PHYSICS OF OUR DAYS

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Observation of very-large-Q^2 anomalous events in ep collisions on the HERA collider

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Abstract. Anomalous events with very high momentum transfer values were observed on the proton – electron collider HERA at DESY, not accounted for by the Standard Model of elementary particles.

Two collaborations, H1 and ZEUS, working on HERA (Hadron – Electron Ring Accelerator facility) collider at DESY (Deutsches Electronen-Synchrotron, see below), have discovered an excess of events with very high values of kinematic variables x (or mass $M = \sqrt{xs}$), y, and Q^2 over the expected. Here x is the part of the momentum of a proton carried by a scattered parton (a quark or a gluon); s is the energy of an electron – proton collision in the centre of mass of the proton – electron system; Q^2 is the square of the momentum transferred during the collision; $y = Q^2/M^2$, M is the mass of the electron – parton system.

Both international groups, H1 and ZEUS, have independently analyzed data on deep inelastic scattering (DIS) collected at HERA since 1994. For three years, the accelerator operated with a positron beam (energy 27.5 GeV) colliding with protons (energy 820 GeV). The registered events look like typical DIS: an incoming positron interacts with a parton (most probably a quark) inside a proton and is scattered through a large angle, and the outcoming parton generates a hadronic jet. That is why variables like x and y, which characterize the interaction of the incoming positron with a parton (quark) inside proton, are chosen to present the results.

Both groups have compared the results of their measurements with Monte Carlo calculations based on the Standard Model for DIS with a neutral current (NC) (NC describes the exchange of an intermediate Z-boson or a photon). Distributions of the transferred momenta coincide well with the calculated ones for $Q^2 < 15000$ GeV^2, however for higher Q^2 they exceed the expected values. The probability that this is a statistical fluctuation is less than 1%, so it seems unlikely that the events registered can be explained within the framework of the Standard Model. The predictions are reliable enough and cannot vary significantly.

A similar excess is found in the invariant mass distribution for masses higher than 175 GeV. Large-momentum events with such masses are mostly interesting in that they fall into a so far unexplored kinematic region of DIS. The number of large-momentum events registered on H1 detector (see Tables 1 – 3) is 12 against the five expected. Two events with $Q^2 > 35000$ GeV^2 have been registered in the ZEUS experiment against the expected value of 0.145 events. An excess is also present for events with charged currents, but there the event number is even smaller and the statistics is insufficient to draw definite conclusions. Table 1 lists the total number of registered and expected events with $Q^2 > 10000$ GeV^2 for H1 and ZEUS experiments. The total result is obtained by simple summation, while the errors are square-added. The different numbers of expected H1 and ZEUS events are due to different integral luminosities, the methods of kinematic reconstruction of events, the difference in resolution by the transferred momentum Q^2 and in the registration efficiency under chosen restrictions. For example, the e-method in H1 means that the kinematic characteristics of the event were restored using only the registered positron, and the 2α-method in ZEUS uses information on the angles of both the positron and hadronic jet. The last column displays the probability that the registered events are fluctuations of the calculated number of deep inelastic events. In Table 2 we present a sample of the same events, as in Table 1, for $y > 0.25$, ordered by the kinematic variables M and x. Table 3 is constructed similarly to Table 2 for $y > 0.4$. Both groups hope that in 1997, when the information is to be obtained from March to October, the statistics will be larger and the situation can be clarified by the autumn.

The fact that the experimental data agree well with the Standard Model calculations for $Q^2 < 15000$ GeV^2 indicates that all the efficiencies and possible noise sources are well understood. The events with higher Q^2 cannot be explained by the Standard Model. However, there are some possible explanations for the registered events beyond the Standard Model. They could appear as resonances in a positron-quark system. Leptoquarks, leptogluons, and so-called squarks, whose existence is predicted by supersymmetric theories, could be such new particles. Leptoquarks are hypothetical particles having the quantum numbers of both leptons and quarks. The masses of the registered events are grouped around 200 GeV, which makes the leptoquark hypothesis even more attractive, since a leptoquark, by decaying, yields an energetic hadronic jet and a positron.

On 19 February 1997, this two collaborations presented their results at the seminar of the DESY physics center. They are published in the preprints DESY 97-024 and 97-025 (on which the present note is actually based) and have been submitted to *Zeitschrift für Physik*.

Let us use this occasion to acquaint the reader with the place of action: DESY performs basic research in high-energy and particle physics as well as in the production and application of synchrotron radiation. This is a state scientific center with a budget of about DM 275 000 000 (90% of the

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Table 1.

Q^2, GeV^2	H1: e-method, $y < 0.9$, $\theta_e > 10°$		ZEUS: 2α-method, $E_e > 20$ GeV ($P_{T,e} > 30$ GeV for $\theta_e < 17°$)		H1+ZEUS		
	Data	Calculation	Data	Calculation	Data	Calculation	$P(N \geqslant N_{obs})$
> 10000	20	18.3±2.4	33	32.2±2.0	53	50.5±3.1	0.37
> 15000	12	4.71±0.76	12	8.66±0.66	24	13.4±1.0	0.0074
> 20000	5	1.32±0.27	5	2.76±0.24	10	4.08±0.36	0.010
> 25000	3	0.51±0.16	3	1.01±0.09	6	1.52±0.18	0.0053
> 30000	2	0.23±0.05	2	0.37±0.04	4	0.60±0.06	0.0035
> 35000	0	0.08±0.04	2	0.15±0.01	2	0.23±0.04	0.023

Table 2.

M, GeV	x	H1: e-method, $0.25 < y < 0.9$, $\theta_e > 10°$		ZEUS: 2α-method, $E_e > 20$ GeV ($P_{T,e} > 30$ GeV for $\theta_e < 17°$)		H1+ZEUS		
		Data	Calculation	Data	Calculation	Data	Calculation	$P(N \geqslant N_{obs})$
> 175	> 0.339	11	6.3±1.6	15	11.9±0.70	26	18.2±1.7	0.062
> 190.1	> 0.4	7	3.09±0.86	10	6.03±0.39	17	9.12±0.94	0.016
> 200	> 0.443	4	1.42±0.63	6	3.55±0.24	10	4.97±0.67	0.037
> 212.6	> 0.5	0	0.81±0.26	4	1.75±0.13	4	2.56±0.29	0.026
> 222.9	> 0.55	0	0.47±0.17	4	0.91±0.08	4	1.38±0.19	0.054

Table 3.

M, GeV	x	H1: e-method, $0.4 < y < 0.9$, $\theta_e > 10°$		ZEUS: 2α-method, $E_e > 20$ GeV ($P_{T,e} > 30$ GeV for $\theta_e < 17°$)		H1+ZEUS		
		Data	Calculation	Data	Calculation	Data	Calculation	$P(N \geqslant N_{obs})$
> 175	> 0.339	7	2.35±0.38	5	4.15±0.30	12	6.50±0.48	0.036
> 190.1	> 0.4	6	1.06±0.24	4	2.09±0.17	10	3.15±0.29	0.0018
> 200	> 0.443	3	0.63±0.15	3	1.22±0.10	6	1.85±0.18	0.012
> 212.6	> 0.5	0	0.32±0.11	2	0.61±0.06	2	0.93±0.13	0.24
> 222.9	> 0.55	0	0.22±0.09	2	0.31±0.03	2	0.53±0.09	0.11

funds come from the Federal Ministry of Science and 10% are supplied by the city of Hamburg). There are three thousand scientists from 280 universities and research institutes from 35 countries around the world. 1300 of them study microphysics and 1700 work with synchrotron radiation.

HERA is a world-unique collider in which electron (or positron) beam collides with protons. Such interactions allow to study the internal structure of protons on scales of one thousandth of its size. The colliding beams in HERA circulate in opposite directions and are focused to interact at two points.

The H1 collaboration involves about 400 physicists from 12 countries: Belgium, Czech Republic, France, Germany, Italy, Poland, Russia, Slovak Republic, Sweden, Switzerland, the United Kingdom, and the USA. The ZEUS group has 430 participants from 12 countries: Canada, Germany, Israel, Italy, Japan, Korea, the Netherlands, Poland, Russia, Spain, the United Kingdom, and the USA. The experimental programs of H1 and ZEUS started in 1992, and recently have started a program of experiments using a fixed target, HERMES, which has operated since 1995 and uses a beam of polarized protons to study the spin structure of the proton. The HERA-B experiment should start in 1998, aimed at searching for CP-invariance violation in B-meson decays.

The length of accelerator HERA is 6 km 336 m; it was constructed between 1984 and 1990. The first interaction of the colliding beams was registered in October 1991. In 1992, 50 nbarn^{-1} of the integral luminosity were collected (luminosity is a characteristic of the collision rate of beam particles in an accelerator; multiplied by the process cross-section it yields the number of events of the given type); in 1993 this number increased to 1 pbarn^{-1}, in 1994 to 6, in 1995 to 12.3, and in 1996 to 17.2. In 1997, not less than 20 pbarn^{-1} are expected.

New experimental data should clarify the situation and convince experimenters that they have revealed new physical phenomena. It is not excluded, however, that these data may disappoint them or bring new surprises. We shall see.