Commun.Fac.Sci.Univ.Ank.Series A2-A3
Volume 62, Number 1, Pages 35-52 (2020)
DOI: 10.33769/aupse.676443
ISSN 1303-6009 E-ISSN 2618-6462
http://communications.science.ankara.edu.tr/index.php?series=A2A3

A STUDY ON THE SEARCH POTENTIAL OF DOUBLY CHARGED LEPTONS AT THE SppC BASED *ep* COLLIDERS

A. OZANSOY and O. ALBAYRAK

ABSTRACT. We consider the single production of doubly charged leptons which take part in the extended weak isospin models and have exotic electric charges such as $Q = \pm 2e$ at the SppC based electron-proton (*ep*) colliders. We introduce the effective lagrangians describing the doubly charged lepton gauge interactions with SM leptons. We calculate the decay widths and production cross sections as a function of doubly charged lepton mass. We deal with the $e^- p \to e^- W^- X$ process and plot the kinematical distributions for the final state electron both for the signal and corresponding background. We perform a cut-based analysis to obtain the mass limits and couplings of doubly charged leptons at the SppC based *ep* colliders with the center-of-mass energies of $\sqrt{s} = 8.44$ TeV and $\sqrt{s} = 26.68$ TeV.

1. INTRODUCTION

The Standard Model (SM) of particle physics has a structure with three families of matter particles. Apart from their masses, these families are exact repetition of the first family. SM has no answer for the fermionic family replication. On the other hand, the large number of the fundamental particles and free parameters in the SM bring to mind that question: Is it really a basic theory? Currently, although SM is very compatible with experiments, it is not the final word for particle physics, but it can be considered as the low energy limit of a more fundamental theory. It is clear that theories beyond the SM (BSM) must be envisaged.

Compositeness is one of the BSM theories which is a reasonable candidate to be capable of answering these questions. In composite models, it is considered that there could be one more layer of matter constituents called preons and SM fermions are bound states of preons [1-8]. At the scale of preon binding energies new

Received by the editors: January 17, 2020; Accepted: February 03, 2020.
Key word and phrases: Doubly charged leptons, compositeness scale, electron-proton colliders, weak isospin.

interactions among leptons and quarks may emerge. If leptons and quarks have a composite structure, excited states should be observed. Spin and isospin-1/2 excited fermions are considered as lowest radial and orbital excited states. Excited leptons with weak isospin states $I_W = 0$ (singlet) and $I_W = 1/2$ (doublet) are studied widely in the literature [9- 25].

If we take into account the weak isospin invariance in the framework of compositeness, the weak isospin values can be extended to include the $I_W = 1$ (triplet) and $I_W = 3/2$ (quadruplet) multiplets. These exotic multiplets have new particles (excited leptonic states) with exotic charges $Q = \pm 2e$ and they are called doubly charged leptons [26]. If a signal for the doubly charged lepton is observed in the next generation of colliders, this will provide us pioneering information about the SM family repetition and flavor structure.

The experimental data coming from the Large Hadron Collider (LHC) is quite compatible with the SM and there is no new physics signal of ~ O (a few) TeV (by referring to the LHC energies). To go far beyond the scope of the LHC, designing for the installation of high energy and high luminosity colliders has become very important. Future Circular Collider (FCC) is a 100 TeV center-of-mass energy *pp* collider studied at CERN for the post-LHC era. It is an international project and supported by European Union within the Horizon 2020 Framework for Research and Innovation. The FCC's Conceptual Design Report (CDR) was completed in 2019 and published as four volumes [27-30]. The FCC is planned to be 4 times the LHC in size and bigger than the LHC energy about 7 times.

Another important post-LHC project is Super proton-proton Collider (SppC) project [31]. SppC is the Chinese analog of the FCC with the center-of-mass energy about 70 TeV. The CDR of the project which has two volumes was published in 2018 [32-33]. The first stage of the project will be an electron-positron collider called Circular Electron Positron Collider (CEPC) with a center-of-mass energy of 240 GeV. After this stage is completed, a *pp* collider of approximately 70 GeV in the same tunnel will go into operation.

Except from the compositeness doubly charged leptonic states are encountered in other BSM models, (for example in Type II seesaw mechanisms, some extensions of supersymmetric models, string inspired models etc.), too [34-44]. In the literature there are phenomenological studies for the doubly charged leptons at the LHC [45-54], at the future e^+e^- and $e\gamma$ colliders [55-58], and at the future lepton-proton colliders [59-61]. The first limits for the mass of doubly charged leptons in *ep* collisions obtained as like that, for $L_{int} > 10^4$ fb^{-1}, $M_L > 860$ (1280) GeV at $\sqrt{s} = 1.3$ (1.98) TeV in [59].

In this work, we give the effective lagrangians responsible for the gauge interactions of doubly charged leptons predicted by the extended weak isospin model and calculate the decay widths for different values of compositeness scale (Λ) in Section 2. In Section 3, we introduce the SppC based *ep* colliders. We give our analysis for the search potential of the SppC based *ep* colliders in Section 4 and then we conclude.

2. Doubly Charged Leptons In The Extended Weak Isospin Model

Long before the experimental verification of hadronic constituents (quarks and gluons), the strong isospin symmetry provided important information for understanding the patterns and properties of the hadron resonances. By analogy, the structure of possible fermionic resonances can be understood using the weak isospin (I_W) symmetry. In this way, the quantum numbers of possible excited fermionic states could be obtained without needing the dynamics of the preons explicitly. Since, right-handed SM fermions are in singlets ($I_W = 0$), left-handed SM fermions are in doublets ($I_W = 1/2$) and gauge bosons have $I_W = 0$ (for photon and gluon) or 1 (for $W^{\pm}$ and Z bosons); allowed weak isospin values for excited fermionic states can be $I_W \leq 3/2$. Basic principles of extended weak isospin model are discussed in [26]. In the extended weak isospin model, weak isospin multiplets are extended to $I_W =1$, 3/2. In these exotic multiplets doubly charged leptons with electric charge $Q=-2e$ appear in triplets ($I_W =1$) and in quadruplets ($I_W =3/2$). In Eq. 1 the form of these exotic multiplets are listed as

$$L_1 = \begin{pmatrix} L^0 \\ L^- \\ L^{--} \end{pmatrix}, \quad I_W = 1, \quad Y = -2$$

$$L_{3/2} = \begin{pmatrix} L^+ \\ L^0 \\ L^- \\ L^{--} \end{pmatrix}, I_W = 3/2, \quad Y = -1 \tag{1}$$

and similar for the antiparticles. Here, L can stand for any kind of lepton flavor, Y is the weak hypercharge. Since the weak hypercharge value for all gauge fields is Y=0, a given exotic multiplet couples through the gauge fields to a SM multiplet only with the same Y. Concerning the gauge invariance, the couplings of the doubly charged leptons to SM leptons and gauge bosons have to be of anomalous magnetic moment type. Therefore, the only possible coupling of doubly charged leptons to SM fermions, including both $I_W=1$ and $I_W=3/2$ multiplets, takes place via *W*-boson. The effective Lagrangians describing the gauge interactions of doubly charged leptons with ordinary leptons are given as

$$\mathcal{L}_{GM}^{(1)} = i\frac{gf_1}{\Lambda}\left(\bar{L}\sigma_{\mu\nu}\partial^{\nu}W^{\mu}\frac{1+\gamma_5}{2}l\right)+h.c. \quad (2)$$

$$\mathcal{L}_{GM}^{(3/2)} = i\frac{gf_3}{\Lambda}\left(\bar{L}\sigma_{\mu\nu}\partial^{\nu}W^{\mu}\frac{1-\gamma_5}{2}l\right)+h.c. \quad (3)$$

As seen in Eq. 2 (Eq. 3), $I_W=1$ ($I_W=3/2$) multiplet couples to SM right-handed (left-handed) lepton, because of the fact that a certain exotic multiplet can couple via gauge fields to a SM multiplet with the same value of *Y*. In Eq. 2 and 3, *g* is the *SU*(2) coupling constant and it is equals to $g = g_e/\sin\theta_W$ where $g_e = \sqrt{4\pi\alpha}$. f_1 and f_3 are new coupling constants related to effective interactions of $I_W=1$ and $I_W=3/2$ multiplets, and they are usually set to 1 in the literature. If we want to obtain their exact values we have to take into consideration the model for compositeness. Λ is the compositeness scale, and *L* and *l* stand for doubly charged lepton and SM lepton, respectively. $\sigma_{\mu\nu}$ is an antisymmetric tensor and it is equal to $\sigma_{\mu\nu} = i(\gamma_\mu\gamma_\nu - \gamma_\nu\gamma_\mu)/2$ where γ_μ being the Dirac matrices.

Since doubly charged leptons couple to the SM leptons only via the *W*-boson, the only decay mode is charged weak decay mode, so the branching ratio of the $L^{--}\to l^- W^-$ process is equals to one (BR(%)=100, in other words). Taking into account $f_1=f_3=f$, decay width values for the doubly charged leptons both for the Lagrangians $\mathcal{L}_{GM}^{(1)}$ and $\mathcal{L}_{GM}^{(3/2)}$ are the same. The decay width of the doubly charged lepton with respect to its mass (M_L) for $f_1=f_3=1$ is given in Table 1 for two different values of Λ.

Table 1. Total decay width of doubly charged lepton as a function of its mass for $\Lambda=M_L$ and Λ=5 TeV.

M_L(GeV)	Γ (GeV)	
	$\Lambda=M_L$	Λ=5 TeV
500	4.21	0.0042
1000	8.68	0.35
1500	13.10	1.17
2000	17.49	2.79
2500	21.89	5.47
3000	26.68	9.45
3500	30.66	15.02
4000	35.05	22.43

3. SppC Based *ep* Colliders

Construction of a linear electron accelerator tangential to the proton ring can give the opportunity to collide the electrons and protons. It should be emphasized here that the electron accelerator should be linear since it will be very difficult to reach high energies due to the synchrotron radiation in circular electron accelerators. The advantages and physics potential of the linac-ring type colliders are discussed in [62-63]. Hadron Electron Ring Accelerator (HERA), the only *ep* collider ever operated, has shown that *ep* colliders are competitive to *pp* and *ee* colliders and are very important for BSM physics research. The Large Hadron electron Collider (LHeC) would be the second *ep* collider with the center-of mass energies 1.3 and 1.98 TeV after the HERA [64-65]. Also FCC would have an *ep* option [27]. Recently, using the parameters of the well-known future linear electron accelerator projects, SppC-based various *ep* colliders proposed in [66]. The main parameters of four different options of the SppC-based *ep* colliders are given in Table 2.

Table 2. Main parameters of the SppC-based *ep* colliders. (*These values are obtained from* [66]).

E_e (TeV)	E_p (TeV)	$\sqrt{s}$ (TeV)	L_{ep} ($cm^{-2}s^{-1}$)
0.5	35.6	8.44	2.51×10^{31}
0.5	68	11.66	6.45×10^{31}
5	35.6	26.68	7.37×10^{30}
5	68	36.88	1.89×10^{31}

4. Analysis

Doubly charged leptons can be produced singly through the process $e^- p \to L^{--} X$ at *ep* colliders. The Feynman diagrams representing the related subprocess $e^- q(\bar{q}^{'}) \to L^{--} q^{'}(\bar{q})$ are given in Figure 1.

Figure 1. Feynman diagrams for the subprocess $e^- q(\bar{q}^{'}) \to L^{--} q^{'}(\bar{q})$.

For the sake of simplicity, we have considered only I_W=1 multiplet in our analysis. One of the authors of this paper has showed in [61] that single production cross section for I_W=3/2 multiplet differs slightly from I_W=1 multiplet at *ep* colliders. We implemented the doubly charged lepton interaction vertices in high-energy simulation programme CalcHEP [67-69] and used it for our calculations both for signal and background.

Total production cross section for the single production of doubly charged leptons ($e^- p \to L^{--} X$) at *ep* colliders with center-of-mass energies $\sqrt{s} = 8.44$ TeV and $\sqrt{s} = 26.68$ TeV for Λ=M_L and f_l=1 is shown in Figure 2. To obtain the total cross section we have used the CTEQ6L parton distribution function [70].

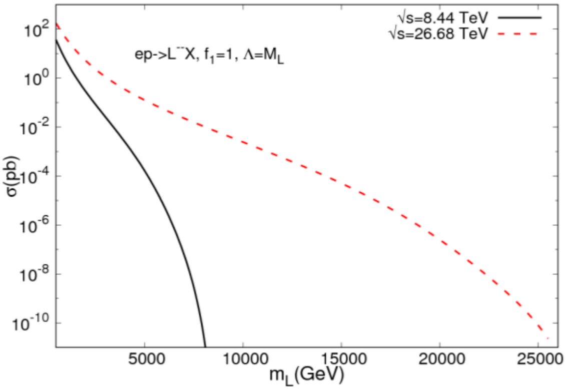


FIGURE 2. Total cross section for the single production of doubly charged leptons at two different SppC-based *ep* colliders.

After the decay of L^{--}, we deal with the $eq(\bar{q}^{'}) \rightarrow eW^{-}q^{'}(\bar{q})$ subprocess. Here we respect the lepton family number conservation. We apply the same generic cuts for the final state electron and jets as

$$p_T^{e,j} > 20\ GeV \tag{4}$$

By applying the generic cuts, we get the some kinematical distributions of the final state electron. There is no more cut on jets. We show normalized transverse momentum (p_T) and normalized pseudorapidity (η) distributions for $\sqrt{s} = 8.44$ TeV and $\sqrt{s} = 26.68$ TeV in Figures 3 and 4, respectively.

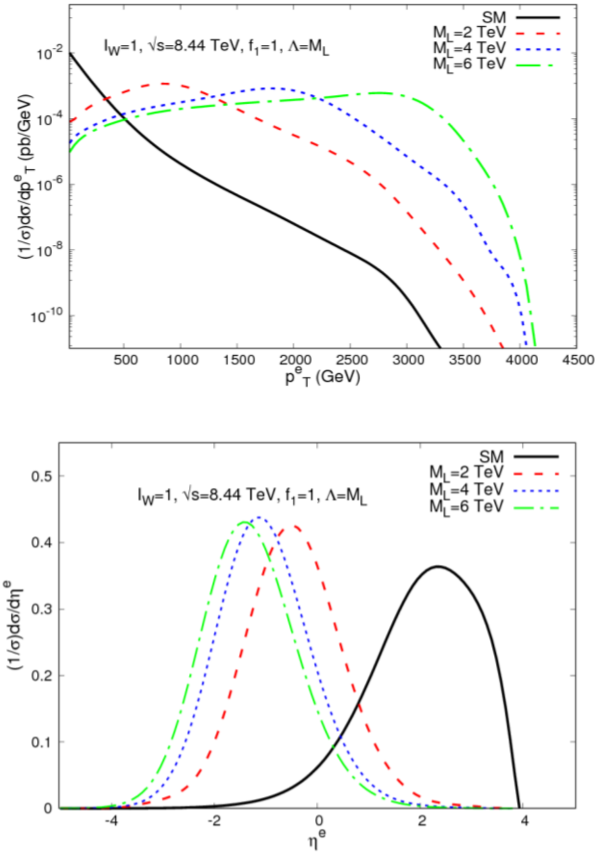


FIGURE 3. Normalized p_T and η distributions for the final state electron at $\sqrt{s}$ =8.44 TeV.

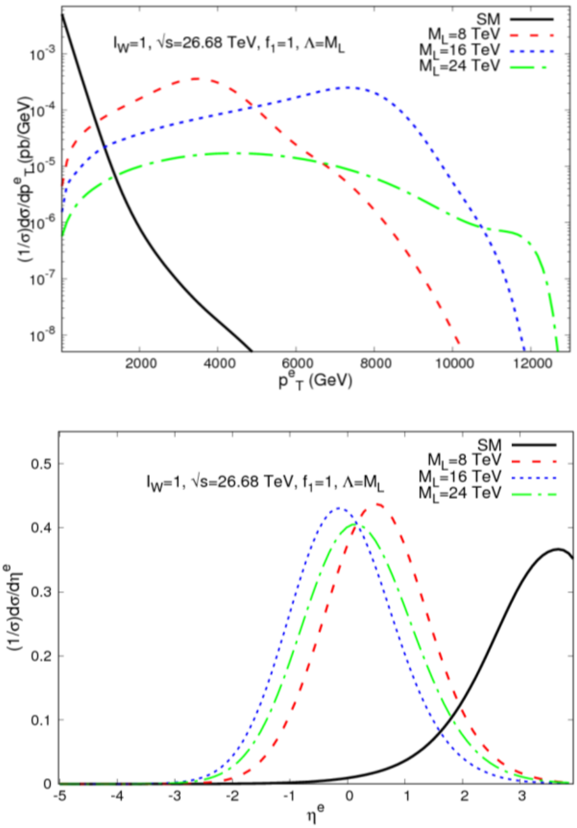


FIGURE 4. Normalized p_T and η distributions for the final state electron at $\sqrt{s}$ =26.68 TeV.

We obtain the discovery cuts by examining these kinematical distributions. We search for the areas which we largely remove the background but not affect the signal much. These discovery cuts are presented in Table 3.

Table 3. Discovery cuts for the doubly charged lepton production at the SppC-based *ep* colliders.

$\sqrt{s}$ (TeV)	p_T^e cut	η^e cut
8.44	$p_T^e > 320$ GeV	$-3.2 < \eta^e < 0.8$
26.68	$p_T^e > 870$ GeV	$-2.2 < \eta^e < 2$

We give the signal and background cross sections before and after the discovery cuts in Table 4 and 5 for $\sqrt{s} = 8.44$ TeV and $\sqrt{s} = 26.68$ TeV, respectively; and it is easily seen from these values that we have reached what we want. The signal cross sections show almost no change after applying the obtained discovery cuts.

Table 4. Signal and background cross sections before and after applying the discovery cuts for $\sqrt{s} = 8.44$ TeV

M_L (TeV)	σ_S (pb)		σ_B (pb)	
	Before cuts	After cuts	Before cuts	After cuts
2	1.21×10^{-1}	1.12×10^{-1}	15.39	0.34
4	1.38×10^{-3}	1.34×10^{-3}		
6	6.03×10^{-6}	5.88×10^{-6}		

Table 5. Signal and background cross sections before and after applying the discovery cuts for $\sqrt{s} = 26.68$ TeV

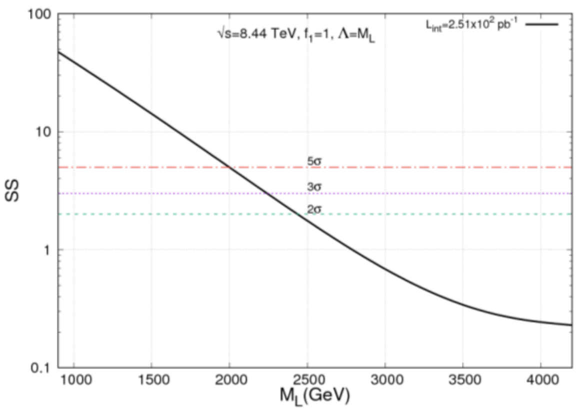
M_L (TeV)	σ_S (pb)		σ_B (pb)	
	Before cuts	After cuts	Before cuts	After cuts
8	4.90×10^{-3}	4.50×10^{-3}	60.48	0.105
16	1.32×10^{-5}	1.29×10^{-5}		
24	1.97×10^{-8}	1.91×10^{-8}		

We choose the hadronic decay mode of *W*-boson as $W \to 2j$. We define the statistical significance (*SS*) of the expected signal yield as

$$SS = \frac{|\sigma_{S+B} - \sigma_B|}{\sqrt{\sigma_B}} \sqrt{L_{\text{int}}} \tag{5}$$

where σ_{S+B} is the cross section due to the all contributions of SM and doubly charged lepton, and σ_B is the SM background cross section, respectively; L_{int} is the integrated luminosity of the collider. We obtain $L_{int,}$ by multiplying the average instantaneous luminosity of the collider given in Table 1 by the factor 10^7 which is the operating time of the collider for approximately 1 year.

In Figure 5, we show the *SS* - M_L plots for the SppC-based *ep* colliders, indicating the 2σ (exclusion), 3σ (observation), and 5σ (discovery) regions, respectively. In Table 6, we list the obtained mass limits for doubly charged leptons at the SppC-based *ep* colliders for f_l=1 and Λ=M_L, taking into account the criteria $SS \geq 2$, $SS \geq 3$ and $SS \geq 5$ which denote the 2σ, 3σ and 5σ limits, respectively.



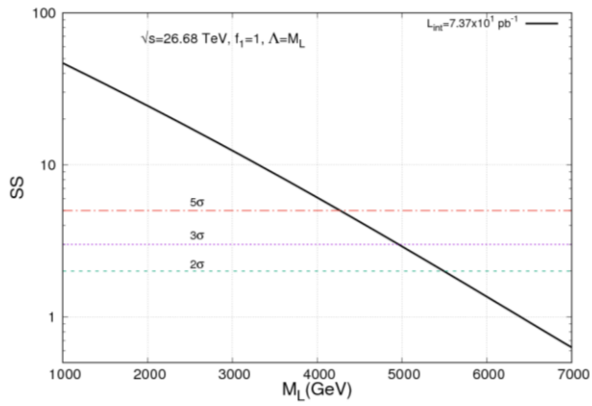


FIGURE 5. *SS* as a function of M_L for the SppC-based *ep* colliders.

Table 6. Mass limits for doubly charged leptons at the SppC based *ep* colliders for $\Lambda=M_L$ and $f_l=1$.

$\sqrt{s}$ (TeV)	L_{int} (pb^{-1})	2σ (Exclusion) (TeV)	3σ (Observation) (TeV)	5σ (Discovery) (TeV)
8.44	2.51×10^2	2.19	2.00	1.75
26.68	7.37×10^3	4.30	3.85	3.30

By using the same discovery cuts we plot the contour plots at Λ-M_L parameter space. We show our contour plots in Figure 6. From these figures we deduce the observation (3σ) limits for the Λ as $\Lambda\sim$ 2.6 (4))TeV for M_L=1.75 (3.30) TeV at $\sqrt{s}$ = 8.44 (26.68) TeV.

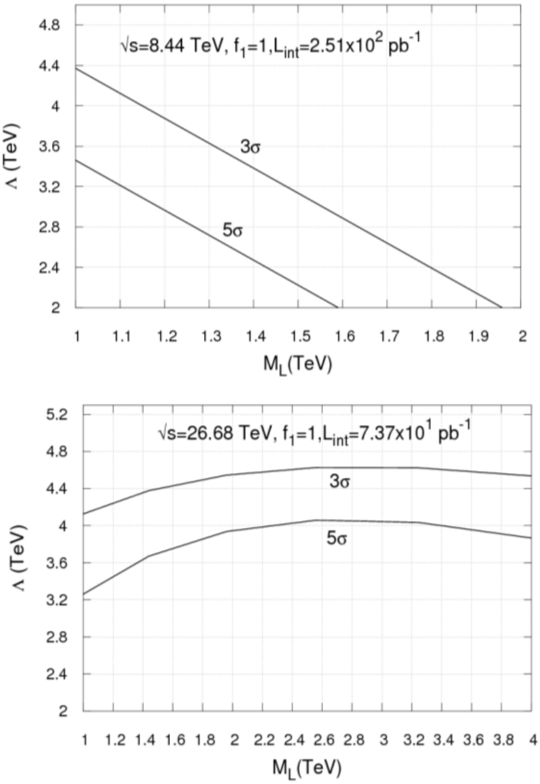


FIGURE 6. Contour plots at the Λ-M_L parameter space for the SppC-based *ep* colliders.

5. CONCLUSION

Using weak isospin invariance may help us to investigate the properties of possible fermionic resonances. Thus, a new perspective on compositeness is developed. In extended weak isospin model, the usual weak isospin multiplets are extended to higher weak isospin multiplets namely, I_W =1 (triplet) and I_W =3/2 (quadruplet) multiplets. The doubly charged leptons are predicted in these exotic multiplets. SppC-based *ep* colliders will give an excellent environment to search for the doubly charged leptons. Taking into account the gauge interactions of doubly charged leptons with SM leptons and applying the cuts obtained from kinematical distributions, we have provided 2σ, 3σ and 5σ mass limits as 2.19 (4.30) TeV, 2.00 (3.85) TeV, and 1.75 (3.30) TeV, respectively at the SppC-based *ep* colliders at $\sqrt{s}$

= 8.44 (26.68) TeV for Λ=M_L and f_l=1. Our results have showed that, SppC-based *ep* colliders can extend the limits for the doubly charged lepton mass nearly two times from those obtained from the *pp* colliders.

References

[1] Terazawa H., Chikashige Y., and Akama K., Unified Model of the Nambu-Jona-Lasino Type for all Elementary Particle Forces, Phys. Rev. D 15-2 (1977) 480-487.

[2] Ne'eman Y., Primitive Particle Model, Phys. Lett. 82B-1 (1979) 69-70.

[3] Terazawa H., Yasue M., Akama K., and Hayashi M., Observable Effects of the Possible Sub-structure of Leptons and Quarks, Phys. Lett. 112B 4-5 (1982) 387-392.

[4] Renard F. M., Excited Quarks and New Hadronic States, Il Nuovo Cimento A 77-1 (1983) 1-20.

[5] Eichten E. J., Lane K. D., and Peskin M. E., New Tests for Quark and Lepton Substructure, Phys. Rev. Lett. 50-11 (1983) 811-814.

[6] de Rujula A., Maiani L., and Petronzio R., Search for Excited Quarks, Phys. Lett. 140B 3-4 (1984) 253-258.

[7] Cabibbo N., Maiani L., and Srivastava Y. N., Anomalous Z Decays: Excited Leptons?, Phys. Lett. 139B 5-6 (1984) 459-463.

[8] Kühn J. and Zerwas P. M., Excited Quarks and Leptons, Phys. Lett. 147B 1-3 (1984) 189-196.

[9] Hagiwara K., Komamiya S., and Zeppenfeld D., Excited Lepton Production at LEP and HERA, Z. für Physik C 29-1 (1985) 115-122.

[10] Boudjema F., Djouadi A., and Kneur J. L., Excited Fermions at e^+e^- and eP Colliders, Z. für Physik C 57-3 (1993) 425-449.

[11] Cakir O., Yilmaz A., and Sultansoy S., Single Production of Excited Electrons at Future e^+e^-, ep and pp Colliders, Phys. Rev. D 70-7 (2004) 075011.

[12] Cakir O., Turk Cakir I., and Kirca Z., Single Production of Excited Neutrinos at Future e^+e^-, ep and pp Colliders Phys. Rev. D 70-7 (2004) 075017.

[13] Caliskan A., Kara S. O., and Ozansoy A., Excited Muon Searches at the FCC-Based Muon-Hadron Colliders, Adv. High Energy Phys. 2017 (2017) 1540243.

[14] Caliskan A., Excited Neutrino Search Potential of the FCC-Based Electron-Hadron Colliders, Adv. High Energy Phys. 2017 (2017) 4726050.

[15] Caliskan A. and Kara S. O., Single Production of the Excited Electrons at the Future FCC-Based Lepton-Hadron Colliders, Int. J. Mod. Phys. A 33-24 (2018) 1850141.

[16] Ginzburg I. F. and Ivanov D. Yu., Excited Leptons and Quarks at $\gamma\gamma$ / γe Colliders, Phys. Lett. B276 1-2 (1992) 214-218.

[17] Koksal M., Analysis of Excited Neutrinos at the CLIC, Int. J. Mod. Phys. A 29-24 (2014) 1450138.

[18] Ozansoy A. and Billur A. A., Search for Excited Electrons Through γγ Scattering, Phys. Rev. D 86-5 (2012) 055008.

[19] Kirca Z., Cakir O., and Aydin Z. Z., Production of Excited Electrons at TESLA and CLIC Based e gamma Colliders, Acta Phys. Polon. B 34-8 (2003) 4079.

[20] Eboli O. J., Lietti S. M., and Mathews P., Excited Leptons at the CERN Large Hadron Collider, Phys. Rev. D 65-7 (2002) 075003.

[21] Inan S. C., Exclusive Excited Leptons Search in Two Lepton Final States at the CERN LHC, Phys. Rev. D81-11 (2010) 115002.

[22] Cakir O., Leroy C., Mehdiyev R., and Belyaev A., Production and Decay of Excited Electrons at the LHC, Eur. Phys. J. C 32-2 (2004) s1-s17.

[23] Belyaev A., Leroy C., and Mehdiyev R., Production of Excited Neutrinos at the LHC, Eur. Phys. J. C 41-2 (2005) 1-10.

[24] Boos E., Volodgin A., Toback D., and Gaspard J., Prospects of Searching for Excited Leptons During Run II of the Fermilab Tevatron, Phys. Rev. D 66-1 (2002) 013011.

[25] Baur U., Spira M., and Zerwas P. M., Excited Quark and Lepton Production at Hadron Colliders, Phys. Rev. D 42-3 (1990) 815-824.

[26] Pancheri G. and Srivastava Y. N., Weak Isospin Spectroscopy of Excited Quarks and Leptons, Phys. Lett. 146B (1984) 87-94.

[27] Abada, A. et al, FCC Collaboration, FCC Physics Opportunities: Future Circular Collider Conceptual Design Report Volume 1, Eur. Phys. J. C79, no.6 (2019) 474.

[28] Abada, A. et al, FCC Collaboration, FCC-ee: The Lepton Collider: Future Circular Collider Conceptual Design Report Volume 2, Eur. Phys. J.ST 228 no.2, (2019) 261-623.

[29] Abada, A. et al, FCC Collaboration, FCC-hh: The Hadron Collider: Future Circular Collider Conceptual Design Report Volume 3, Eur. Phys. J.ST 228 no.4 (2019) 755-1107.

[30] Abada, A. et al, FCC Collaboration, HE-LHC: The High-Energy Large Hadron Collider: Future Circular Collider Conceptual Design Report Volume 4, Eur.Phys.J.ST 228 no.5 (2019) 1109-1382.

[31] Su F., Gao J., Xiao M., Wang D., Wang Y-W., Bai S., Bian T-J., Method Study of Parameter Choice for a Circular Proton-Proton Collider Chin. Phys. C 40-1 (2016) 017001.

[32] CEPC Study Group, "CEPC Conceptual Design Report: Volume 1 - Accelerator", Conceptual Design Report, IHEP-CEPC-DR-2018-01, IHEP-AC-2018-01, arXiv preprint: 1809.00285(2018).

[33] CEPC Study Group, "CEPC Conceptual Design Report: Volume 2 - Physics & Detector", Conceptual Design Report, HEP-CEPC-DR-2018-02, IHEP-EP-2018-01, IHEP-TH-2018-01, arXiv preprint: 1811.10545 (2018)

[34] Chua C. K. and Law S. S. C., Phenomenological Constraints on Minimally Coupled Exotic Lepton Triplets, Phys. Rev D 83 (2011) 055010.

[35] Foot R., Lew H., He X. G., and Joshi G. C., Seesaw Neutrino Masses Induced by a Triplet of Leptons, Zür. Phys. C 44 (1989) 441-444.

[36] Kumericki K., Picek I., and Radovcic B., Exotic Seesaw-Motivated Heavy Leptons at the LHC, Phys. Rev. D 84 (2011) 093002.

[37] Demir D. A., Frank M., Huitu K., Kumar Rai S., and Turan I., Signals of Doubly-Charged Higgsinos at the CERN Large Hadron Collider, Phys. Rev. D 78 (2008) 035013.

[38] Franceschini M. and Mohapatra R., Radiatively Induced Type II Seesaw Models and Vectorlike 5/3 Charge Quarks, Phys. Rev. D 89-5 (2014) 055013.

[39] Dutta B., Mohapatra R. N., and Muller D. J., The Signature at the Tevatron for the Light Doubly Charged Higgsino of the Supersymmetric Left-Right Model, Phys. Rev. D 60 (1999) 095005.

[40] Chacko Z. and Mohapatra R. N., Supersymmetric Left-Right Model and Light Doubly Charged Higgs Bosons and Higgsinos, Phys. Rev. D 58 (1998) 015003.

[41] Frank M., Doubly Charged Higgsino Mediated Lepton Flavor Violating Decays, Phys. Rev. D 62 (2000) 053004.

[42] Cirelli M., Fornengo N., and Strumia A., Minimal Dark Matter, Nucl. Phys. B 753 (2006) 178-194.

[43] del Aguila F., de Blas J., and Perez-Victoria M., Effects of New Leptons in Electroweak Precision Data, Phys. Rev. D 78 (2008) 013010.

[44] Cvetic M., Halverson J., and Langacker P., Implications of String Constraints for Exotic Matter and Z' s Beyond the Standart Model, Journal of High Energy Phys. 1111 (2011) 058.

[45] Delgado A., Garcia Cely C., Han T., and Wang Z., Phenomenology of Lepton Triplet, Phys. Rev. D 84 (2011) 073007.

[46] Biondini S., Panella O., Pancheri G., Srivastava Y. N., and Fano L., Phenomenology of Excited Doubly Charged Heavy Leptons at the LHC, Phys. Rev. D 85 (2012) 095018.

[47] Alloul A., Frank M., Fuks B., and de Traubenberg M. R., Doubly-Charged Particles at the Large Hadron Collider, Phys. Rev. D 88 (2013) 075004.

[48] Leonardi R., Panella O., and Fano L., Doubly Charged Heavy Leptons at LHC via Contact Interactions, Phys. Rev. D 90-3 (2014) 035001.

[49] You Y., Chong-Xing Y., and Yun X., Pair Production of the Doubly Charged Leptons via Electroweak Vector Boson Fusion at the Large Hadron Collider, Chin. Phys. Lett. 31 (2014) 021201.

[50] Ma T., Zhang B., and Cacciapaglia G., Triplet with a Doubly-Charged Lepton at the LHC, Phys. Rev. D 89-1 015020 (2014); Doubly Charged Lepton from an Exotic Doublet at the LHC, Phys. Rev. D 89-9 (2014) 093022.

[51] Yu Y., Yue C-X., and Yang S., Signatures of the Quintuplet Leptons at the LHC, Phys. Rev. D 91-9 (2015) 093003.

[52] Okada H. and Yagyu K., Three-loop Neutrino Mass Model with Doubly Charged Particles from Isodoublets, Phys. Rev. D 93-1 (2016) 013004.

[53] Chen C-H. and Nomura T., Bounds on LFV Higgs Decays in a Vector-like Lepton Model and Searching for Doubly Charged Leptons at the LHC, Eur. Phys. J. C 76 (2016) 353.

[54] Leonardi R., Alunni L., Romeo F., Fano L., and Panella O., Hunting for Heavy Composite Majorana Neutrinos at the LHC, Eur. Phys. J. C 76 -11 (2016) 593.

[55] Zeng Q-G., Ji L., and Yang S., Pair Production of the Doubly Charged Leptons Associated with a Gauge Boson γ or Z in e^+e^- and γγ Collisions at Future Linear Colliders, Commun. Theor. Phys. 63-3 (2015) 331-339.

[56] Biondini S. and Panella O., Exotic Leptons at Future Linear Colliders, Phys. Rev. D 92-1 (2012) 015023.

[57] Guo Y-C., Yue C-X., Lui Z-C, The Signatures of Doubly Charged Leptons in Future Linear Colliders, J. Phys. G. Nucl. Part. Phys. 44 (2017) 085004.

[58] Zeng Q-G., Production of the Doubly Charged Leptons at the ILC, Eur. Phys. Lett. 111 (2105) 21003.

[59] Yu Y., Guo Y-C., Lui Z-C., Fan W-J., Mei Y., and Zhang J., The Signatures of Doubly Charged Leptons at LHeC, J. Phys. G. Nucl. Part. Phys. 45 (2018) 125003.

[60] Ozansoy A., Investigating Doubly Charged Leptons at the Future Energy Frontier Muon-proton Colliders, Communications Fac. Sci.Univ. Ank. Series A2-A3, 61,1 (2019) 111-128.

[61] Ozansoy A., Doubly Charged Lepton Search Potential of the FCC-Based Energy Frontier Electron-Proton Colliders, https://arxiv.org/abs/1912.07351 (2019).

[62] Sultansoy S., Four ways to Tev scale, Turkish Journal of Physics 22, no:1 (1998) 575-594.

[63] Sultansoy S., Linac-ring type colliders: second way to TeV scale, The European Phys. Journal 33, supplement 1 (2004) s1064-1066.

[64] Abelleira Fernandez J. L. et al. (LHeC Study Group), A Large Hadron Electron Collider at CERN, Journal of Phys. G 39 (2012) 075001.

[65] Bruening O. and Klein M., The Large Hadron Electron Collider, Mod. Phys. Lett. A 28 - 16 (2013) 1330011.

[66] Canbay A. C., Kaya U., Ketenoglu B., Oner B. B., and Sultansoy S., SppC based energy frontier lepton-proton colliders:luminosity and physics, Adv. in High Energy Phys. 2017 (2017) 4021493.

[67] Belyaev A., Christensen N. D., and Pukhov A., CalcHEP 3.4 for Collider Physics Within and Beyond the Standard Model, Computer Phys. Commun. 184-7 (2013) 1729-1769.

[68] Pukhov A., CalcHEP 2.3: MSSM, Structure Functions, Event Generation, Batchs, and Generation of Matrix Elements for other Packages, (2004) https://arxiv.org/abs/hep-ph/0412191.

[69] Pukhov A., Boos E., Dubinin M., Edneral V., Ilyin V., Kovalenko D., Kryukov A., Savrin V., Shichanin S., and Semenov A., CompHEP- a Package for Evaluation of Feynman Diagrams and Integration Over Multi-particle Phase Space. User's Manual for Version 33, (1999) https://arxiv.org/abs/hep-ph/9908288.

[70] Stump D., Huston J., Pumplin J., Tung W-K., Lai H. L., Kuhlmann S., and Owens J.F, Inclusive jet production, parton distributions and the search for new physics, JHEP 0310 (2003) 046.

Current Address: A. OZANSOY: Ankara University, Faculty of Sciences, Department of Physics, Ankara, TURKEY
E-mail: aozansoy@science.ankara.edu.tr
Orcid ID: https://orcid.org/0000-0002-9042-1372

Current Address: O. ALBAYRAK: Ankara University, Faculty of Sciences, Department of Physics, Ankara, TURKEY
E-mail: ouzhn06@hotmail.com
Orcid ID: https://orcid.org/0000-0002-4541-4385