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D0

Search for Fourth Generation Neutral Heavy Leptons

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The D0 Collaboration

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Search for Fourth Generation Neutral Heavy Leptons

The DØ Collaboration¹
(July 1995)

A search for fourth generation neutral heavy leptons (ν_4) in W decays was carried out with the DØ detector at the Fermilab Tevatron at $\sqrt{s} = 1.8$ TeV. The ν_4 is assumed to be produced via mixing with the first generation neutrino only. We looked for a three electron final state event topology. The data used in this analysis represent 12.2 pb^{-1} taken during the 1992 – 1993 run. No candidates were found. We set a preliminary limit beyond the LEP limit for the considered mixing case on the $|U_{e4}|^2 - m_{\nu_4}$ plane.

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I. MOTIVATION

Among all possible new particle searches, a fourth generation neutrino draws the most immediate attention. Taking the mass structure of the known fundamental fermions as the most natural approach, the neutrino would be the lightest member of a new fourth generation and thus the most accessible to discovery by present experiments.

II. PHYSICS

We search for a fourth generation sequential Dirac neutrino (ν_4) in W decays, which means that the fourth generation neutrino is the simplest extension of the three generation Standard Model (SM) neutrinos; *i.e.* it has the same weak interaction properties as the three generation neutrinos. Measurements at the SLAC Linear Collider (1) and the CERN LEP Collider (2) rule out the possibility of a ν_4 at 95 % confidence level for a mass smaller than $45 \text{ GeV}/c^2$.

If such a fourth generation neutrino exists, it could be massive and mixed to other generations in analogy with the quark sector. Assuming the mass of the ν_4 to be less than that of its charged partner, the channels open for the decay of the ν_4 are as shown in Fig. 1. Assuming the ν_4 mixes with only one other generation, its lifetime can be expressed as (1)

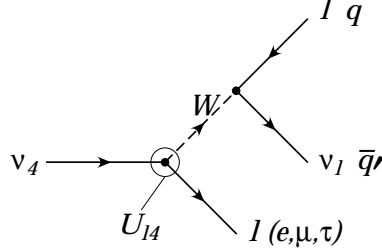


FIG. 1. Possible ν_4 decay channels.

$$\tau(\nu_4 \rightarrow l^- X^+) = \left[\frac{m_\mu}{m_{\nu_4}} \right]^5 \frac{\tau(\mu \rightarrow e\nu\bar{\nu}) Br(\nu_4 \rightarrow l^- e^+ \nu)}{|U_{14}|^2 f}, \quad (1)$$

where f is a phase space suppression factor for massive final state particles which is ≈ 1 for $m_{\nu_4} > 45$ GeV.

The production and decay of ν_4 in $p\bar{p}$ collisions via W may be represented (in lowest order) by the diagram in Fig. 2.

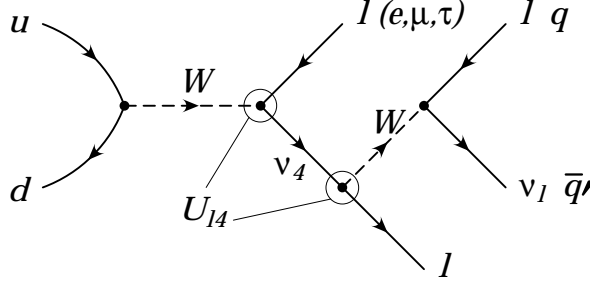


FIG. 2. Feynman diagram describing production and decay of a massive fourth generation neutrino in $p\bar{p}$ collisions via W .

The expected event topology is therefore (e.g. for $\nu_1 - \nu_4$ mixing)

$$\begin{aligned} \underline{e e e} + \cancel{E}_T &\sim 11+2 \% \\ \underline{e e \mu} + \cancel{E}_T &\sim 11+2 \% \\ W^+ \rightarrow e^+ \nu_4 \rightarrow e e \tau(\text{jet}) + \cancel{E}_T &\sim 7 \% \\ e e + 2 \text{ jets} &\sim 67 \% \end{aligned}$$

The underlined tri - lepton ($3l$) final states are a very distinctive signature consisting of three charged leptons and missing transverse energy (\cancel{E}_T) from the neutrino with little background. The additional two per cent in the eee and $ee\mu$ channel are from the leptonic decays of the tau; they are not considered in this analysis. The expected number of produced trilepton events is given by

$$\begin{aligned} N(p\bar{p} \rightarrow W \rightarrow \nu_4 l \rightarrow 3l) &= \sigma \cdot Br(W \rightarrow e\nu) \cdot \int \mathcal{L} dt \cdot f_m \cdot |U_{14}|^2 \\ &\times Br(\nu_4 \rightarrow 2l\nu) \cdot \epsilon(3l) \end{aligned} \quad (2)$$

where $\epsilon(3l)$ is the trilepton detection efficiency, σ is the W production cross section, and f_m is the mass threshold factor (3).

$$f_m = \left[1 - \frac{(m_{\nu_4})^2}{(m_W)^2} \right]^2 \cdot \left[1 + \frac{(m_{\nu_4})^2}{2(m_W)^2} \right] \quad (3)$$

III. ANALYSIS

In this analysis mixing of the ν_4 with the first lepton generation neutrino is assumed with the search restricted to the $eee + \cancel{E}_T$ channel. Events were selected from data taken with the DØ detector (4) at the Fermilab Tevatron at $\sqrt{s} = 1.8$ TeV. The data used in this analysis represent 12.2 pb^{-1} accumulated during the 1992 – 1993 run.

Two triggers (combined as logical .OR.) with the following specifications were utilized:

- a single electron trigger requiring an electromagnetic cluster with transverse energy $E_T > 20$ GeV, passing shape and isolation cuts;
- a dielectron trigger requiring 2 electromagnetic clusters, each with $E_T > 10$ GeV, passing isolation cuts.

From these data, three-electron events were selected offline requiring all three electrons to have $E_T > 5$ GeV, pseudorapidity $|\eta| < 2.5$, matching 1 or 2 drift chamber tracks and to pass isolation and shape cuts. Only 10 events survive this loose filter. Subsequently, tighter quality requirements for the electrons and kinematic cuts on electron E_T and event \cancel{E}_T were used to further separate signal from background.

The kinematic cuts on the electron E_T are partly dictated by the E_T thresholds of the utilized triggers. Two sets of offline kinematic requirements (again combined by logical .OR.) are used corresponding to the two triggers. All cuts and their effect on the data are summarized in Table 1. No events survive the analysis cuts.

REQUIREMENTS	EVENTS REMAINING
three isolated electromagnetic clusters which satisfy shower shape cuts, $E_T > 5$ GeV and pseudorapidity $ \eta < 2.5$ with matched drift chamber tracks	10
electron kinematics: $E_{T_{1/2/3}} > 13/13/5$ GeV or $E_{T_{1/2/3}} > 22/5/5$ GeV	5
$\cancel{E}_T > 10$ GeV	0

TABLE 1. Cuts imposed on data sample and their effects.

Backgrounds may be divided into two main classes: physics background produced by SM processes and backgrounds due to particle misidentification. For this analysis physics backgrounds (e.g. production of WZ pairs subsequently decaying to $eee + \cancel{E}_T$) are negligible. This leaves background due to misidentification of photons and jets as electrons.

Our preliminary study indicates that we expect about one background event in our data sample. A more rigorous estimation of the expected number of background events is under way.

A combination of Monte Carlo and data was used to determine the detection efficiencies for this analysis. Monte Carlo events were generated using a modified version of PYTHIA (5,6) and the DØ version of the GEANT (7) detector simulator. The events were subsequently processed by the offline trigger simulator and by the reconstruction software package.

ν_4 mass	Geo/Kin Acc.	Quality Cuts	Trigger Eff.	Track. Cor.	Overall Eff.
45.0	15.1±1.1%	69.7±5.2%	92.2±4.5%	74.5±2.9%	7.2±1.3%
50.0	17.6±1.2%	72.0±5.0%	86.4±4.6%	74.7±2.9%	8.2±1.4%
55.0	18.1±1.2%	72.2±5.0%	94.5±4.3%	75.0±3.0%	9.3±1.6%
60.0	19.6±1.3%	71.9±4.9%	87.6±4.5%	75.0±3.0%	9.3±1.6%
65.0	19.1±1.2%	70.2±5.0%	84.9±4.6%	74.6±2.9%	8.5±1.5%
70.0	15.9±1.2%	65.3±5.2%	86.7±4.8%	75.9±3.0%	6.8±1.2%
75.0	12.6±1.1%	65.1±5.5%	81.8±5.4%	75.6±3.0%	5.1±1.0%
80.0	19.0±1.2%	74.4±4.6%	93.8±4.3%	75.1±3.0%	10.0±1.6%

TABLE 2. Detection efficiencies for each ν_4 mass. A typical example for the contributions of the statistical and systematic errors to the total error on the overall efficiency is (for $m_{\nu_4} = 60$ GeV): 9.26 ± 0.92 (stat) ± 1.25 (syst) %.

The efficiencies for each ν_4 mass are given in Table 2. The number in each column is calculated with respect to the previous column going from left to right. The columns are the following:

- Mass ν_4 : Mass of the ν_4 ;
- Geo/Kin Acc: Geometric/Kinematic Acceptance for events in % with at least 3 elec-

Overall analysis efficiency

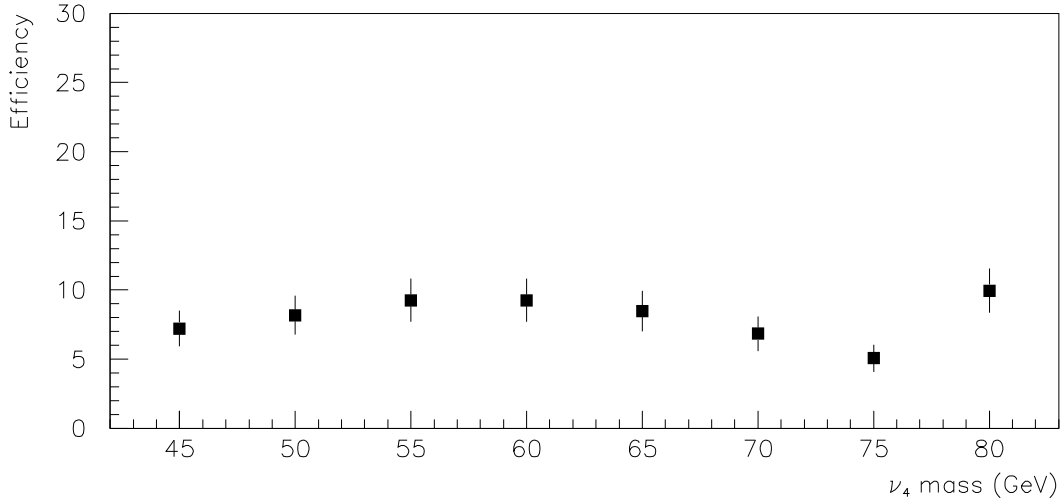


FIG. 3. Overall detection efficiency as a function of ν_4 mass.

trons required, within the $|\eta|$ range and passing kinematic cuts;

- Quality Selection: percentage of the events within Geometric/Kinematic Acceptance fulfilling the electron quality requirements;
- Trigger: percentage of events passing the quality cuts that fire one of the triggers used;
- Tracking Correction: Correction for known difference between Monte Carlo and real tracking efficiency for all three electrons combined;
- Overall Efficiency: Final number used for limit calculation (see Fig. 3). The apparent rise in the overall efficiency at 80 GeV/ c^2 ν_4 mass is coming from the fact that the W 's that decay to ν_4 with the mass close to the W mass are on the average heavier than the mass of the W 's that decay to lower mass ν_4 's because of the W width.

Errors to be considered in this analysis include statistical errors on the Monte Carlo samples plus systematic errors. Systematic errors arise from the following sources:

- Electron ID:
 - statistical uncertainty on the Monte Carlo sample used to determine the efficiency of the electron quality requirements: 0.8% to 2.4% for electron E_T from 5 GeV to 25 GeV.
 - statistical uncertainty in the determination of the tracking efficiency: 2.4% in forward detector region, and 2.2% in the central region.
 - statistical uncertainty on the efficiency requiring drift chamber track match with calorimeter shower cluster: 1%.
- Differences between software trigger and trigger simulator: 4%

- Uncertainty in integrated luminosity: 5.4 %

The overall systematic error was determined by calculating the efficiencies using the upper/lower variations in the systematic errors given above. These errors are included in Table 2.

IV. CONCLUSION

With the results from the previous sections, we are able to exclude a region (beyond the existing LEP excluded region) on the $|U_{e4}|^2 - m_{\nu_4}$ plane at 95% C.L. as shown in figure 4.

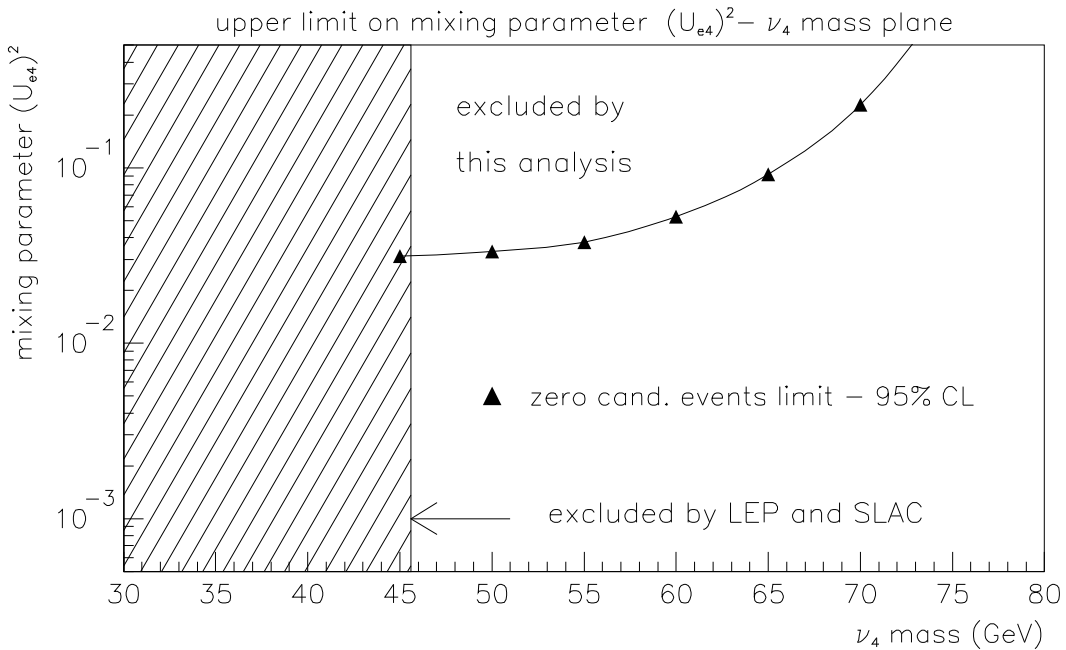


FIG. 4. DØ preliminary 95% C.L. excluded region on the $|U_{e4}|^2 - m_{\nu_4}$ plane for the considered mixing.

This limit represents the boundary including possible variations as determined by the error calculation; it was determined using eqn. 2 and the results are preliminary.

From the shape of the limit curve it is evident that the limit is dominated by the phase space suppression increasing with the ν_4 mass. This is to be compared to the relatively level distribution of the overall detection efficiencies (see Fig. 3). The efficiencies in general are dependent on the mixing for each value of m_{ν_4} . The increasing decay length (see eqn. 1) will eventually allow more and more ν_4 to leave the detector undecayed. However, this effect is not noticeable in this analysis since the decay length of the ν_4 is well below 0.1 mm for all values of $|U_{e4}|$ in reach. For a ν_4 mass > 70 GeV the luminosity for the analysed data is not sufficient to set a limit.

We showed that this analysis is sensitive to the considered mixing case using only data taken with the DØ detector in the 1992 - 1993 run. For the ongoing 1994 - 1995 run more than six times the integrated luminosity is expected to be delivered to DØ, thereby

increasing the sensitivity by a significant amount. We also plan to study other final state channels and other mixing cases.

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