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Linac-ring type colliders: Second way to TeV scale

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Abstract. Main parameters and the physics search potentials of the linac-ring type lepton-hadron and photon-hadron colliders are discussed. The THERA (TESLA on HERA), "NLC"-LHC and "CLIC"-VLHC proposals are considered.

1 Introduction

An exploration of (multi-)TeV scale at constituent level is the main goal of High Energy Physics in the foreseen future. At the end of the last centure, four ways to TeV scale, namely, ring type hadron machines, linear electron-positron machines, ring type muon colliders and linac-ring type lepton-hadron colliders were discussed (see [1] and references therein). Today, we deal with following situation:

– Hadron colliders. The LHC with 14 TeV center-of-mass energy will start hopefully in 2007 and a hundred TeV energy VLHC is under consideration.
– Linear colliders. The CLIC is the sole machine with more than 1 TeV energy, and 3 TeV center-of-mass energy is considered as third stage.
– Muon colliders. After the boom in 1990's, main activity is transferred to the ν-factory options.
– Lepton-hadron colliders. The sole realistic way to (multi-)TeV scale is represented by linac-ring type machines.

Therefore, as the second way to (multi-)TeV scale, linac-ring type lepton-hadron colliders require more attention of the HEP community. Referring to reviews [1-4] for more details of these machines, as well as their additional γp, eA, γA and FEL γA options, we present here non-conventional approach to future energy frontiers for HEP. It may be well possible that, instead of constructing linear e^+e^- colliders in the first stage, more attention must be paid to realizing linac-ring type ep colliders with the same electron beam energy (see Table 1).

2 Linac-ring type colliders

Linac-ring type colliders were proposed more than thirty years ago [5]. Starting from the 1980's, this idea has been revisited with the purposes of achieving high luminosities at particle factories [6-11] and high energies at lepton-hadron and photon-hadron collisions [1-4]. In the last three years:

– THERA with $\sqrt{s} = 1 \div 1.6$ TeV and $L \sim 10^{31}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ had been included in the TESLA TDR [12] as the most advanced proposal among linac-ring type ep colliders
– The idea of QCD Explorer (70 GeV "CLIC" on LHC) was proposed at the informal meeting held at CERN to discuss the possibility to intersect CLIC with LHC last summer [13]
– A comparison of e-linac and e-ring versions of the LHC and VLHC based ep colliders is performed in [14] and the linac options are shown to be preferable.

3 Linac-ring ep vs. linear e^+e^-

Even a quick glance at Table 1 is enough to be sure that linac-ring ep colliders may be as important as linear e^+e^- colliders. Although the luminosity of the previous is less than that of the second by an order, the center-of-mass energy is an order higher. Considering the Standard Model, if linear lepton colliders are important for investigation of Higgs mechanism responsible for electroweak symmetry breaking, then linac-ring ep colliders have the same importance for investigation of the region of small x_g at high Q^2 which is crucial for QCD. As for the BSM physics, the linac-ring ep potential is at least comparable to the potential of corresponding lepton collider. Although physics potential of the former is not investigated as well as that of the last, the statement of the previous sentence can be easily supported by rescaling of the conclusions presented in [15] where LHC, LEP-LHC and CLIC are compared. All that mentioned so far, clearly indicates that linac-ring ep colliders have a unique potential both for the SM and BSM physics research. Moreover, additional γp, eA, γA and FEL γA options enforce this potential.

Earlier, the idea of using high energy photon beams, obtained by Compton backscattering of laser light off a beam of high energy electrons, was considered for γe and $\gamma\gamma$ colliders (see [16] and references therein). Then the same method was proposed for constructing γp colliders on the base of linac-ring type ep machines [17]. Rough estimations of the main parameters of ep and γp collisions are given in [18]. The dependence of these parameters on the distance z between conversion region and collision point was analyzed in [19], where some design problems were considered. It should be mentioned that γ options are unique features of linac-ring type lepton-hadron colliders.

The luminosity estimations presented in the Table 1 are rather conservative and can be improved further by applying advanced methods such as "dynamic focusing" proposed in [20]. We believe that further developments will follow provided that the subject is taken seriously by accelerator physics community.

4 THERA (TESLA-HERA) and QCD explorer

Three versions of TESLA-HERA based ep collisions are considered in the TESLA TDR [12]: $E_e = 250$ GeV and $E_p = 1$ TeV with $L = 0.4 \times 10^{31}\text{cm}^{-2}s^{-1}$, $E_e = E_p = 500$ GeV with $L = 2.5 \times 10^{31}\text{cm}^{-2}s^{-1}$ and $E_e = E_p = 800$ GeV with $L = 1.6 \times 10^{31}\text{cm}^{-2}s^{-1}$. In order to achieve sufficiently high luminosity at QCD Explorer (QCD-E with $\sqrt{s} = 1.4$ TeV) modification of CLIC and/or LHC beams is needed. For example, super-bunch option of the LHC will give opportunity to reach $L \sim 10^{31}\text{cm}^{-2}s^{-1}$ with nominal CLIC parameters [21].

In principle, THERA and QCD-E will extend the HERA kinematics region by an order in both Q^2 and x and, therefore, the parton saturation regime can be achieved. The SM physics topics (structure functions, hadronic final states, high Q^2 and small x_g region etc) which can be investigated at THERA are presented in [12]. It seems that QCD-E will provide better kinematics for these topics, however detailed studies are needed. The BSM search capacity will be defined by future results from the LHC. For example, if the first family leptoquarks and/or leptogluons have masses less than 1 TeV, they will be produced copiously. In general, the physics search program of THERA and QCD-E is a direct extension of the HERA search program.

The γp option essentially enlarges the THERA potential (it seems that this option is not promising for QCD-E due to low energy of electron beam). This option will give a unique opportunity to investigate small x_g region due to registration of charmed and beauty hadrons produced via $\gamma g \to Q\bar{Q}$ sub-process. Concerning the BSM physics one can mention resonant production of the first family excited quarks (if their masses are less than 1 TeV), associate production of gaugino and first family squarks (if the sum of their masses is less than 0.5 TeV), resonant production of t-quarks due to anomalous interactions etc.

The eA and γA options of THERA, as well as eA option of QCD-E will give a unique opportunity to investigate small x_g region in nuclear medium and allow the exploration of a non-DGLAP hard dynamics in the kinematics where α_s is small while the fluctuations of parton densities are large [22].

Colliding of TESLA ("CLIC") FEL beam with nuclei from HERA (LHC) may give a unique possibility to investigate "old" nuclear phenomena in rather unusual conditions. The main idea is very simple [1, 23]: ultra-relativistic ions will see laser photons with energy ω_0 as a beam of photons with energy $2\gamma_A\omega_0$, where γ_A is the Lorentz factor of the ion beam. The huge number of expected events and small energy spread of colliding beams will give opportunity to scan an interesting region with keV accuracy.

5 "NLC"-LHC

The center-of-mass energies which will be achieved at different options of this machine [24] are an order larger than those at HERA and ~ 3 times larger than the energy region of THERA and LEP-LHC. Certainly, $L_{ep} \simeq 10^{32}\text{cm}^{-2}s^{-1}$ is quite realistic estimation for "TESLA"-LHC (the factor 7 comparing to THERA is straightforward due to larger value of γ_p at LHC). For "CLIC"-LHC, $L_{ep} \simeq 10^{31}\text{cm}^{-2}s^{-1}$ can be achieved with super-bunch structure of LHC and nominal parameters of 0.5 TeV CLIC (higher luminosity will require a modification of CLIC parameters, too). The ep option, which will extend both the Q^2-range and x-range by more than two orders of magnitude comparing to those explored by HERA, has a strong potential for both SM and BSM research. Concerning the γp option, the advantage in spectrum of back-scattered photons and sufficiently high luminosity ($L_{\gamma p} > 10^{31}\text{cm}^{-2}s^{-1}$) will clearly manifest itself in a search for different phenomena. Rough estimations [1, 2] show that the total capacity of ep and γp options for direct BSM physics (SUSY, compositness etc) research essentially exceeds that of a 0.5 TeV linear collider.

In the case of LHC nucleus beam IBS effects in main ring are not crucial because of larger value of γ_A. The main principal limitation for heavy nuclei coming from beam-beam tune shift may be weakened using flat beams at collision point. Rough estimations show that $L_{eA} \cdot A > 10^{31}\text{cm}^{-2}s^{-1}$ can be achieved at least for light and medium nuclei. For γA option, limitation on luminosity due to beam-beam tune shift is removed in the scheme with deflection of electron beam after conversion [19] and sufficiently high luminosity can be achieved for heavy nuclei, too. Certainly, nuclei options of "NLC"-LHC will bring out great opportunities for QCD and nuclear physics research. For example, γA option will give an opportunity to investigate formation of the quark-gluon plasma at very high temperatures but relatively low nuclear density (according to VMD, proposed machine will be at the same time ρ-nucleus collider).

Due to a larger γ_A at LHC the requirement on wavelength of the FEL photons is weaker than in the case of TESLA-HERA based FEL γA collider. Therefore, the possibility of constructing a special FEL for this option may be a matter of interest. In any case the realization of FEL γA colliders depends on the interest of "traditional" nuclear physics community.

6 "CLIC"-VLHC

There are a number of papers devoted to possible *ep* colliders based on VLHC [14, 25, 26]. Two *e*-ring type options are evaluated: *ep* collisions in VLHC booster [25, 26] and *ep* collisions in VLHC main ring [25]. The first option is not a matter of interest because of LEP-LHC and THERA covering the same energy region. For the second option, where the construction of 180 GeV *e*-ring in the VLHC tunnel is proposed, there are a number of objections and the most important one is following: instead of constructing a multi-hundred *km* *e*-ring it is more wise to construct a few *km* *e*-linac with the same parameters [14].

Concerning high energy frontiers, even 1 TeV *e*-linac ("TESLA", "NLC/JLC") will provide $\sqrt{s}_{ep} = 20$ TeV, whereas 3 (5) TeV CLIC corresponds to $\sqrt{s}_{ep} = 34$ (45) TeV. Taking in mind THERA estimations one can expect $L_{ep} \simeq 10^{33}\text{cm}^{-2}s^{-1}$ for "TESLA"-VLHC, whereas $L_{ep} \simeq 10^{32}\text{cm}^{-2}s^{-1}$ is rather conservative estimation for "CLIC"-VLHC. Let me remind that γp option will provide almost the same center-of-mass energy and luminosity as *ep* option. Obviously, Linac-VLHC based *ep*, γp, *eA* and γA colliders will give opportunity to investigate a lot of particle and nuclear physics topics in a best manner.

Table 1. Energy frontiers

Colliders	Hadron	Lepton	Lepton-Hadron
1990's	Tevatron	SLC/LEP	HERA
$\sqrt{s}$, TeV	2	0.1/0.2	0.3
L, 10^{31} cm^{-2}s^{-1}	1	0.1/1	1
2010's	LHC	"NLC"	"NLC"-LHC
$\sqrt{s}$, TeV	14	0.5	3.7
L, 10^{31} cm^{-2}s^{-1}	10^3	10^3	$1 \div 10$
2020's	VLHC	CLIC	"CLIC"-VLHC
$\sqrt{s}$, TeV	200	3	34
L, 10^{31} cm^{-2}s^{-1}	10^3	10^3	$10 \div 100$

7 Conclusion

The importance of linac-ring type ep colliders was emphasized by Professor B. Wiik at Europhysics HEP Conference in 1993 [27]. Following previous article [28], he argued TESLA type linear accelerator to be used as linac. The argument is still valid for LHC-based *ep* collider. As for VLHC-based *ep* collider, CLIC type linear accelerator seems to be advantageous, since the energy of TESLA of reasonable size is less than 1 TeV for the time being.

At the first glance, our way of arguing and conclusions seem to be a bit unusual. However, it might happen that LHC results will support this approach. Therefore, linac-ring type lepton-hadron and photon-hadron colliders must be taken into account as seriously as linear lepton and photon colliders.

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References

1. S. Sultansoy: Four Ways to TeV Scale, Turk. J. Phys. **22**, 575 (1998); hep-ex/0007043
2. R. Brinkmann et al.: DESY-97-239 (1997), physics/9712023
3. S. Sultansoy: DESY-99-159 (1999), hep-ph/9911417
4. S. Sultansoy et al.: hep-ex/0106082
5. P.L. Csonka and J. Rees: Nucl. Instum. Meth. **96**, 149 (1971)
6. P. Grosse-Wiesmann: Nucl. Instrum. Meth. A **274**, 21 (1989); CERN-PPE 91–96 (1991)
7. P. Grosse-Wiesmann et al.: CERN-PPE/90-113 (1990)
8. S. Sultansoy: Turk. J. Phys. **17**, 591 (1993); ibid. **19**, 789 (1995)
9. D.B. Cline: UCLA-CAA-0131-7-96 (1996)
10. A.K. Ciftci et al.: Turk. J. Phys. **24**, 747 (2000)
11. A.K. Ciftci et al.: hep-ex/0201044
12. H. Abramovitz et al.: in TESLA TDR, DESY-2001-011, ECFA-2001-209 (2001); A.K. Ciftci, S. Sultansoy, and O. Yavas: Nucl. Instr. Meth. A **472**, 72 (2001); The THERA Book, DESY-LC-REV-2001-062; www.ifh.de/thera
13. O. Cakir, S.A. Cetin, A. De Roeck, G. Guignard, D. Schulte, I. Wilson, and S. Sultansoy: Informal Meeting on CLIC-LHC Interface, 23 August 2002, CERN
14. Y. Islamzade, H. Karadeniz, and S. Sultansoy: hep-ex/0207013; hep-ex/0204034
15. U. Amaldi: Proc. of the Workshop on Physics at Future Accelerators, CERN Yellow Report 87–07, vol. 1, p. 323 (1987)
16. V.I. Telnov: Nucl. Instr. Meth. A **294**, 72 (1990)
17. S.I. Alekhin et al.: Int. J. Mod. Phys. A **6**, 21 (1991)
18. S.F. Sultanov: IC/89/409, Trieste (1989)
19. A.K. Ciftci et al.: Nucl. Instr. Meth. A **365**, 317 (1995)
20. R. Brinkmann and M. Dohlus: DESY-M-95-11 (1995); R. Brinkmann: Turk. J. Phys. **22**, 661 (1998)
21. D. Schulte and F. Zimmermann: QCD Explorer Based on LHC and CLIC, in preparation
22. L. Frankfrut and M. Strikman: Nucl. Phys. Proc. Suppl. **79**, 671 (1999)
23. H. Aktas et al.: Nucl. Instr. Meth. A **428**, 271 (1999)
24. O. Yavas, A.K. Ciftci and S. Sultansoy: Proc. of the 7-th European Particle Accelerator Conference (26–30 Jun 2000, Vienna, Austria), p. 391
25. J. Norem and T. Sen: ANL-HEP-PR-99-103, FERMILAB-PUB-99/347 (1999)
26. I. Ben-Zvi et al.: in eProceedings of Snowmass 2001, eConf C010630, SLAC-R-599
27. B. Wiik: Recent Developments in Accelerators, Proc. of the International Europhysics Conference on High Energy Physics (22–28 July 1993, Marseille, France), p. 739
28. M. Tigner, B. Wiik, and F. Willeke: Proc. of the 1991 IEEE Particle Accelerator Conference, vol. 5, p. 2910