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A Search for Excited Neutrinos in $e^{-}p$ Collisions at HERA

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Abstract

We present a search for excited neutrinos using $e^{-}p$ data taken by the H1 experiment with an integrated luminosity of 15 pb^{-1}. No evidence for excited neutrino production is found and mass dependent exclusion limits on cross-sections and on the ratio of coupling constants to the compositeness scale are derived.

Abstract: 956
Parallel session: 11
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Convincing evidence for a substructure of fermions would be established by the discovery of excited quarks and leptons which are predicted by composite models. 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 an excited neutrino (ν^*) through t-channel W boson exchange. In this paper we present a search for ν^* production followed by the electroweak radiative decays $\nu^* \to \nu\gamma$ and $\nu^* \to eW$. 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. At a ν^* mass of 200 GeV the expected ν^* cross-section for e^-p collisions is more than two orders of magnitudes larger than for e^+p collisions previously analysed [1].

A full description of the H1 detector can be found in reference [2]. Here the components used for this analysis are briefly described. The forward direction ($z > 0$) is the proton beam direction and a direct referential (z, θ, φ) is used later in this paper. The interaction region is surrounded by a system of drift and proportional chambers covering the angular range $7^o < \theta < 176^o$. The tracking system is placed inside a finely segmented liquid argon (LAr) calorimeter covering the polar angular range $4^o < \theta < 154^o$. The electromagnetic part is made of lead/argon and the hadronic part of stainless steel/argon [3]. 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 [4, 5].

Production cross-section and decay of excited neutrinos can be calculated using an effective Lagrangian [6]. The cross-section and the branching ratio depend then 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 $\nu^* \to \nu\gamma$ and $\nu^* \to eW_{\hookrightarrow q\bar{q}}$ comprise more than 80% of the branching ratio of the excited neutrino under the hypothesis $f = -f'$. The channel $\nu^* \to eW_{\hookrightarrow q\bar{q}}$ dominates the decay mode for the hypothesis $f = +f'$ with more than 60% branching ratio.

The selection of excited neutrino event candidates is based on the requirement of either missing transverse energy ($\boldsymbol{E_t}$) and at least one high transverse energy (E_t) electromagnetic cluster or two high E_t hadronic jets and an electron. An electromagnetic cluster is defined as an energy deposit in the LAr with more than 95% of its energy in the electromagnetic part of the calorimeter. If this electromagnetic cluster is linked to a track, then it is taken as an electron, else if there are no tracks in a radius of 12 cm around the cluster, this electromagnetic cluster is considered to be a photon. In the forward part of the LAr which is farther from the interaction point, the track-cluster link condition is relaxed to 24 cm. A cone algorithm adapted from the LUCELL scheme being part of the JETSET package [7] is used to search for hadronic jets (later called jets in this paper).

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 vertex within ± 35 cm of 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). A simulation of ν^* production using COMPOS [8] is performed to adjust discriminating cuts and to calculate acceptances. All Monte Carlo generators are interfaced to a full simulation of the H1 detector response.

The systematic errors on the mean background expectation come from the limited energy resolution on one hand and from theoretical modelling on the other hand. The uncertainties in the energy scale in the electromagnetic part of the LAr ranges between 0.7% in the central part of the calorimeter up to 3% in the forward region. The uncertainties in the energy scale in the hadronic parts of the calorimeter was taken to be 4%. The uncertainty on the integrated luminosity is 2.25%. For the $\nu^* \rightarrow \nu\gamma$ channel an uncertainty of 40% on the background was added to take into account the lack of modelling of the QED radiation on the quark line in DJANGO [9]. For the estimate of the $\nu^* \rightarrow eW_{\hookrightarrow q\bar{q}}$ background an uncertainty of 15 % was added. That was determined by a comparison to data of either a Monte Carlo with $O(\alpha_s)$ QCD matrix elements which approximates the higher order emission of partons using the concept of parton showers, or perturbative QCD calculations to order $O(\alpha_s^2)$ which produces an exact leading order calculation of the three parton final state [10].

The final state of an excited neutrino that decays in a neutrino and a photon 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. Photons with a transverse momentum (P_t) of more than 16 GeV are searched in events with a missing momentum of more than 16 GeV. To reject NC DIS background where the scattered electron (sometimes mistaken as a photon) is preferably scattered backward, photons are required to be in the forward part of the calorimeter ($\theta < 1.8$ rad). For missing transverse energies greater than 30 GeV photons in the very forward region ($\theta < 1$ rad) are also accepted if they are linked to a track and are identified as an electron. In that particular region the conversion rate $\gamma \rightarrow ee$ and the number of fake linked photons due to the high multiplicity of hadronic charged particles from jets are expected to be high. In order to reconstruct the primary vertex position from charged particles, the recoil jet of the struck quark is also required. In order to 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 must 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 (by requiring $\Delta\varphi(\text{jet},\gamma) > 0.35$ rad). These selection criteria are summarised in table 1. In this channel 2 events have been found for an expected SM background (mainly CC DIS) of 2.56 $\pm 0.17 \pm 1.20$ events (statistical error is given first followed by the systematical one). The SM expectation corresponds to 2.24 CC DIS, 0.31 NC DIS and 0.01 γp events. Efficiencies are given in figure 1 as function of the excited neutrino mass.

	Photon-like candidates	Electron-like candidates
E_t	> 16 GeV	> 30 GeV
θ	< 1.8 rad	< 1 rad
P_t	> 16 GeV	> 16 GeV
	+ recoil jet	+ recoil jet
$\Delta\varphi(\text{jet},\gamma)$	> 0.35 rad	> 0.35 rad

Table 1: Selection cuts for the $\nu^* \rightarrow \nu\gamma$ channel.

The final state of an excited neutrino decaying into an electron and a W boson that itself

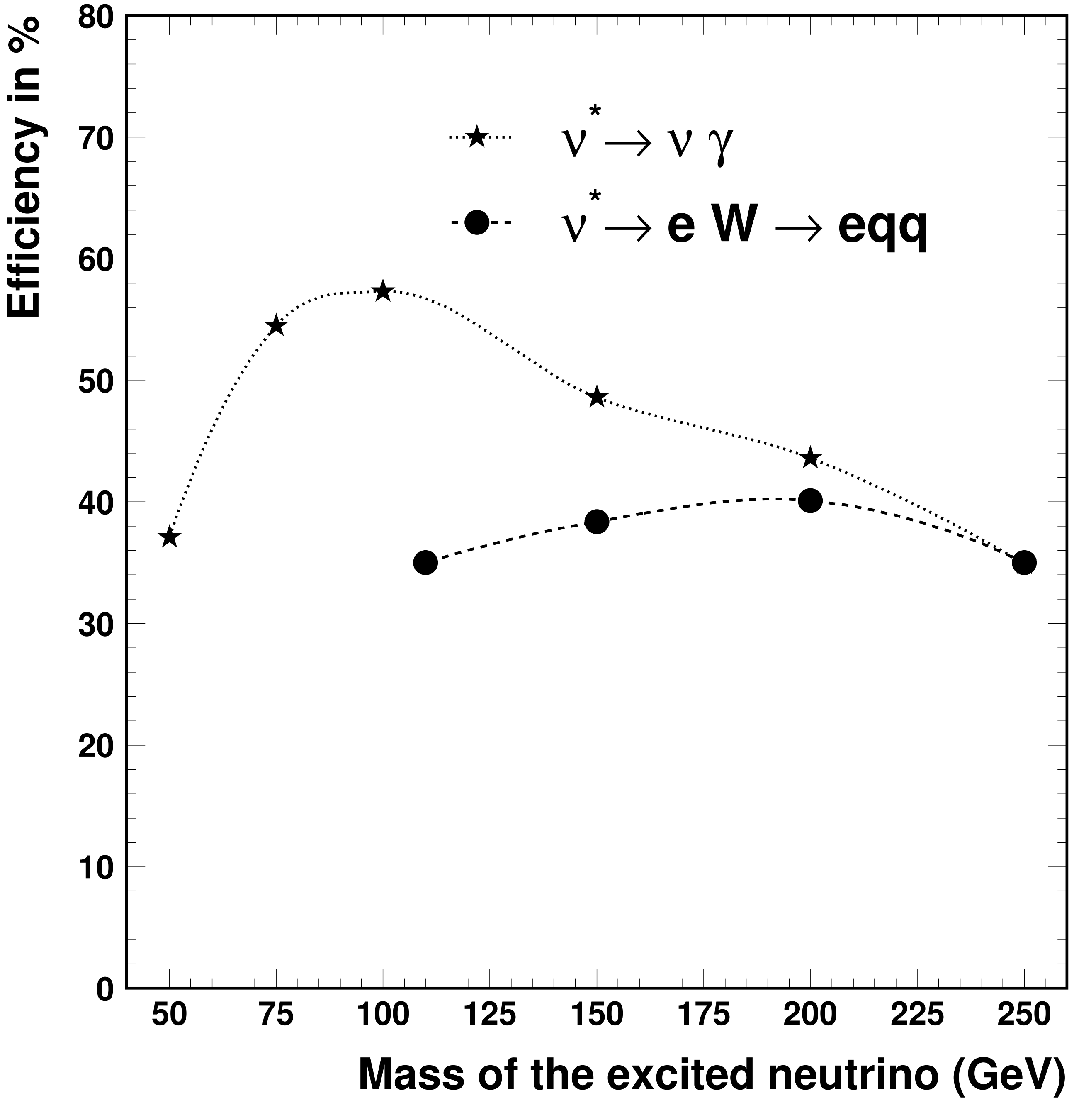

Figure 1: Acceptance of the selection cuts for both channels.

decays into 2 quarks is characterised by an electron and 2 jets. The main SM background originates from NC DIS events. Photoproduction becomes negligible as soon as an electron of high transverse momentum is required (P_t^{ele} >15 GeV). The electron must be found in the forward part of the detector. The exact limit on the polar angle of the electron (θ^{ele}) varies with the transverse momentum of the electron (see table 2). More NC DIS events can be rejected by requiring at least one jet of the event to have a transverse energy E_t(jet1) greater than 32 GeV. For W identification all dijet combinations of the event are considered and the invariant masses are calculated. A W candidate is defined by the two jets with the invariant mass closest and within 15 GeV to the nominal W boson mass. NC DIS events are rejected by requiring a third jet which is associated with the recoil of the excited neutrino. When P_t^{ele} is greater than 65 GeV, there is almost no SM background left and all other requirements are removed. These cuts are summarised in table 2. In this data sample, 4 events pass these selection cuts for an expected SM background of 7.74 $\pm 1.38 \pm 1.63$ events (almost all expected to be NC DIS). Efficiencies are given in figure 1.

P_t^{ele} (GeV)	$15-65$	>65
E_t(jet1) (GeV)	>32	
θ^{ele} (rad)	$<(2-(P_t^{ele}-15)*0.015)$	All cuts
dijet inv. Mass (GeV)	$M_W \pm 15$	removed
	+ recoil jet	

Table 2: Selection cuts for the $\nu^* \to eW_{\hookrightarrow q\bar{q}}$ channel.

In this analysis the number of observed events in the 2 channels and the predictions of the SM are in good agreement. Therefore upper limits on the product of the ν^* production cross-section and the decay channel branching ratio have been derived in a Bayesian way following [11] at 95% confidence level. Background and its uncertainties are included in these calculations and follows the procedure of [1]. The inferred limits are shown in figure 2 as function of the ν^* mass. These results improve significantly earlier published H1 e^-p results [12] which are based on an integrated luminosity of 0.528 pb^{-1}. Figure 3 shows the limits on $\frac{f}{\Lambda}$ obtained with the hypothesis $f=-f'$ (left) and $f=+f'$ (right). For $f=-f'$ both channels are combined using the method described in [1] and taken into account in the limit calculation. For the hypothesis $f=+f'$ the $\nu^* \to \nu\gamma$ decay is forbidden, thus only the $\nu^* \to eW_{\hookrightarrow q\bar{q}}$ limit is shown. At 220 GeV with the coupling found here, the intrinsic decay width of the excited neutrino is of the order of 20 GeV and thus the Narrow Width Approximation (NWA) assumed by the generator becomes less accurate. To take this into account, a band reflecting the uncertainty due to the use of the NWA has been added to the limit. In figure 4, these new limits are compared with the limits obtained by H1 from e^+p data. The LEP experiments [13, 14, 15] have also reported on excited neutrino searches and the L3 results are shown on figure 4. Even with the lower luminosity the new H1 results improve the previous ones obtained from e^+p data, as expected. Using the assumption $\frac{f}{\Lambda}=\frac{1}{M_{\nu^*}}$, excited neutrino of masses between 50 and 150 GeV for $f=-f'$ and between 110 and 134 GeV for $f=+f'$ are excluded.

In summary, using e^-p data taken from 1998 to 1999 a search for excited neutrinos production has been performed and no indication of a signal was found. Therefore new limits on f/Λ

for the production of excited neutrinos in high energy ep interactions have been inferred which extend beyond the mass reach of LEP experiments. Results obtained by the LEP experiments for the excited neutrino are more stringent but limited to excited neutrino masses below 195 GeV. Assuming $\frac{f}{\Lambda} = \frac{1}{M_{\nu*}}$ and $f = -f'$ ($f = +f'$) excited neutrinos are excluded in the mass range 50-150 GeV (resp. 110-134 GeV) at 95% confidence Level.

References

[1] H1 Collaboration, contributed paper **955** , ICHEP 2000, Osaka, 27th of July - 2nd of August 2000.

[2] H1 Collaboration, I. Abt et al *Nucl. Instr. and Meth.* **A 386** (310 and 348) 1997.

[3] H1 Calorimeter Group, B. Andrieu et al., *Nucl. Instr. and Meth.* **A 336** (1993) 460.

[4] H1 Calorimeter Group, B. Andrieu et al., *Nucl. Instr. and Meth.* **A 344** (1994) 492.

[5] H1 Calorimeter Group, B. Andrieu et al., *Nucl. Instr. and Meth.* **A 350** (1994) 57 and *Nucl. Instr. and Meth.* **A 336** (1993) 499.

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

[7] 7.3 and 7.4: T. Sjöstrand, Lund. Univ. preprint LU-TP-95-20 (August 1995) 321pp; *ibid*, CERN preprint TH-7112-93 (February 1994) 305pp.

[8] T. Köhler, Proc. of the Workshop Physics at HERA, Eds. W. Buchmüller, G.Ingelman, DESY Hamburg 1991, Vol 3, p 1526.

[9] DJANGO 6.2 G.A. Schuler and H. Spiesberger, Proc. of the Workshop

[10] T. Carli, Renormalisation scale dependencies in di-jet production at HERA, Proceedings of the Workshop “Monte-Carlo Generators for HERA Physics”, DESY-PROC-99-02, A.T. Doyle, G. Grindhammer, G. Ingelman and H. Jung (Editors);
P. Bate, ”High Transverse Momentum 2-jet and 3-jet Cross-section Measurements in Photoproduction”, Thesis submitted to The University of Manchester, december 1999;
H1 Collaboration, First Measurement of Three jet Cross Sections in DIS at HERA, abstract 157, Tampere, HEP99.

[11] R. M. Barnett et al., *Phys. Rev.* **D 54** (1996) 1,
O. Helene, *Nucl. Instr. and Meth.* **A 212** (1983) 319.

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

[13] L3 collaboration, *Phys. Lett.* **B 473** (2000) 177.

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

[15] OPAL Collaboration, G. Abbiendi et al., *Eur. Phys. J.* **C 14** (2000) 73-84.

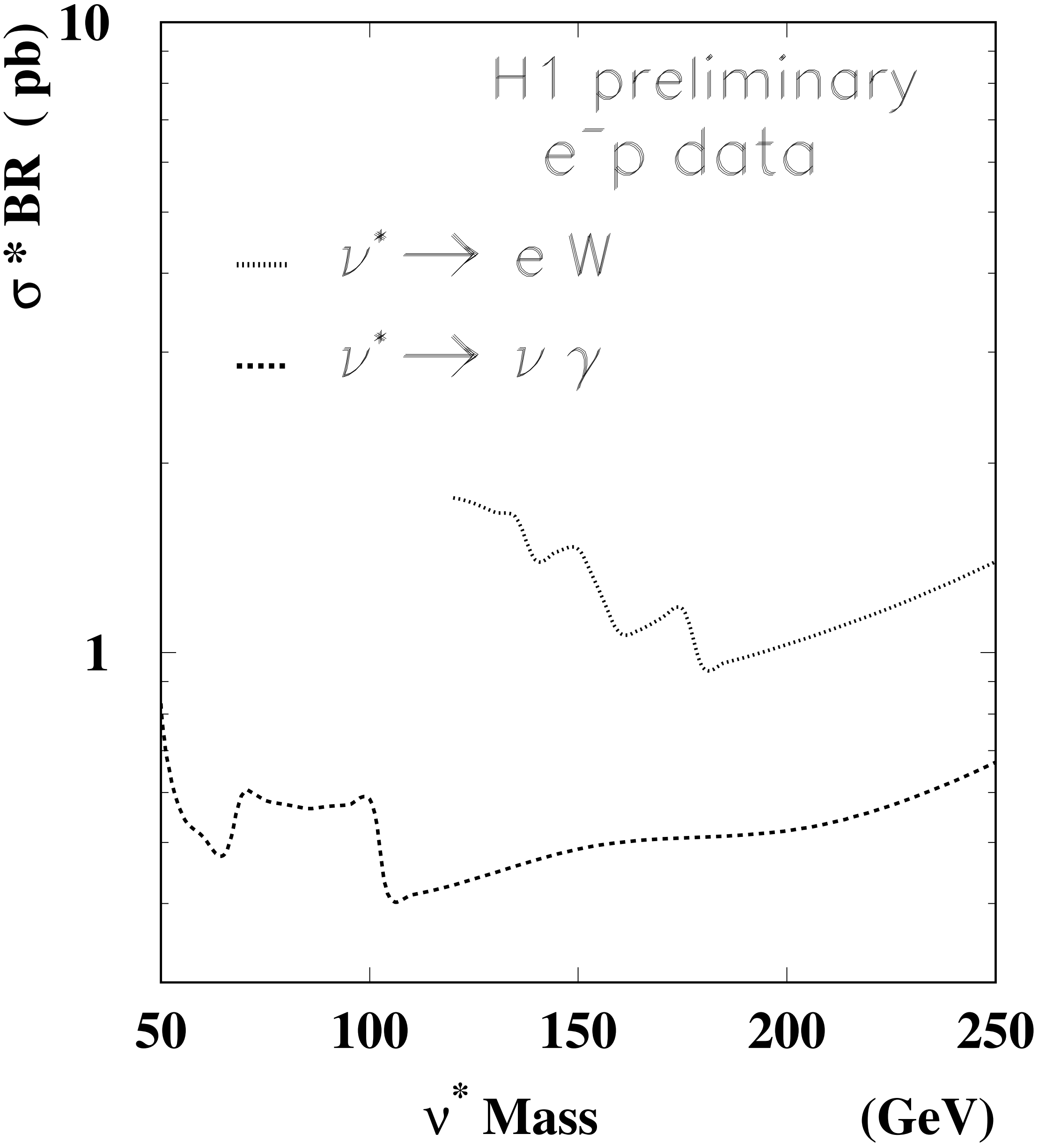

Figure 2: Upper limits at the 95% confidence level on the product of the excited neutrino cross-section and the decay branching fraction for the $\nu^* \rightarrow \nu\gamma$ (dashed line) and $\nu^* \rightarrow eW_{\hookrightarrow q\bar{q}}$ (dotted line). The areas above the lines are excluded.

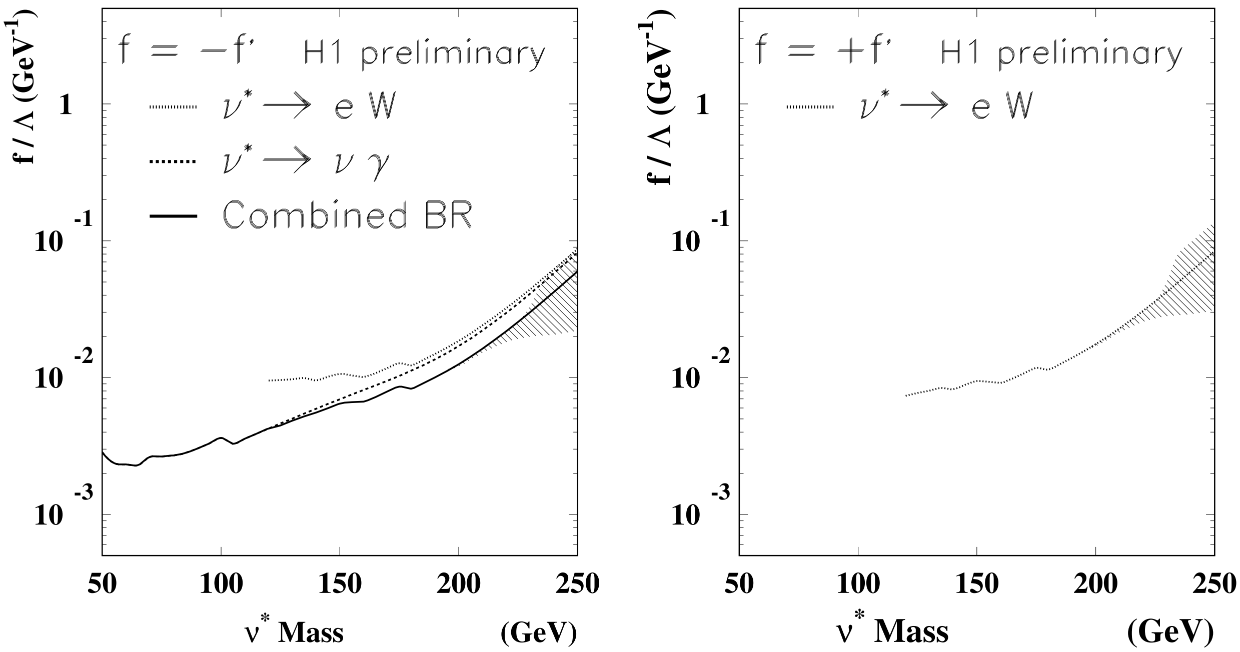

Figure 3: Exclusion limits on coupling constants at 95% confidence level as a function of the mass for excited excited neutrino production. The assumptions $f = -f'$ (left) and $f = +f'$ (right) are made respectively. Exclusion limits are given for each channel: $\nu^* \to \nu\gamma$ (dashed line) and $\nu^* \to eW_{\hookrightarrow q\bar{q}}$ (dotted line) and for both channels combined (full line). The areas above the lines are excluded. The hatched band reflects the uncertainty due to the use of the NWA.

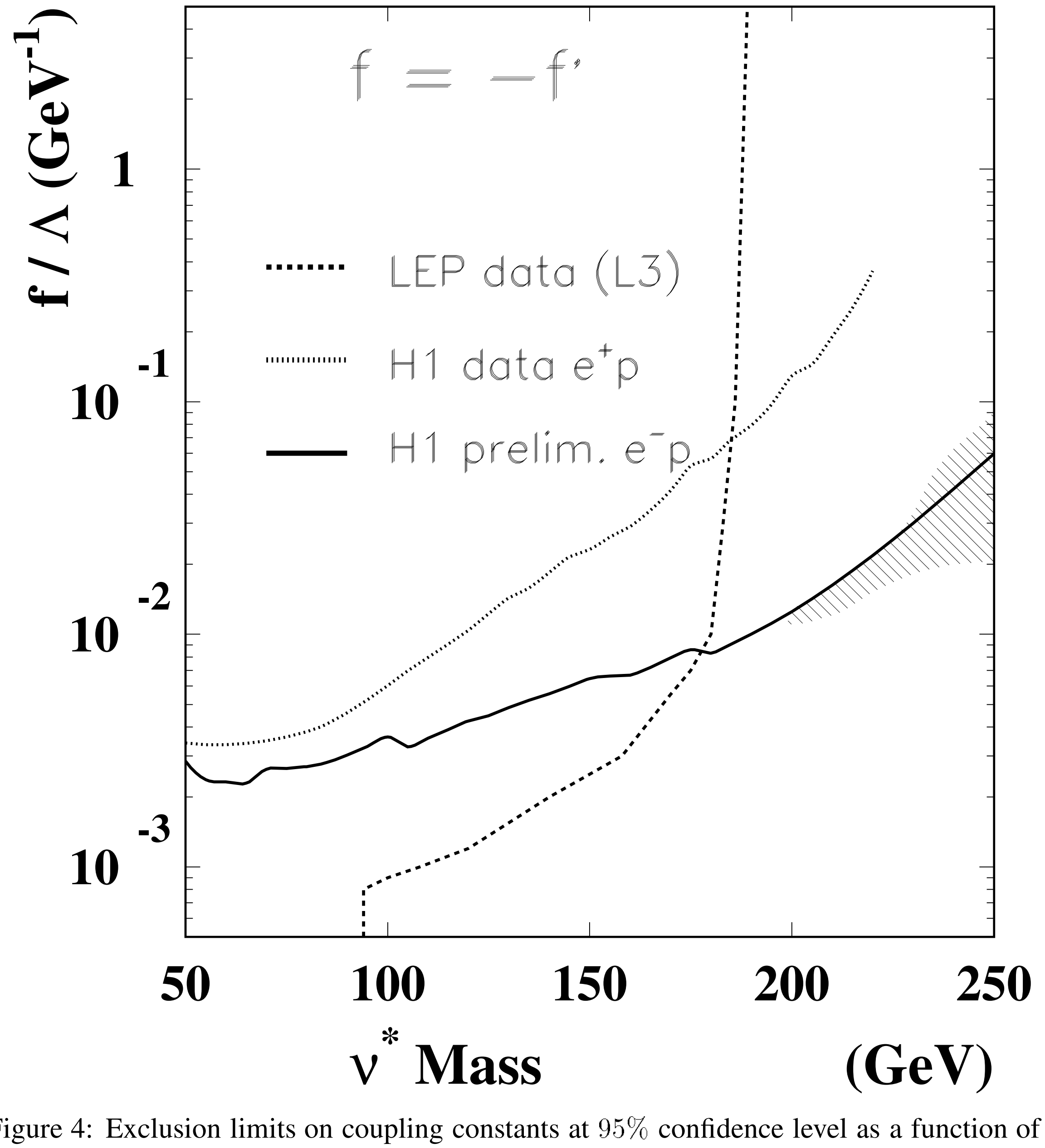

Figure 4: Exclusion limits on coupling constants at 95% confidence level as a function of the mass for excited excited neutrino production. The assumption $f = -f'$ is made. Exclusion limits are given for H1 $e^{-}p$ (full line) with an integrated luminosity of 15 pb^{-1}, H1 $e^{+}p$ data (dotted line) with an integrated luminosity of 37 pb^{-1} and L3 (dashed line). The areas above the lines are excluded. The hatched band reflects the uncertainty due to the use of the NWA.