POSSIBILITY OF SEARCHING FOR FOURTH GENERATION NEUTRINO AT FUTURE ep COLLIDERS

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Abstract

We investigate the production of fourth generation neutrino in the context of new $e\nu_4W$ magnetic dipole moment type interaction in $ep$ collisions at the future lepton-hadron colliders. We have obtained the mass limits of 700 GeV for THERA ($\sqrt{S}=1$ TeV) and 2.8 TeV for LC\(\otimes\) LHC ($\sqrt{S}=3.74$ TeV).

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I. INTRODUCTION

So far no clear experimental evidence of new physical phenomena beyond the Standard Model (SM) has been observed. The existence of the new massive neutrino at high energy colliders would be strong evidence of new physics. Therefore, searching for a new massive neutrino has high priority at collider experiments. These neutrinos play also the basic role in cosmology for solving the dark matter puzzle. Heavy neutrino searches at lepton-hadron colliders has some advantages, larger masses, for instance, are accessible compared to current $e^+e^-$ colliders [1].

The purpose of this paper is to investigate the possible single production of a heavy neutrino ($\nu_4$) in $ep$ collisions in the context of new $e\nu_4 W$ anomalous magnetic dipole moment type interaction and analyze the background using optimal cuts. The THERA ($\sqrt{S}=1$ TeV) and LC⊗LHC ($\sqrt{S}=3.74$ TeV) are two proposed ep machine options [2, 3] for which we present the numerical results of these study.

Bounds on the possible heavy neutrino masses are obtained either from experiments at accelerators or cosmological arguments. Among the several arguments, the experimental data of LEP and SLAC rule out the possibility of $\nu_4$ with mass smaller than 45 GeV [4] while the cosmological limit for the upper bound is 3 TeV [5]. We assumed arrange of 200 Gev - 3 TeV for the single heavy lepton masses.

II. CROSS SECTION AND DISTRIBUTIONS

The single production of heavy leptons $\nu_4$ can occur via the t-channel $W$ exchange reaction $eq \to \nu_4 q'$, by proposing the following new charged current $e\nu_4 W$ interaction

$$\mathcal{L}_{cc} = \frac{g}{\sqrt{2}} \bar{e}[\gamma_\mu + \frac{i}{2m_{\nu_4}} \kappa_{\nu_4} \sigma_{\mu\nu} q'] P_L \nu_4 W^\mu + h.c., \quad (1)$$

which parallels the coupling structure for $\tau\nu W$ vertex [6]. In Eq. 1 $\kappa_{\nu_4}$ is the anomalous magnetic dipole moment factor, $q$ is the momentum carried by exchanged charged $W$ boson, $g$ denotes the gauge coupling relative to SU(2) symmetries and $W^\mu$ is the field of $W$. The differential cross section can be written as
\[
\frac{d\sigma}{dt} = \frac{g^4 [\kappa_{\nu_4}^2 ((2\hat{s} + \hat{t})m_{\nu_4}^2 - \hat{s}(\hat{t} + \hat{s}) - m_{\nu_4}^4)\hat{t} + 4m_{\nu_4}^2\hat{s}(\hat{s} - m_{\nu_4}^2)]}{256\pi \hat{s}^2 m_{\nu_4}^2 [(\hat{t} - M_W^2)^2 + \Gamma_W^2 M_W^2]} \tag{2}
\]

where \(\Gamma_W\) and \(M_W\) are the decay width and mass of mediator \(W\). The total production cross section is obtained by the integration over the parton distributions in the proton:

\[
\sigma_{\text{tot}} = \int_{x_{\text{min}}}^{1} f_q(x) dx \int_{t_-}^{t_+} \frac{d\sigma}{dt} dt
\tag{3}
\]

where \(t_- = -(\hat{s} - m_{\nu_4}^2)\), \(t_+ = 0\) and \(x_{\text{min}} = m_{\nu_4}^2 / S\). For the parton distribution functions \(f_q(x)\) we have used the MRST and taken \(\kappa_{\nu_4} = 0.1\) for illustrative purposes. The results for the cross sections are displayed in Fig. 1 for the mass range from 100 to 900 GeV at THERA, and in Fig. 2 from 100 GeV to 3 TeV at LC\(\otimes\)LHC. For the mass values larger than 200 GeV, the cross sections are not sensitive to the \(\kappa_{\nu_4}\) values at all. When the fourth generation neutrino is produced, it will decay via charged current interaction \(\nu_4 \rightarrow l W\) where \(l = e, \mu, \tau\) and we concentrate only on \(\nu_4 \rightarrow e W\) decay channel in this work. We consider the relevant background from the semileptonic reaction \(e u \rightarrow e W d\). We present background and signal cross section with respect to invariant mass of \(eW\) satisfying \(|m_{eW} - m_{\nu_4}| < 10\) GeV for the mass range \(m_{\nu_4} = 100-500\) GeV and \(|m_{eW} - m_{\nu_4}| < 20\) GeV for the mass range \(500-1000\) GeV at THERA in Table I. In Table II we display background and signal cross section with similar parameters except \(|m_{eW} - m_{\nu_4}| < 50\) GeV for the mass range \(1-3.4\) TeV for LC\(\otimes\)LHC. All calculations for the background were done using the high energy package CompHEP with CTEQ6L distribution function.

We present the distribution of invariant mass \(m_{W e}\) with cuts \(p_T^{e-j} > 10\) GeV for the background process \(e u \rightarrow e^-W^+ d\) for THERA in Fig. 3 and for LC\(\otimes\)LHC in Fig. 4. Finally, in Fig. 5 and Fig. 6 we show the \(p_T\) distributions due to the \(\nu_4\) production at THERA and LC\(\otimes\)LHC, respectively.

| \(m_{\nu_4}\) (GeV) | \(100\) | \(200\) | \(300\) | \(400\) | \(500\) | \(600\) | \(700\) | \(800\) | \(900\) |
|------------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| \(\sigma_s\) (pb) | 80.41 | 56.80 | 35.77 | 19.77 | 9.23  | 3.41  | 0.88  | 0.12  | 0.003 |
| \(\sigma_B\) (pb) | 0.019 | 0.024 | 0.012 | 0.0052| 0.0020| 0.0013| 3.2 \(10^{-4}\) | 4.34 \(10^{-5}\)| 1.31 \(10^{-6}\) |

TABLE I: Total cross sections of signal and background at THERA for \(\kappa_{\nu_4} = 0.1\).
III. CONCLUSION

We have shown that, if we take the limit values $S/\sqrt{S+B} > 5$, without being depended on anomalous coupling for masses greater than 200 GeV, calculated cross sections provide new 700 GeV neutrinos at the $\sqrt{S}=1$ TeV THERA ep collider, while this limit could be as high as 2.8 TeV at the $\sqrt{S}=3.74$ TeV LC×LHC option. The number of events corresponding to these limits are about 35 and 40 respectively.

Acknowledgments

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FIG. 1: The total production cross section of the subprocess $eu \rightarrow \nu d$ as a function of $m_{\nu_4}$ at THERA.

FIG. 2: The total production cross section of the subprocess $eu \rightarrow \nu d$ as a function of $m_{\nu_4}$ at LC@LHC.
FIG. 3: The invariant mass $m_{W^+e}$ distribution of the background at THERA($\sqrt{S}$=1 TeV).

FIG. 4: The invariant mass $m_{W^+e}$ distribution of the background at LC\(\otimes\)LHC($\sqrt{S}$=3.74 TeV).
FIG. 5: $p_T$ distribution of the background at THERA ($\sqrt{S}=1$ TeV).

FIG. 6: $p_T$ distribution of the background at LC$\otimes$LHC($\sqrt{S}=3.74$ TeV).