LEPTON FLAVOR CHANGING NEUTRAL CURRENT PROCESSES AT LEPTON–HADRON COLLIDERS

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We investigate the potentials of high energy lepton–proton colliders to detect a flavor changing $l-l'-Z$ or $l-l'-\gamma$ coupling from the processes $ep\to\mu(\tau)$X and $\mu p\to\tau$X. For the $l-l'-Z$ coupling we consider string inspired E_6 model whereas $l-l'-\gamma$ coupling is analyzed in the framework of Anomalous Magnetic Moment type Interaction (AMMI) model.

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1. Introduction

In the Standard Model (SM) lepton flavor is conserved in neutral current processes at tree level. Many searches for lepton Flavor Changing Neutral Current (FCNC) processes have been performed within different extensions of the SM [1]. In this paper we study e–μ, e–τ transitions in ep and μ-τ transitions in μp collisions. For numerical evaluations the center of mass energy and luminosity values [2] of future lepton–hadron colliders are given in Tables I and II . The two dynamical models we use allowing the above transitions are string inspired E_6 [3] and anomalous magnetic moment interactions AMMI [4]. The processes $ep\to\mu(\tau)$X and $\mu p\to\tau$X occur in t-channel exchange of a neutral vector boson, Z in E_6 and γ in AMMI .

In E_6, flavor violating $l-l'-Z$ vertices arise from the mixings between right handed components of the ordinary and new heavy charged leptons:

$$\Gamma^\mu = i g_Z b_{ll'Z}\gamma^\mu(1+\gamma_5)\,, \tag{1}$$

where $g_Z=g_e/\sin\theta_W\cos\theta_W$, θ_W is the weak mixing angle and $b_{ll'Z}$ denotes some combination of the leptonic mixing angles.

In the second model the interaction vertices $l-l'-\gamma$ are:

$$\Gamma^\mu = i\kappa_{ll'\gamma}\sigma_{\mu\nu}q^\nu\,, \tag{2}$$

where q is the momentum transfer through the intermediate photon and $\kappa_{ll'\gamma}$=a$_{ll'\gamma}(\frac{e}{2m_e})$ denotes the anomalous magnetic transition moment.

2. Analysis

Differential cross section for the subprocess $lq \to l'q$ in E$_6$ is obtained as:

$$\frac{d\hat{\sigma}}{d\hat{t}} = \frac{b_{ll'Z}^2 g_Z^4}{16\pi\hat{s}^2[(\hat{t}-M_Z^2)^2+M_Z^2\Gamma_Z^2]}\Big[(a_q+v_q)^2\hat{t}^2 + (a_q+v_q)^2(2\hat{s}-m_{l'}^2)\hat{t} + 2\hat{s}(a_q^2+v_q^2)(\hat{s}-m_{l'}^2)\Big], \quad (3)$$

where $\hat{s} = x$S is the center of mass energy of the incoming lepton and quark. Using the experimental limits for FCNC Z decays; BR($Z \to e\mu$) $< 1.7\times 10^{-6}$, BR($Z \to e\tau$) $< 9.8\times 10^{-6}$ and BR($Z \to \mu\tau$) $< 1.2\times 10^{-5}$ [5] we obtain the upper bound values of b$_{ll'Z}$:

$$b_{e\mu Z} < 0.504\times 10^{-2}\,,$$
$$b_{e\tau Z} < 1.209\times 10^{-2}\,,$$
$$b_{\mu\tau Z} < 1.338\times 10^{-2}\,.$$

The total cross section is obtained by folding $\hat{\sigma}$ over the parton distribution functions inside the proton [6] as follows:

$$\sigma = \int_{x_{\min}}^{1} dx \int_{t_-}^{t_+} \frac{d\hat{\sigma}}{d\hat{t}} f_q(x) d\hat{t}\,, \quad (4)$$

where $x_{\min} = \frac{m_{l'}^2}{S}$ and $t_+ = 0, t_- = -(\hat{s}-m_{l'}^2)$. These phase space boundaries are obtained in the $m_e = m_q = 0$ case. The results of the integrated cross sections for various lepton–proton colliders are presented in Table I. We see that $\sigma(ep \to \tau X) \cong 6\sigma(ep \to \mu X)$.

TABLE I

Cross section values for the FCNC processes.

Colliders	$\sqrt{S}$(GeV)	$\mathcal{L}$(cm^{-2}s^{-1})	$\sigma(ep\to\mu$X)(pb)	$\sigma(ep\to\tau$X)(pb)	$\sigma(\mu p\to\tau$X)(pb)
Thera 1	1000	4×10^{30}	0.96×10^{-2}	5.57×10^{-2}	—
Thera 2	1000	2.5×10^{31}	0.96×10^{-2}	5.57×10^{-2}	—
Thera 3	1600	1.6×10^{31}	1.12×10^{-2}	6.50×10^{-2}	—
LINAC⊗LHC	5300	10^{33}	1.36×10^{-2}	7.85×10^{-2}	—
μ-Tevatron	894	10^{31}	—	—	6.48×10^{-2}
μp	3000	10^{32}	—	—	9.02×10^{-2}

The differential cross section in AMMI model is calculated as:

$$\frac{d\hat{\sigma}}{d\hat{t}} = \frac{\alpha e_0^2 \kappa_{ll'\gamma}^2}{2\hat{s}^2} \left[m_{l'}^2 - 2\hat{s} + (2\hat{s} m_{l'}^2 - m_{l'}^4 - 2\hat{s}^2) \frac{1}{\hat{t}} \right] , \tag{5}$$

where α is the fine-structure constant and e_0 is the quark charge in units of the electron charge e. In the integral (4) we take a $t_{\rm cut} = 0.01$GeV to avoid a divergency due to the photon propagator. Now we use the experimental upper bounds for the flavor-violating μ and τ decays; BR($\mu \to e\gamma$) $< 1.2\times 10^{-11}$, BR($\tau \to e\gamma$) $< 2.7\times 10^{-6}$ and BR($\tau \to \mu\gamma$) $< 1.1\times 10^{-6}$ to put the limits on $\mathrm{a}_{ll'\gamma}$;

$$\mathrm{a}_{\mu e\gamma} < 6.36 \times 10^{-13} ,$$
$$\mathrm{a}_{\tau e\gamma} < 1.24 \times 10^{-8} ,$$
$$\mathrm{a}_{\tau \mu\gamma} < 0.79 \times 10^{-8} .$$

The results for the integrated cross-sections are given in Table II.

TABLE II

Cross section values for the LFV processes.

Colliders	$\sqrt{S}$(GeV)	$\mathcal{L}$(cm^{-2}s^{-1})	$\sigma(ep \to \mu X)$(pb)	$\sigma(ep \to \tau X)$(pb)	$\sigma(\mu p \to \tau X)$(pb)
Thera 1	1000	4×10^{30}	1.71×10^{-18}	6.54×10^{-10}	—
Thera 2	1000	2.5×10^{31}	1.71×10^{-18}	6.54×10^{-10}	—
Thera 3	1600	1.6×10^{31}	1.81×10^{-18}	6.95×10^{-10}	—
LINAC⊗LHC	5300	10^{33}	2.09×10^{-18}	8.02×10^{-10}	—
μ-Tevatron	894	10^{31}	—	—	3.00×10^{-10}
μp	3000	10^{32}	—	—	2.65×10^{-10}

3. Conclusion

Our main results indicate that future lepton–hadron colliders are promising machines for investigation of FCNC processes predicted by E_6 model. Unfortunately this statement is not applicable for LFV processes predicted by AMMI model. According to Table I we expect $N(e \to \tau) = 785$ and $N(e \to \mu) = 136$ events per year at LINAC⊗LHC and $N(\mu \to \tau) = 90$ events per year at μp collider. In the case of no observations of these events, our results show that about 2 order of higher accuracy compering to the current limits will be achieved.

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