Submitted to

International Europhysics Conference on High Energy Physics, July 12, 2001, Budapest

EPS 2001:	Abstract:	**823**
	Parallel Session	**6**
	Plenary Session	**6**

XX International Symposium on Lepton and Photon Interactions, July 23, 2001, Rome

LP 2001:	Abstract:	**515**
	Parallel Session	**S11**
	Plenary Session	**S11**

www-h1.desy.de/h1/www/publications/conf/conf_list.html

SEARCH FOR EXCITED NEUTRINOS AT HERA

H1 Collaboration

Abstract

We present a search for excited neutrinos using e^-p data taken by the H1 experiment at $\sqrt{s} = 318$ GeV with an integrated luminosity of 15 pb^{-1}. No evidence for excited neutrino production is found. Mass dependent exclusion limits are determined for the ratio of the coupling to the compositeness scale, f/Λ, independently of the relative values of the coupling constants f and f'.

The discovery of excited quarks or leptons, as predicted by composite models, would supply convincing evidence for a substructure of fermions. Electron-proton interactions at very high energies provide ideal conditions to look for excited states of first generation fermions. In particular the magnetic-transition coupling of the electron to a heavy fermion would allow for single production of excited neutrinos (ν^*) through t-channel W boson exchange. In this paper we present a search for ν^* production followed by the electroweak radiative decays $\nu^* \to \nu\gamma$, $\nu^* \to eW$ or $\nu^* \to \nu Z$. The analysis makes use of 15 pb^{-1} of e^-p data with an electron beam energy of 27.6 GeV and a proton beam energy of 920 GeV collected in 1998 and 1999 with the H1 experiment at HERA. Compared to previous H1 results from e^-p collisions [1] the analysis benefits from an increase in luminosity by a factor of 30 and in the center-of-mass energy from 300 GeV to 318 GeV. Furthermore, it also improves significantly on results derived from larger luminosity of e^+p data at a center-of-mass energy of 300 GeV [2], due to a much larger cross-section for ν^* production in e^-p scattering as compared to the e^+p case. At a ν^* mass of 200 GeV the ratio of those cross-sections is of the order of 100. Production cross-sections and decays of excited neutrinos can be calculated using an effective lagrangian [3, 4]. The cross-section and the branching ratio depend on coupling constants f and f' for the gauge groups $SU(2)$ and $U(1)$ and a compositeness mass scale Λ. The electroweak decay channels $\nu^* \to \nu\gamma$, $\nu^* \to eW$ and $\nu^* \to \nu Z$ cover all possible decay channels of the excited neutrino. As shown in [4], the width of the ν^* is a function of f, f' and Λ. For the coupling constants our analysis is sensitive to, the decay width of the ν^* can be larger than the detector resolution. This experimental resolution is of the order of 10 GeV, while the natural width of the ν^* can reach a few hundred GeV at high masses. Within the framework of this analysis the narrow width approximation (NWA) is valid for masses below 200 GeV. In this approximation the production and decay of the ν^* are factorized, and we use the COMPOS [5] generator for our calculations. For larger masses, the full cross-section of ν^* production and the 3-body decay is evaluated with COMPHEP [6] using the lagrangian [4]. In the overlap region the compability of COMPOS and COMPHEP has been verified.

The data presented in this analysis have been collected with the H1 apparatus [7]. Here only the detector components most relevant for this analysis are described briefly. The interaction region is surrounded by a system of drift and proportional chambers covering the angular range $7^o < \theta < 176^o$[1]. The tracking system is placed inside a finely segmented liquid argon (LAr) calorimeter covering the polar angular range $4^o < \theta < 154^o$ [8]. Energy resolutions of $\sigma_E/E \simeq 12\%/\sqrt{E} \oplus 1\%$ for electrons and $\sigma_E/E \simeq 50\%/\sqrt{E} \oplus 2\%$ for hadrons have been obtained in test beam measurements [9, 10]. The tracking system and calorimeters are surrounded by a superconducting solenoid and an iron yoke instrumented with streamer tubes. Leakage of hadronic showers outside the calorimeter is measured by analogue charge sampling of the streamer tubes with a resolution [11] of $\sigma_E/E \simeq 100\%/\sqrt{E}$.

The selection of ν^* events is based on photon or electron identification, missing transverse energy ($E_t^{\rm miss}$), and the identification of jets, depending on the search channel. Electromagnetic clusters are identified with more than 95% of the energy in the electromagnetic part of the calorimeter and certain isolation criteria [12]. They are further differentiated into electron and photon candidates, depending on whether a charged track is pointing to the cluster center within a radius of 12 cm or not. In the forward region of the calorimeter this condition is relaxed to 24

[1]The forward direction ($z > 0$) is the proton beam direction and a direct frame (z, θ, φ) is used later in this paper.

cm. Jets are reconstructed from the hadronic final state using a cone algorithm, adapted from the LUCELL scheme in the JETSET package [13].

Background not related to e^-p collisions is rejected by requiring that the event time coincides with the time of the bunch crossing, by using topological filters, and by requiring a primary interaction vertex reconstructed within ± 35 cm around the nominal vertex value. The Standard Model (SM) backgrounds which could mimic the ν^* signatures are Neutral Current Deep Inelastic Scattering (NC DIS), Charged Current Deep Inelastic Scattering (CC DIS) and photoproduction processes (γp). The background expectation from NC DIS and CC DIS is calculated by the event generator Django [14]. It includes first order QED corrections based on HERACLES [15], and QCD radiation based on the Colour Dipole Model [16]. Parton densities are taken from the MRST [17] parametrization which includes constraints from DIS measurements at HERA up to squared momentum transfer $Q^2 = 5000\mathrm{GeV}^2$ [18, 19, 20, 21]. The hadronisation process is simulated in the Lund string fragmentation scheme using JETSET. Direct and resolved γp processes, including prompt photon production, are simulated with PYTHIA [22]. All Monte Carlo samples are interfaced to a full simulation of the H1 detector response.

The $\nu^* \to \nu\gamma$ channel is characterised by missing transverse energy and an electromagnetic cluster in the LAr. The main SM background is expected to come from CC DIS events. Events are selected with an identified photon with a transverse momentum (P_t) greater than 16 GeV and a total missing transverse energy E_t^{miss}greater than 16 GeV. To reject NC DIS background where the scattered electron (sometimes mistaken as a photon) is preferably scattered by small angles, photons are accepted in the forward region of the detector only ($\theta < 1.8$ rad). For $E_t^{\mathrm{miss}}>$ 30 GeV photons in the very forward region ($\theta < 1$ rad) are also accepted if they are linked to a track and thus have been identified as an electron. In that particular region the conversion rate $\gamma \to ee$ and the number of randomly assigned tracks is expected to be high due to the high multiplicity of hadronic charged particles from jets. In order to be able to reconstruct the event vertex position from charged particles, the event is required to contain a jet (P_t^{jet} >5 GeV). To further suppress background from events with hadronic energy fluctuations of jets resulting in a measured missing transverse momentum, the projection of the missing transverse energy on the plane perpendicular to the recoil jet is required to be greater than 8 GeV. To reduce the influence of photons coming from QED radiation on the quark line, the jet must be isolated from the photon in the φ plane ($\Delta\varphi$(jet,γ) $>$ .35 rad). In total, 2 events are found in this channel, for an expected background of $3.0 \pm 0.2 \pm 1.2$ events (statistical error is given first followed by the systematical one). The background is composed of 2.7 events from CC DIS and 0.3 events from NC DIS with negligible contributions from γp. The resulting selection efficiencies are shown in fig. 1.

The $\nu^* \to eW_{\hookrightarrow q\bar{q}}$ channel is characterised by an electromagnetic cluster with an associated track and two jets. The main SM background are NC DIS events. Photoproduction events do not contribute significantly for electrons with high transverse momentum. A cut $P_t^{ele} >$ 12.5 GeV is chosen. At very high transverse momentum $P_t^{ele} >$ 85 GeV the background from NC DIS is low and no further cuts are made. For a transverse momentum 65 GeV $< P_t^{ele} <$ 85 GeV two jets with an invariant mass M_{dijet} >50 GeV are required, consistent with the expectation of a W decay. For a transverse momentum 12.5 GeV $< P_t^{ele} <$ 65 GeV three jets are required and cuts on the electron polar angle and jet variables are made. The electron polar angle cut is P_t^{ele} dependent and ranges from 1.20 to 2.25 rad. To reconstruct a W candidate, the dijet-pair with invariant mass closest to the nominal W boson mass is accepted with an invariant mass is in the range 65 GeV $< M_{\text{dijet}} <$ 87 GeV. The third jet is assumed to be the recoil jet. The two jets chosen as W candidate are ordered by their transverse momentum such that $P_t^{jet1} > P_t^{jet2}$. As many background events have a second jet in the forward direction an additional requirement on its polar angle, $\theta^{jet2} > 0.2$ rad, is made if the transverse momentum of the second jet is lower than 30 GeV. After those cuts, 6 events survive in the data. The expected background is $7.0 \pm 0.6 \pm 1.4$ events mainly from NC DIS with negligible contribution from CC DIS and γp. The resulting efficiencies are depicted in fig. 1.

The $\nu^* \to \nu Z_{\hookrightarrow q\bar{q}}$ channel is characterised by two jets and missing transverse energy E_t^{miss}. The main background are CC DIS events and moderate contributions from γp, whereas the NC DIS contribution is significantly suppressed for large E_t^{miss}. A cut $E_t^{\text{miss}} > 10$ GeV is chosen. At $E_t^{\text{miss}} > 40$ GeV only two jets are required, while at lower E_t^{miss}a third jet is required and events with an electron or photon candidate are rejected. Similar to the eW case a Z candidate is reconstructed from the dijet-pair with invariant mass closest to the nominal Z boson mass. It is accepted if M_{dijet} >76 GeV. Again those two jets are ordered. To suppress further the background from CC DIS a cut on the polar angle $\theta^{jet2} > 0.15$ rad is applied. In the region of relatively low missing transverse momentum 10 GeV $< E_t^{\text{miss}} < 20$ GeV an additional requirement is made on the transverse momentum of jet 1 (P_t^{jet1} >50 GeV). With these criteria, 1 candidate event is found in the data, for an expected background of $3.7 \pm 0.2 \pm 0.9$ events. The background consists mainly of CC DIS (2.3 events), and γp (1.3 events). The resulting signal efficiencies are given in fig. 1.

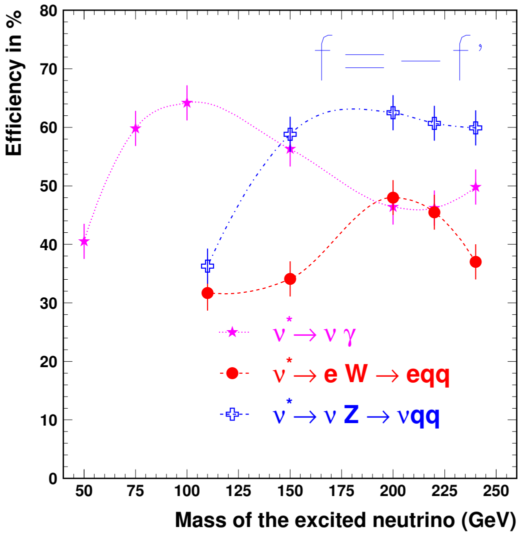


Figure 1: Acceptance of the selection cuts for the 3 channels, with the hypothesis $f = -f'$.

The main source of systematic uncertainties are the limited knowledge of the absolute energy scale and missing higher order corrections in the event generators which are used for the background estimation. The uncertainties of the electromagnetic energy scale amount to 0.7% in the central part of the detector and up to 3% in the forward region. For the hadronic part an uncertainty of 4% is assigned. Due to the lack of QED radiation from the quark line in the DJANGO generator, the background expectation is varied by 40% in the $\nu^* \to \nu\gamma$ channel. For the $\nu^* \to eW_{\hookrightarrow q\bar{q}}$ and $\nu^* \to \nu Z_{\hookrightarrow q\bar{q}}$ channels the 3-jet cross-section is varied by 15%, to account for differences observed between perturbative calculations of the order $O(\alpha_s^2)$ [23, 24, 25] and the parton shower approach. The statistical error of the Monte Carlo generations is taken into account as systematic error on the efficiencies. Finally, the limited precision of the luminosity measurement gives an additional normalisation uncertainty of 2.25%.

In all three search channels the number of observed and expected events are in good agreement. Upper limits on the coupling $\frac{f}{\Lambda}$ have been derived as described in [2] following the Bayesian approach [26, 27], at 95% confidence level. Systematic uncertainties are taken into account [2]. The resulting limits after combination of all decay channels, are given as a function of the ν^* mass in fig. 2, for the hypothesis $f = -f'$ and $f = +f'$. Note that the decay $\nu^* \to \nu\gamma$ is forbidden for $f = +f'$. These results improve significantly our limits published earlier in e^-p [1] and e^+p [2] collisions. The LEP experiments also have reported on excited neutrino searches [28, 29, 30]. To illustrate their sensitivity, the L3 results [28] are depicted in fig. 2. Using the assumption $\frac{f}{\Lambda} = \frac{1}{M_{\nu^*}}$ excited neutrinos with masses between 50 GeV and 150 GeV (110 GeV and 123 GeV) are excluded by this analysis for the assumption $f = -f'$ ($f = +f'$).

Less model-dependent limits can be derived if arbitrary ratios f'/f are considered. Fig. 3 illustrates how the limits depend on that ratio for various ν^* mass hypothesis. By choosing the point with the worst limit for each mass hypothesis, limit has been derived which do not depend on the ratio f'/f anymore. The result is shown in fig. 4 for masses below 225 GeV and -5< f'/f <5. It deviates from the limit obtained assuming $f = +f'$ only for high ν^* masses. Limits on the single ν^* production independent of f'/f also have been shown previously by the OPAL collaboration [30].

In summary, using e^-p data taken from 1998 to 1999 a search for excited neutrinos production has been performed and no indication of any signal was found. Therefore new limits on f/Λ, independent of the ratio f'/f, have been inferred which extend beyond the mass reach of LEP experiments.

We are grateful to the HERA machine group whose outstanding efforts have made and continue to make this experiment possible. We thank the engineers and technicians for their work in constructing and now maintaining the H1 detector, our funding agencies for financial support, the DESY technical staff for continual assistance, and the DESY directorate for the hospitality which they extend to the non DESY members of the collaboration.

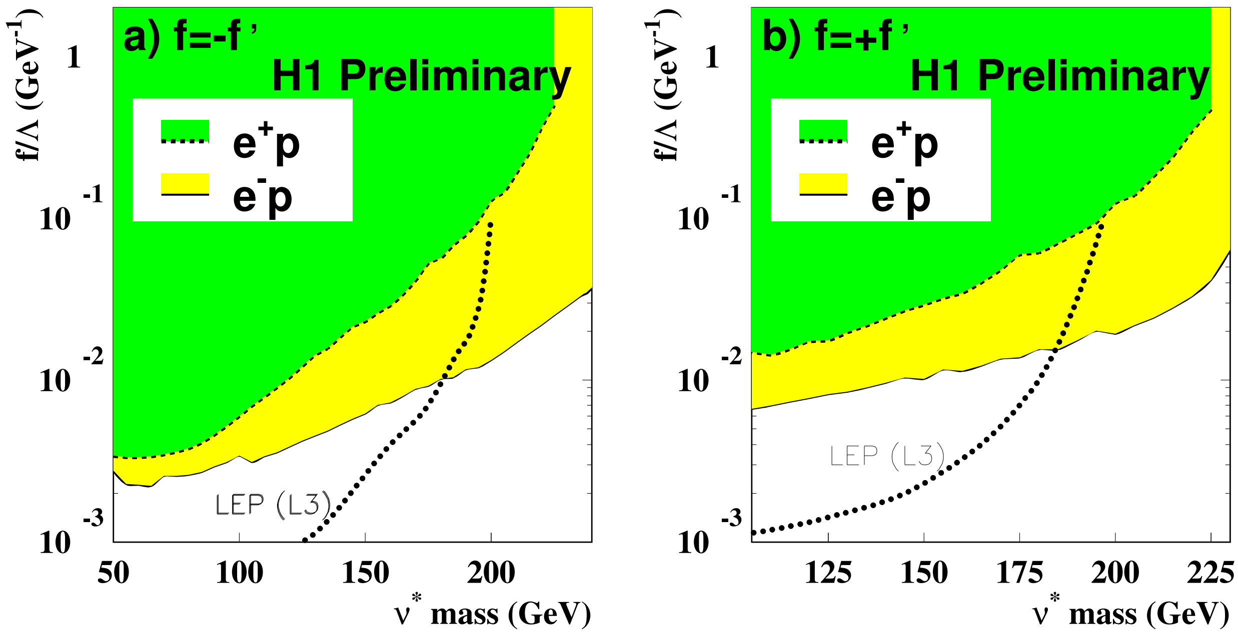


Figure 2: Exclusion limits on coupling constants at 95% confidence level as a function of the mass for excited neutrino production with the assumptions (a) $f = -f'$ and (b) $f = +f'$. Exclusion limits are given for H1 e^-p (full line) with an integrated luminosity of 15 pb^{-1}, H1 e^+p data [2] (dashed line) with an integrated luminosity of 37 pb^{-1} and L3 [28] (dotted line).

Figure 3: Exclusion limits on coupling constants at 95% confidence level as a function of the value of f'/f for excited neutrino production. Each curve corresponds to a different ν^* mass, the circles indicate the maximum (worst limit) of each curve. The areas above the lines are excluded.

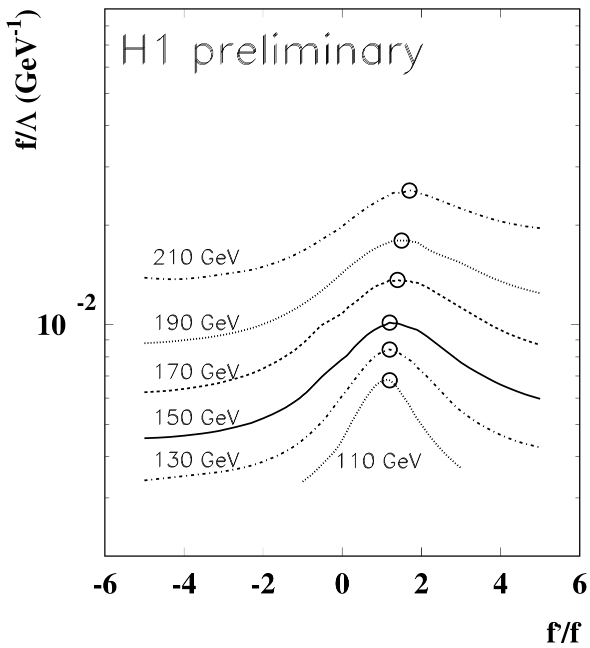
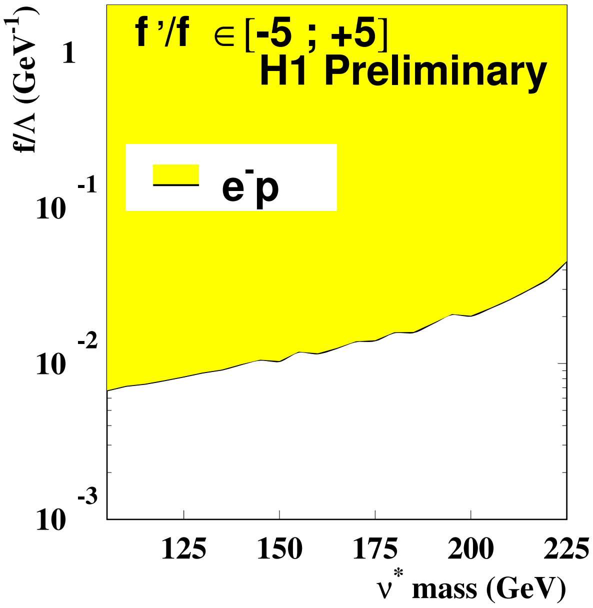


Figure 4: Exclusion limits on coupling constants at 95% confidence level as a function of the mass for excited neutrino production. All f'/f values have been considered in the interval $[-5; +5]$ (see figure 3), so this limit is independent of the relation between f and f' in that interval. The areas above the lines are excluded.



References

[1] T. Ahmed *et al.* [H1 Collaboration], Phys. Lett. B **340** (1994) 205.

[2] C. Adloff *et al.* [H1 Collaboration], Eur. Phys. J. C **17** (2000) 567.

[3] K. Hagiwara, D. Zeppenfeld and S. Komamiya, Z. Phys. C **29** (1985) 115.

[4] U. Baur, M. Spira and P. M. Zerwas, Phys. Rev. D **42** (1990) 815.

[5] T. Kohler, *In *Hamburg 1991, Proceedings, Physics at HERA, vol. 3* 1526-1541* .

[6] A. Pukhov *et al.*, hep-ph/9908288.

[7] I. Abt *et al.* [H1 Collaboration], Nucl. Instrum. Meth. A **386** (1997) 310.

[8] B. Andrieu *et al.* [H1 Calorimeter Group Collaboration], Nucl. Instrum. Meth. A **336** (1993) 460.

[9] B. Andrieu *et al.* [H1 Calorimeter Group Collaboration], Nucl. Instrum. Meth. A **344** (1994) 492.

[10] B. Andrieu *et al.* [H1 Calorimeter Group Collaboration], Nucl. Instrum. Meth. A **350** (1994) 57.

[11] W. Braunschweig *et al.* [H1 Collaboration], Nucl. Instrum. Meth. A **270** (1988) 334.

[12] A. Schöning, "Untersuchung von Prozessen mit virtuellen und reellen $W^{\pm}$-Bosonen am H1-Detektor bei HERA", Thesis University of Hamburg, 1996.

[13] T. Sjostrand, hep-ph/9508391.

[14] G. A. Schuler and H. Spiesberger, *In *Hamburg 1991, Proceedings, Physics at HERA, vol. 3* 1419-1432* .

[15] A. Kwiatkowski, H. Spiesberger and H. J. Mohring, Comput. Phys. Commun. **69** (1992) 155.

[16] B. Andersson, G. Gustafson, L. Lonnblad and U. Pettersson, Z. Phys. C **43** (1989) 625.

[17] A. D. Martin, R. G. Roberts, W. J. Stirling and R. S. Thorne, Eur. Phys. J. C **4** (1998) 463.

[18] S. Aid *et al.* [H1 Collaboration], Nucl. Phys. B **470**, 3 (1996).

[19] C. Adloff *et al.* [H1 Collaboration], Nucl. Phys. B **497**, 3 (1997).

[20] M. Derrick *et al.* [ZEUS Collaboration], Z. Phys. C **69**, 607 (1996).

[21] M. Derrick *et al.* [ZEUS Collaboration], Z. Phys. C **72**, 399 (1996).

[22] T. Sjostrand, Comput. Phys. Commun. **82** (1994) 74.

[23] T. Carli, hep-ph/9906541.

[24] P. Bate, "High Transverse Momentum 2-jet and 3-jet Cross-section Measurements in Photoproduction", Thesis University of Manchester, 1999.

[25] H1 Collaboration, abstract 157, Tampere, HEP99 conference.

[26] R. M. Barnett *et al.* [Particle Data Group Collaboration], Phys. Rev. D **54** (1996) 1.

[27] O. Helene, Nucl. Instrum. Meth. A **228** (1984) 120.

[28] M. Acciarri *et al.* [L3 Collaboration], Phys. Lett. B **502** (2001) 37.

[29] P. Abreu *et al.* [DELPHI Collaboration], Eur. Phys. J. C **8** (1999) 41.

[30] G. Abbiendi *et al.* [OPAL Collaboration], Eur. Phys. J. C **14** (2000) 73.