k) = \sum_{n=0}^{k} \frac{(\langle n \rangle_{ZEU})^n}{n!} e^{-\langle n \rangle_{ZEU}}; \quad (8b)$$

$$p_{\text{max}} = \max_j \left\{ p(n_{ZEU} \leq j) \cdot p(n_{H1} \geq \lceil c \cdot j \rceil) \right\}. \quad (8c)$$

The interpretation of eqs.(8a,b) is straightforward. The denominator $p_{\text{max}}$ in eq.(8), given in eq.(8c), is the maximal value of the numerator for any combination of $n_{ZEU}$ and $n_{H1}$, assuming only that $n_{H1} \geq \lceil c \cdot n_{ZEU} \rceil$ where $\lceil x \rceil$ refers to taking the integer part of $x$ and $c$ is defined in eq.(3). Note that this maximum is obviously always reached if the number of H1 events is as small as allowed by this constraint; hence only the number of ZEUS events $j$ needs to be scanned in eq.(8c). This normalization ensures that $P$ reaches unity for some range of $\langle n \rangle_{ZEU}$ in the simple test case where both experiments see the same number of events and $c = 1$, in agreement with an intuitive definition of the compatibility of the two experiments. Numerically, $p_{\text{max}} \simeq 0.35$ to 0.4 for the case at hand.

The dependence of $P$ on $\langle n \rangle_{ZEU}$ is shown in Fig. 1. One concludes that the number of excess events seen by the two groups are compatible with each other only at the 5.2% (3.7%) level for $c = 0.60$ (0.55). This conclusion is completely independent of the $M_e$ distributions discussed above. If the error in eq.(3) could be interpreted as simple statistical uncertainty, one would conclude that the overall probability that the two experiments are consistent with each other is less than 0.5%. This number is slightly smaller than the probability that either one of the experiments is compatible with the SM. The predominance of the systematic error in eq.(3) makes it difficult to give such a precise estimate of the level of (in)compatibility of the results of the two experiments; however, it seems clear that it cannot be much above the 1% level.

This means that any interpretation of the existing data sets that assume them to be statistically independent has to assume that at least one fluctuation occurred which had an a priori probability of no more than 1%.$^1$ Of course, it still remains true that an interpretation

$^1$In the opposite case, i.e. if ZEUS had seen “too many” events compared to H1, the inequalities in the numerator in eq.(8c) would have to be reversed.

$^2$More exactly, one needs two independent fluctuations, in the event numbers and $M_e$ distributions, with combined probability of 1% or less.
Figure 1: The probability $P$ defined in eq.(6) is shown as a function of the *expected* number of events that should have been seen by the ZEUS experiment for given cross section. $c = \langle n \rangle_{H1}/\langle n \rangle_{ZEUS}$, see eq.(5).

within the SM would need *two* such fluctuations. However, since one fluctuation of this kind evidently has to have happened anyway,$\S$ one can at present only conclude that the recent HERA data disfavor the SM at the 99% level, as opposed to the 99.99% level. Of course, an “exclusion” of the SM at the 99% c.l. is not very impressive. For example, both the L3 “$l^+l^-\gamma\gamma$” events [10] and the ALEPH “$\tau^+\tau^-V$” events [11] “excluded” the SM at significantly higher confidence level, and nevertheless later proved to be spurious (most likely due to fluctuations). I would therefore not be surprised at all if the SM weathered this most recent onslaught as well.

References

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$\S$The only way around this conclusion seems to require the assumption that the H1 and ZEUS data sets are somehow *not* statistically independent. This, however, quickly takes one into the realm of conspiracy theories.
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