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ANOMALOUS SINGLE PRODUCTION OF THE FOURTH GENERATION QUARKS AT FUTURE ep AND γp COLLIDERS

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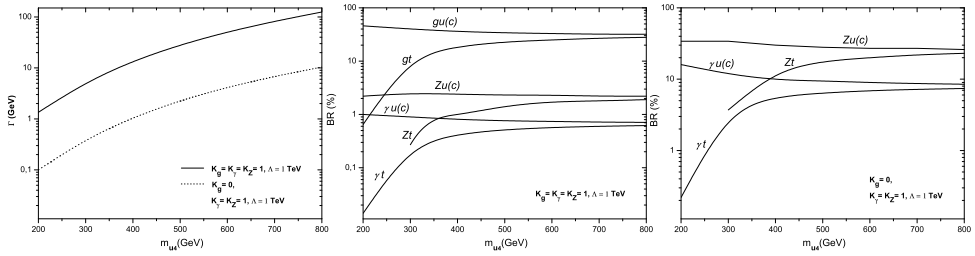
Abstract. - Possible anomalous single productions of the fourth standard model generation up and down type quarks at LHC based ep and γp colliders are studied. Some decay channels are considered. Signatures for signals and corresponding standard model backgrounds are discussed. Discovery limits for quark mass and achievable values of anomalous coupling strength are determined.

Colliders with TeV enegy are needed for discovery of the fourth SM generation fermions if they exist (see [1] and references therein). The fourth generation quarks will be produced in pairs copiously at the Large Hadron Collider (LHC). Lepton colliders are the best place for pair production of the fourth generation charged lepton and neutrino. The discovery capacity of lepton collider could be enlarged if the anomalous interactions of the fourth generation fermions with the first three ones exist. Such anomalous interactions seems to be quite natural due to large masses of the fourth generation fermions. These anomalous interactions could provide also single production of the fourth generation fermions at future lepton-hadron [2, 3] and gamma-hadron colliders. Lepton-hadron colliders with $\sqrt{s}$ = 1.3-1.4 TeV are named QCD Explorer or LHeC depending on electrons provided by linac or ring, respectively [4]. Reference [5] has given estimations of the luminosity values for various configuration and parameter sets of LHC and electron accelerator. For the choice of a cw superconducting energy recovery e-linac with a upgrated LHC, the integrated luminosity for a year has been estimated $10 fb^{-1}$. The integrated luminosity for a year has been estimated $4.1 fb^{-1}$, for the choice of pulsed superconducting e-linac with a



(a) (b) (c)

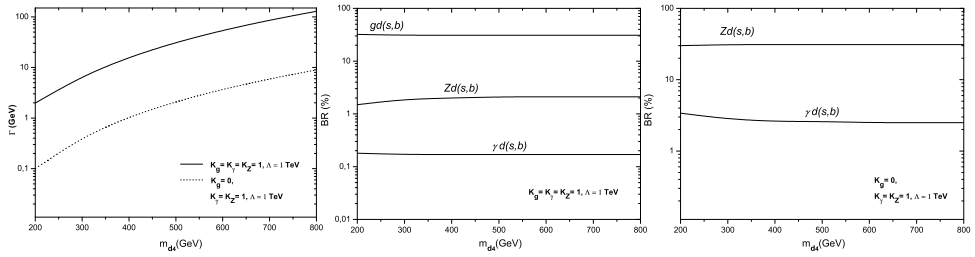
Figure 1: (a) The total and (b), (c) the partial decay widths of the fourth SM generation up type quarks as a function of the quark mass

upgrated LHC. While the first choice has better luminosity, it is not possible to found a gamma-p collider on base of it. The real gamma production through Compton back scattering technique on the base of the ep collider is possible on the second choice. In this case, the integrated luminosity of γp collider reaches the maximum value of $2.665 fb^{-1}$. In this study the possible anomalous single productions of the fourth generation up and down type quarks at LHC based ep and γp colliders are considered.

The effective Lagrangian for the flavor changing neutral current (FCNC) interactions of u_4 and d_4 quarks can be rewritten from [6, 7] with minor modifications as:

$$\mathcal{L} = \left(\frac{\kappa_\gamma^{q_i}}{\Lambda}\right) e_q g_e \bar{q}_4 \sigma_{\mu\nu} q_i F^{\mu\nu} + \left(\frac{\kappa_Z^{q_i}}{2\Lambda}\right) g_Z \bar{q}_4 \sigma_{\mu\nu} q_i Z^{\mu\nu} + \left(\frac{\kappa_g^{q_i}}{\Lambda}\right) g_s \bar{q}_4 \sigma_{\mu\nu} T^a q_i G_a^{\mu\nu} + H.c. \ , \quad (1)$$

where $i = 1, 2, 3$ denotes the generation index. $\kappa_\gamma^{q_i}$, $\kappa_Z^{q_i}$ and $\kappa_g^{q_i}$ are anomalous couplings for the electromagnetic, the weak (neutral current) and the strong interactions, respectively. Λ is the cutoff scale for the new physics and e_q is the quark charge. g_e, g_Z and g_s are the electroweak and the strong coupling constants. In the above equa-



(a) (b) (c)

Figure 2: (a) The total and (b), (c) the partial decay widths of the fourth SM generation down type quarks as a function of the quark mass

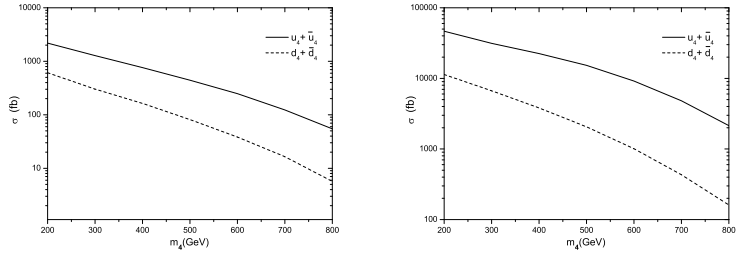
Table 1: Signal and SM background cross sections for $ep \to u_4(d_4)X \to q\ell^+\ell^-X$ and $\gamma p \to u_4(d_4)X \to q\gamma X$ processes

m_4 (GeV)	Quark Type	Signal σ (fb) for $ep \to u_4(d_4)X \to q\ell^+\ell^-X$		Signal σ (fb) for $\gamma p \to u_4(d_4)X \to q\gamma X$	
		$\kappa/\Lambda = 1$ TeV^{-1}	$\kappa_g/\Lambda = 0$	$\kappa/\Lambda = 1$ TeV^{-1}	$\kappa_g/\Lambda = 0$
No Cut					
300	u_4	8.68	163	564	7340
	d_4	2.44	40	33.9	540
600	u_4	1.45	19	136	1820
	d_4	0.32	5	5.13	81
SM Bck. σ (fb)		97.7		$3.19 \cdot 10^8$	
With Cut					
300	u_4	–	3.37	380	4940
	d_4	–	1.75	–	390
600	u_4	–	0.94	61	800
	d_4	–	0.35	–	38
SM Bck. σ (fb)		0.64		1220	

tion, $\sigma_{\mu\nu} = i(\gamma_\mu\gamma_\nu - \gamma_\nu\gamma_\mu)/2$. $F^{\mu\nu}$, $Z^{\mu\nu}$ and $G_a^{\mu\nu}$ are field strength tensors of the photon, the Z boson and gluons, respectively. T_a is the Gell-Mann matrices.

We have calculated the anomalous single production cross sections of the fourth SM generation quarks at the linac-LHC and γp colliders based on it using CompHEP with CTEQ6L1 [8]. The total decay width Γ of the fourth generation up (down) type quarks and the relative branching ratios are plotted with assumption of $\kappa_\gamma^{q_i} = \kappa_Z^{q_i} = \kappa_g^{q_i}$ and $\kappa_\gamma^{q_i} = \kappa_Z^{q_i} = 1$, $\kappa_g^{q_i} = 0$ in Fig. 1 (Fig. 2). $\Lambda = 1$TeV is selected at calculations. Single anomalous production cross sections of the fourth generation quarks are given for ep collider at Fig. 3a and γp collider at Fig. 3b.

In this study, $ep \to u_4(d_4)X \to qZX \to q\ell^+\ell^-X$ and $\gamma p \to u_4(d_4)X \to q\gamma X$ processes (and their H.c.) are considered as a signature of anomalous interactions of



(a) (b)

Figure 3: The total production cross sections of the fourth SM generation up and down type quarks at (a) ep and (b) γp colliders

Table 2: Statistical signifances (SS) for for $ep \to u_4(d_4)X \to q\ell^+\ell^-X$ and $\gamma p \to u_4(d_4)X \to q\gamma X$ processes by using $\kappa_\gamma^{q_i} = \kappa_Z^{q_i} = 1,\ \kappa_g^{q_i} = 0$

m_4 (GeV)	Quark Type	SS for $ep \to d_4(u_4)X \to q\ell^+\ell^-X$ $L = 10$ fb^{-1}	$L = 4.1$ fb^{-1}	SS for $\gamma p \to d_4(u_4)X \to q\gamma X$ $L = 2.665$ fb^{-1}
300	u_4	13.3	8.5	231
	d_4	6.9	4.4	18.2
600	u_4	3.7	2.4	37.4
	d_4	1.4	0.9	1.8

the fourth generation up and down type quarks (q is u or c for u_4 and d, s or b for d_4 and ℓ is e or μ). The SM background for this processes is potentially much larger than the signal. However, after applying some kinematic cuts, it is posiible to decrease background to the reseonable levels. We choose the following cuts for the first process: $P_T > 10$ GeV for the scattered electron, $P_T > 80$ GeV for leptons coming from Z boson, $P_T > 20$ GeV for jet; $|\eta_{j,l}| < 2.5$, $\Delta R > 0.4$ between the leptons and jet. For the second process similar cuts are applied. Only leptons on the cuts related to leptons coming from Z boson are replaced by photons. The calculated signal and SM background cross sections are given in Table 1. The statistical significance (SS) values, evaluated from $SS = (\sigma_S/\sqrt{\sigma_B})\sqrt{L_{int}}$, where L_{int} is the integrated luminosity of the collider, are presented in Table 2 for both processes after applying above cuts.

As a result of this study it is shown that when anomalous coupling for strong interactions is close to one, ep and γp colliders are almost blind to anomalous interactions. These colliders give possibility to investigate effects of both anomalous couplings of electromagnetic and weak interactions for $\kappa_g^{q_i} = 0$. Observation limits (at 3σ) as low as 0.33 (0.52) TeV^{-1} are reachable for the (κ_γ/Λ) at $m_4 = 300\,(600)$ GeV for the up and down type quarks (combined) at γp collider. Meanwhile, 0.38 (0.76) TeV^{-1} for the (κ_Z/Λ) is reachable at $m_4 = 300\,(600)$ GeV for the ep collider with $L = 10\ fb^{-1}$.

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REFERENCES

[1] A. K. Çiftçi, R. Çiftçi , S. Sultansoy, *Phys. Rev. D* **72**, 053006 (2005).

[2] A. K. Çiftçi, R. Çiftçi, S. Sultansoy, *Phys. Lett. B* **660**, 534 (2008).

[3] A. K. Çiftçi *et al.*, *Mod. Phys. Lett. A* **23**, 1047 (2008).

[4] S. Sultansoy, *Eur. Phys. J. C* **33 s01**, 1064 (2004); Proc. of Particle Accelerator Conference, Knoxville 2005, p. 4329.

[5] F. Zimmermann *et al.*, Proc. of EPAC08, pp 2847 (2008).

[6] T. G. Rizzo, *Phys. Rev. D* **56**, 3074 (1997).

[7] E. Arık, O. Cakır, S. Sultansoy, *Europhys. Lett.* **62**, 332 (2003).

[8] J. Pumplin *et al.*, JHEP **0207**, 012 (2002) [hep-ph/0201195].