The Fourth SM Family Leptons and Quarks

at ep and γp Collider Options of the LHeC

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1-3 September 2009

Oversight

The Fourth Generation Fermions

As the LHC run approaches, the interest on fourth standard model (SM) generation is increasing. Recent workshop @ CERN to review the different aspects of 4 generations

- B. Holdom *et al.*, arXiv:hep-ph 0904.4698 (2009).

In Standard Model, flavor democracy predicts the existence of a heavy fourth SM generation.

- H. Fritzsch, Phys. Lett. B 184 (1987) 391.
- A. Datta, Pramana 40 (1993) L503.
- A. Çelikel, A.K. Çiftçi, S. Sultansoy, Phys. Lett. B 342 (1995) 257.

The Dirac masses of the new fermions are predicted to be almost degenerate and lie between 300 and 700 GeV, whereas, the masses of known fermions belonging to lighter three generations appear due to small deviations of the democracy.

- S. Atag, A. Çelikel, A.K. Çiftçi, S. Sultansoy, U.O. Yilmaz, Phys. Rev. D 54 (1996) 5745.
- A.K. Çiftçi, R. Çiftçi, S. Sultansoy, Phys. Rev. D 72 (2005) 053006.

The fourth generation quarks will be produced in pairs copiously at the Large Hadron Collider (LHC).

- E. Arik, et al., Phys. Rev. D 58 (1998) 117701.

In addition, the extra SM families will enhance the SM Higgs boson production.

- E. Arik et al., Eur.Phys.J.C26:9-11,2002.

Also, Higgs Boson may help to discover the new neutrino at the LHC.

- T. Cuhadar-Donszelmann et al., JHEP 0810:074,2008.

And, possible impact of the fourth generation quarks on production of a charged Higgs Boson at the LHC.

- $gg \to \bar{u_4} u_4 \to W^- \bar{b} b h^+ \to W^- \bar{b} b t \bar{b} \to W_{l\nu} \bar{b} b \bar{b} b W_{jj}$

- R. Çiftçi, A.K. Çiftçi, S. Sultansoy, arXiv:hep-ph 0807.0831 (2008).

Even, discovery potential of the fourth generation charged lepton is demonstrated for the LHC through process of $pp \to e_4\nu_4 \to W\nu_4\nu_4 \to W_{l\nu}W_{jj}\mu W_{jj}\mu$

9 "backgroundless" events/fb^{-1}

- V.E. Ozcan, S. Sultansoy, G. Unel, J. Phys. G 36, 095002 (2009).

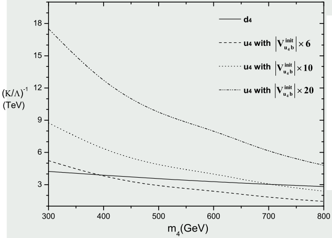
Linear lepton colliders are the best place for pair production of the fourth generation charged lepton and neutrino.

- A.K. Çiftçi, R. Çiftçi, S. Sultansoy, Phys. Rev. D 65 (2002) 055001.
- R. Çiftçi, A.K. Çiftçi, E. Recepoglu, S. Sultansoy, Turk. J. Phys. 27 (2003) 179.
- A.K. Çiftçi, R. Çiftçi, S. Sultansoy, Phys. Rev. D 72 (2005) 053006.

Anomalous production at various collider options

The discovery capacity of LHC and 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.

Anomalous single productions of the fourth generation quarks at the LHC



PHYSICAL REVIEW D **78**, 075018 (2008)

Anomalous single production of the fourth generation quarks at the CERN LHC

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Possible anomalous single productions of the fourth standard model generation up and down type quarks at CERN Large Hadron Collider are studied. Namely, $pp \to u_4(d_4)X$ with subsequent $u_4 \to bW^+$ process followed by the leptonic decay of the W boson and $d_4 \to b\gamma$ (and its H.c.) decay channel are considered. Signatures of these processes and corresponding standard model backgrounds are discussed in detail. Discovery limits for the quark mass and achievable values of the anomalous coupling strength are determined.

Single Resonant Production of the Fourth Generation Charged Leptons at γe Colliders

- $\gamma e \to \ell_4 \to e\gamma$
- $\gamma e \to \ell_4 \to eZ$
- R. Çiftçi, A.K. Çiftçi, S. Sultansoy, arXiv:hep-ph 0902.2800 (2009).

☞ Anomalous single production of the fourth generation charged leptons at future ep colliders. ($E_e = 70 - 500$GeV)

- $ep \to l_4 X \to ZeX$
- A.K. Çiftçi et al., Mod. Phys. Lett. A23, 1047-1054 (2008).

☞ Anomalous single production of the fourth generation neutrino at future ep colliders. ($E_e = 70 - 500$GeV)

- $ep \to \nu_4 X \to \mu W X$
- $ep \to \nu_4 X \to eWX$
- A.K. Çiftçi et al., Phys. Lett. B660, 534-538 (2008).

☞ A Comparative Study of the Anomalous Single Production of the Fourth Generation Quarks at ep and γp Colliders. $(E_e = 60\text{GeV})$

- $u_4(d_4) \to q\gamma$
- $u_4(d_4) \to qZ \to q\ell^+\ell^-$

- R. Çiftçi, A.K. Çiftçi, arXiv:0904.4489 [hep-ph].

This presentation is based on the last 3 papers related to anomalous single productions of the fourth generation fermions at the future ep and γp colliders .

QCD Explorer-LHeC

Proceedings of EPAC08, Genoa, Italy WEPP154

LINAC-LHC ep COLLIDER OPTIONS

F. Zimmermann, F. Bordry, H.-H. Braun, O.S. Brüning, H. Burkhardt, A. de Roeck, R. Garoby, T. Linnecar, K.-H. Mess, J. Osborne, L. Rinolfi, D. Schulte, R. Tomas, J. Tuckmantel, CERN, Switzerland; A. Eide, EPFL, Switzerland; F.J. Willeke, BNL, U.S.A.; S. Chattopadhyay, Cockcroft I., UK; B.J. Holzer, DESY, Germany; J. Dainton, M. Klein, Liverpool U., UK; A. Vivoli, LAL, France; S. Sultansoy, TOBB ETU, Turkey; A.K. Ciftci, Ankara U., Turkey; H. Aksakal, Nigde U., Turkey

Abstract

We describe various parameter scenarios for a linac-ring ep collider based on LHC and an independent electron linac. Luminosities between 10^{31} and 10^{33} cm^{-2}s^{-1} can be achieved with a s.c. linac, operated either pulsed or in cw mode with optional recirculation, at a total electric wall-plug power of order 20 MW. Higher luminosities of several 10^{33} cm^{-2}s^{-1} can be reached by investing more electric power or by energy recovery. Finally, merits of a linac-ring ep collider are discussed.

SCENARIOS

Colliding the LHC 7-TeV protons with a 25–140 GeV e$^{\pm}$ beam would both extend the discovery reach of the LHC, and enable precision physics with LHC data [1, 2]. e$^+$p collisions are desirable in addition to e$^-$p. One way to realize such ep collider is by installing a new lepton ring in the LHC tunnel, implying a new lepton injector too [3, 4]. The THERA study [5] inspired looks at an alternative LHC-based "QCD Explorer" colliding LHC protons with electrons delivered by a linac [6].

Possible linac-ring scenarios include a n.c. linac, a pulsed s.c. linac, and a cw s.c. linac with or without energy recovery in various configurations, as shown in Fig. 1.

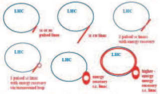

Figure 1: Scenarios for the linac-ring ep collider.

A s.c. linac can accelerate long trains of bunches with 25 or 50 ns spacing, matching the LHC fill pattern. Therefore, its luminosity in collisions with the LHC can be much

Table 1: Proton beam scenarios

	$N_{b,p}$	T_{sep}	$\epsilon_p \gamma_p$	β_p^*
LHC	1.7×10^{11}	25 ns	3.75 μm	0.25 m
LHC*	5×10^{11}	50 ns	3.75 μm	0.10 m

ter is decelerated [8]. More conventional energy recovery is possible by means of a recirculating linac, e.g. similar to ELFE [9], or with a turnaround loop as proposed for a future X-ray FEL [10]. Possible layouts are sketched in Fig. 2. For highest beam energy, the ERL with its recircu-

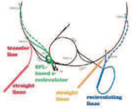

Figure 2: Example linac layouts on LHC site.

lating arcs could be installed in the LHC tunnel itself, blurring the distinction between ring-ring and linac-ring LHeC options [11].

Two proton scenarios are listed in Table 1: (1) the nominal LHC beam combined with reduced proton interaction-point (IP) beta functions β_p^* of 0.25 m as foreseen for 2013, and (2) a higher brightness beam [corresponding to scenario "LPA" of [12]] available from an upgraded LHC injector chain, including a 5 GeV s.c. proton linac (SPL) and a 50-GeV synchrotron (PS2), by 2017. This second scenario also assumes $\beta_p^* = 0.1$ m, which may be possible by (1) focusing only one of the two proton beams, thereby relaxing aperture constraints; (2) dedicated ep runs, allowing for a chromatic correction twice as strong as for two low-β

QCD Explorer-LHeC

Table 2: Electron-beam parameters for various (s.c.) linac-ring LHeC scenarios. The β^* values are calculated for a normalized e- emittance of 20 μm. Parameters marked by asterisks refer to 'LHC*' of Table 1.

energy [GeV]	20	20	60	60	60	120
option	cw 4-pass	cw 4-p. ERL	cw 4-pass	cw 4-p. ERL	pulsed	pulsed
bunch population $N_{b,e}$ [10^9]	0.06, 0.12*	1.3, 2.6*	0.1, 0.2*	0.3, 0.6*	17, 34*	7, 14*
average current [μA]	400	8650	74	2050	820	340
beam power at IP [MW]	8.0	172	4.5	120	49	48
IP beta function [m]	0.25, 0.098*	0.25, 0.098*	0.74, 0.30*	0.74, 0.30*	0.74, 0.30*	1.72, 0.69*
luminosity [10^{31} cm^{-2}s^{-1}]	2.7, 20*	58, 430*	0.5, 3.7*	14, 100*	5.5, 41*	2.3, 17*
total electrical power [MW]	20	20	20	20	100	100

tance between 10 and 100 μm is expected after bunching and acceleration.

[1] E. Arik, S. Sultansoy, hep-ph/0302012 (2003).
[2] S. Sultansoy, Eur. Phys. J. C 33 (2004) 1064.
[3] D. Schulte, F. Zimmermann, CLIC-Note-589 (2004).
[4] P.L. Csonka, J. Rees, Nucl. Instr. and Meth. 96 (1971) 149.
[5] S.F. Sultanov, IC/89/409, Trieste, 1989.
[6] P. Grosse-Wiesmann, Nucl. Instr. and Meth. A 274 (1989) 21; P. Grosse-Wiesmann, SLAC-PUB-4545.
[7] A.K. Ciftci, S. Sultansoy, O. Yavas, Nucl. Instr. and Meth. A 472 (2001) 72.
[8] S. Sultansoy, Turk. J. of Phys. 22 (1998) 575.
[9] J.B. Dainton, et al., hep-ex/0603016; J.B. Dainton, et al., Proceedings of EPAC, 2006, p. 670.

γp Collider

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Conversion efficiency and luminosity for gamma-proton colliders based on the LHC-CLIC or LHC-ILC QCD explorer scheme

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Abstract

Gamma-proton collisions allow unprecedented investigations of the low x and high Q^2 regions in quantum chromodynamics. In this paper, we investigate the luminosity for "ILC" × LHC($\sqrt{s_{ep}}$ = 1.3 TeV) and "CLIC" × LHC($\sqrt{s_{ep}}$ = 1.45 TeV) based γp colliders. Also we determine the laser properties required for high conversion efficiency.

PACS: 13.60.Fz; 41.75.–i; 42.55.–f

Keywords: Photon–Proton collisions; Luminosity

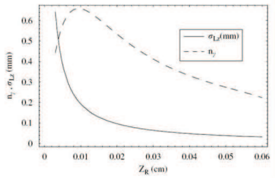


Fig. 2. Conversion efficiency and laser pulse length vs. Z_R for "CLIC-1".

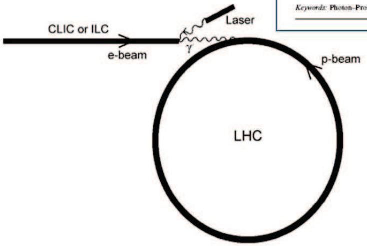
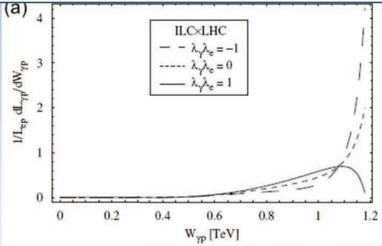


Fig. 1. Schematic of the proposed colliders.



Lagrangians

The effective Lagrangian for magnetic type anomalous interaction of the fourth generation charged lepton and neutrino

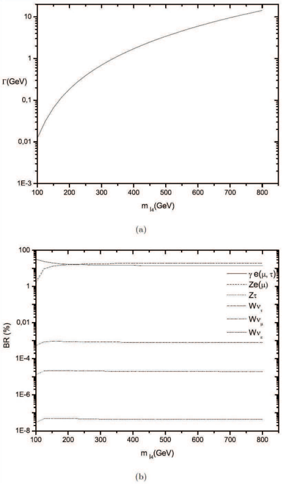
- $\mathcal{L}_{nc} = \left(\frac{\kappa_\gamma^{\ell_4 \ell_i}}{\Lambda}\right) e_\ell g_e \overline{\ell_4} \sigma_{\mu\nu} \ell_i F^{\mu\nu} + \left(\frac{\kappa_Z^{\ell_4 \ell_i}}{2\Lambda}\right) g_Z \overline{\ell_4} \sigma_{\mu\nu} \ell_i Z^{\mu\nu} + h.c.$
- $\mathcal{L}_{cc} = \left(\frac{g_W}{\sqrt{2}}\right) \overline{l_i} \left[|V_{\nu_4 l_i}| \gamma_\mu + \frac{i}{2\Lambda} \kappa_W^{\nu_4 l_i} \sigma_{\mu\nu} q^\nu \right] P_L \nu_4 W^\mu + h.c.$
- $\mathcal{L}_{nc} = \left(\frac{g_Z}{2}\right) \overline{\nu_i} \frac{i}{2\Lambda} \kappa_Z^{\nu_4 \nu_i} \sigma_{\mu\nu} q^\nu P_L \nu_4 Z^\mu + h.c.$

The effective Lagrangian for the magnetic type FCNC of the fourth generation quarks

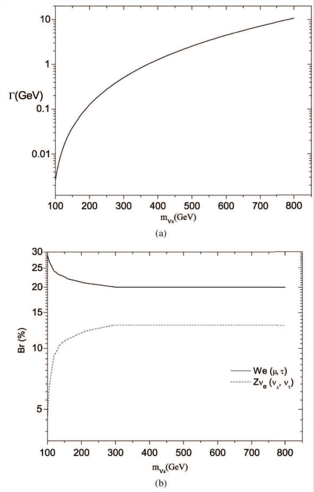
- $\mathcal{L}_{nc} = \left(\frac{\kappa_\gamma^{q_4 q_i}}{\Lambda}\right) e_q g_e \bar{q}_4 \sigma_{\mu\nu} q_i F^{\mu\nu} + \left(\frac{\kappa_Z^{q_4 q_i}}{2\Lambda}\right) g_Z \bar{q}_4 \sigma_{\mu\nu} q_i Z^{\mu\nu} + \left(\frac{\kappa_g^{q_4 q_i}}{\Lambda}\right) g_s \bar{q}_4 \sigma_{\mu\nu} T^a q_i G_a^{\mu\nu} + h.c.$

Decay widths and branching ratios

For the fourth family charged lepton:

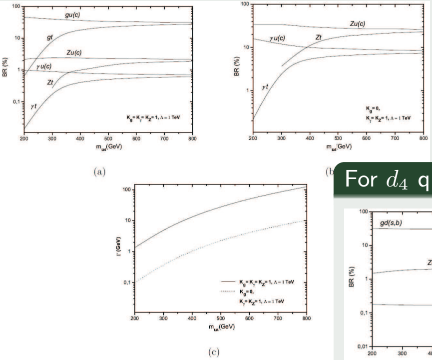


For the fourth family neutrino:

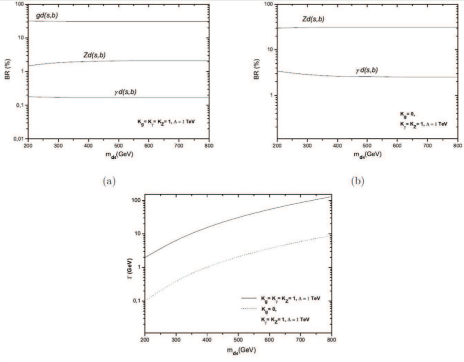


More decay widths and branching ratios

For u_4 quark:

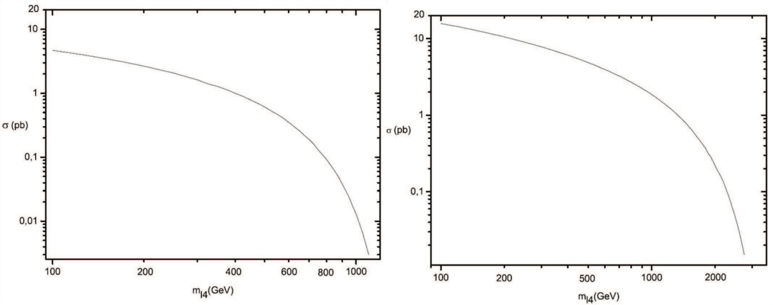


For d_4 quark:



$ep \to l_4 X \to ZeX$

Production cross sections: $\sqrt{s} = 1.4$ TeV and $\sqrt{s} = 3.74$ TeV



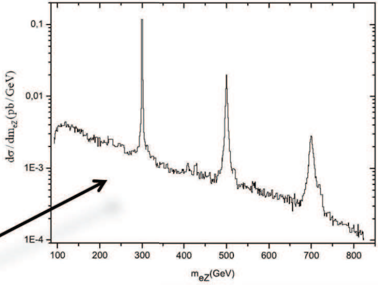
$ep \rightarrow l_4 X \rightarrow ZeX$:

$(\frac{\kappa}{\Lambda})_{min} = 0.26$ for $\sqrt{s} = 1.4$ TeV and $(\frac{\kappa}{\Lambda})_{min} = 0.14$ for $\sqrt{s} = 3.74$ TeV

and $ep \rightarrow l_4 X \rightarrow ZeX$ processes. In the former process anomalous decay of l_4 can be detected easily at ep colliders due to no background. Number of events for $m_{l_4} = 300\,(700)$ GeV at $\sqrt{s} = 1.4$ TeV and $\sqrt{s} = 3.74$ TeV with 1 fb^{-1} integrated luminosity are 240 (30) and 1170 (460), respectively. However, the latter process

Table 2. Total cross-section of signal and background for $\sqrt{s} = 1.4$ TeV and $(K/\Lambda) = 1$ TeV^{-1}.

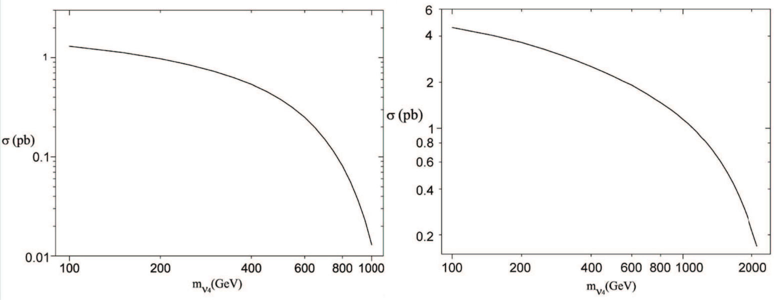
m_{l_4} (GeV)	σ_{S+B} (pb)	σ_B (pb)	SS
200	0.49	0.09	42.16
300	0.33	0.05	39.60
400	0.21	0.03	32.86
500	0.13	0.02	24.59
600	0.075	0.015	15.49
700	0.039	0.009	10.00
800	0.019	0.005	6.26
900	0.0076	0.002	3.96
1000	0.0028	0.0011	1.62



$ep \rightarrow l_4 X \rightarrow ZeX$

$ep \to \nu_4 X \to W(e, \mu)X$

Production cross sections: $\sqrt{s} = 1.4$ TeV and $\sqrt{s} = 3.74$ TeV



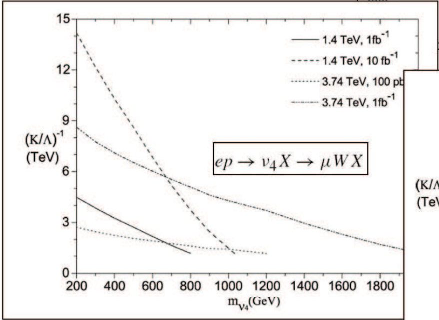
$ep \to \nu_4 X \to W(e,\mu)X$

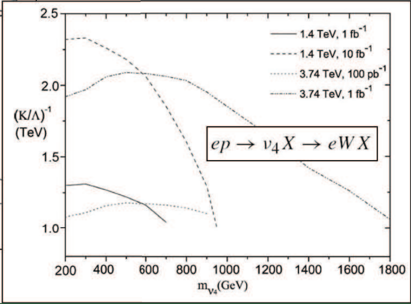
Event numbers of $ep \to \nu_4 X \to \mu W X$ for $\sqrt{s} = 1.4$ TeV, $(\kappa/\Lambda) = 1$ TeV^{-1}

m_{ν_4} (GeV)	N_S	
	$L_{int} = 1$ fb^{-1}	$L_{int} =$
200	201	2010
300	148	1480
400	106	1060
500	74	740
600	47	470
700	27	270
800	14	140
900	6	60
1000	2	22

The cross section of signal and background of $ep \to \nu_4 X \to eWX$ for $\sqrt{s} =$ 1.4 TeV, $(\kappa/\Lambda) = 1$ TeV^{-1}

m_{ν_4} (GeV)	σ_S (pb)	σ_B (pb)	SS	
			$L_{int} = 1$ fb^{-1}	$L_{int} = 10$ fb^{-1}
200	0.201	0.560	8.49	26.86
300	0.148	0.293	8.64	27.34
400	0.106	0.172	8.08	25.56
500	0.074	0.086	7.98	25.23
600	0.047	0.049	6.71	21.23
700	0.027	0.025	5.40	17.07
800	0.014	0.012	4.04	12.78
	0.006	0.005	2.64	8.34
	0.002	0.004	1.10	3.48

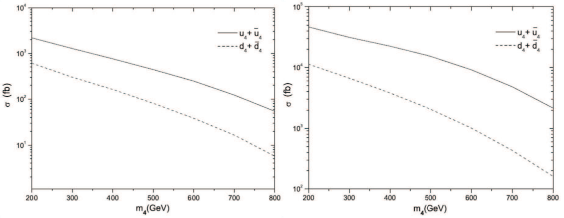




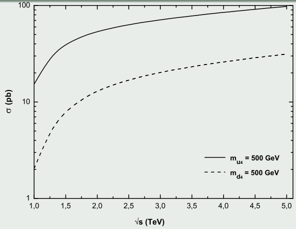
$ep \to eq_4X \to e\gamma jX + h.c.$ and $\gamma p \to q_4X \to \gamma jX + h.c.$

$ep \to eq_4X \to e\ell^+\ell^- jX + h.c.$ and $\gamma p \to q_4X \to \ell^+\ell^- jX + h.c.$

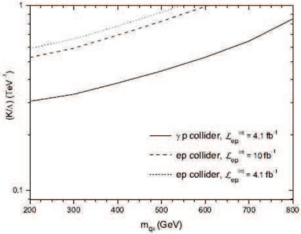
Production cross sections: ep and γp colliders at $\sqrt{s} = 1.3$ TeV



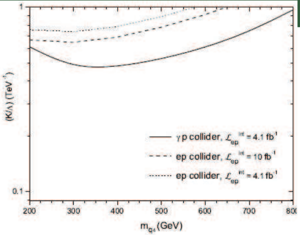
Production cross sections: γp collider for $m_{q_4} = 500$ GeV



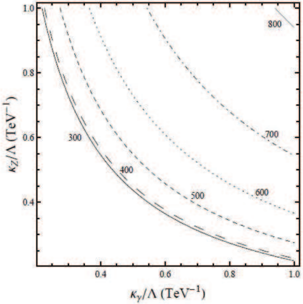
$q_4 \to \gamma q$ and $q_4 \to Zq$ processes at ep and γp colliders



(a)

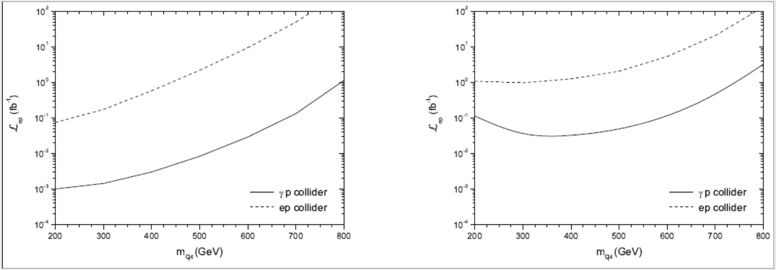


(b)



$q_4 \to \gamma q$ and $q_4 \to Zq$ processes at ep and γp colliders

The lowest necessary luminosity values of ep colliders to observe (a) $q_4 \to \gamma q$ anomalous process and (b) $q_4 \to Zq$ anomalous process



Conclusion

When the anomalous coupling for strong interactions is close to one, ep and γp colliders are almost blind to anomalous interactions of the fourth generation quarks.

In this case, hadron colliders like LHC will be discovery machines.

ep and γp colliders enable us to investigate effects of both anomalous couplings of electromagnetic and weak interactions for $\kappa_g^{q_i} = 0$.

- This type anomalous interactions takes place through Weizsacker-Williams photons or Z boson at the LHC.
- However, LHC based ep and γp colliders have better observation reaches of anomalous couplings compare to the LHC.

The advantage of the γp collider with respect to ep collider for single production of q_4 is obvious even with $1/100$ (for $q_4 \to \gamma q$) and $1/10$ (for $q_4 \to Zq$) of luminosity of ep collider.

ep and γp colliders are almost only place to investigate anomalous coupling strengths of electroweak interactions separately.

Such as κ_Z^{qq4}, κ_γ^{qq4}, κ_Z^{ll4}, κ_γ^{ll4} and $\kappa_W^{l\nu 4}$