THE POTENTIAL OF THE LINAC-RING TYPE COLLIDERS FOR
PARTICLE AND NUCLEAR PHYSICS

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Abstract

Linac-ring type colliders will open new windows for both energy frontier and particle factories. Concerning the first direction, these machines seem to be a sole way to TeV scale in lepton-hadron collision at constituent level. An essential advantage of the linac-ring type lepton-hadron colliders is the possibility of the construction of γp, γA and FELγ-A colliders based on them. Today, eRHIC, THERA (TESLA on HERA) and Linac*LHC can be considered as realistic candidates for future lepton-hadron and photon hadron colliders. When it comes to factories, one can reach essentially higher luminosities comparing to standard ring-ring type machines. For example, L=10^{34} cm^{-2}s^{-1} can be achieved for phi and charm-tau factories. In this presentation we briefly discuss the parameters and physics search potential of the linac-ring type machines.

1 INTRODUCTION

There are two well-known ways to reach TeV scale c.m. energies at constituent level: the ring-ring type proton-proton colliders and the linear e^+e^- colliders (including γe and γγ options [1]). Recently two more methods have been added to the list, namely: the ring type μ^+μ^- colliders [2] and the linac-ring type ep and eA colliders [3] (including γp, γA and FELγA options [4-6]).

The investigation of physics phenomena at extreme small x but sufficiently high Q^2 is very important for understanding the nature of strong interactions at all levels from nucleus to partons. At the same time, the results from lepton-hadron collidres are necessary for adequate interpretation of physics at future hadron colliders. Today, linac-ring type ep machines and additional options based on them seem to be the main way to TeV scale in lepton-hadron and photon-hadron collisions.

On the other hand, the idea of colliding of the electron beam from a linac with the positron beam stored in a ring is widely discussed during the last decade in the context of high luminosity particle factories, namely, B factory, φ factory, c-τ factory etc.

2 THERA BASED COLLIDERS

The opportunity to collide electron and photon beams from TESLA with proton and nucleus beams in HERA were taken into account by choosing the direction of TESLA tangential to HERA [7].

Main parameters of three possible options for THERA based ep collider are presented in Table 1.

| Option  | Option  | Option  |
|---------|---------|---------|
| E_e, TeV | 0.25    | 0.5     | 0.8    |
| E_p, TeV | 1.0     | 0.5     | 0.8    |
| √s, TeV | 1.0     | 1.0     | 1.6    |
| L,10^{33} cm^{-2}s^{-1} | 0.4 | 2.5 | 1.6 |

A brief account of some SM physics topics (structure functions, hadronic final states, high Q^2 region etc.) is presented below [7]:
- The extension of kinematic range down to x~10^{-6} allows access to the high parton-density domain and its detailed exploration in the deep-inelastic regime.
- The measurement of proton structure functions at THERA will be essential for determining quark and gluon distributions in the proton in an unexplored kinematic region.
- The study of forward-going jets at THERA is expected to reveal the mechanism for the evolution of QCD radiation at low x.
- The total cross sections for charm and beauty production are expected to increase by factors of three and five, respectively, as compared to HERA.
- THERA will operate beyond the electroweak unification scale and is thus a truly “electroweak interaction machine”.
- THERA will probe physics beyond the Standard Model.

Referring for details to [4] and [8] let us note that luminosity of γp collisions is approximately one half of the luminosity of ep collisions (photon beam is obtained due to Compton backscattering of laser beam on electron beam from TESLA). A partial list of physics goals of THERA based γp collider is following [9,10]:

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3 LinacxLHC Based Colliders

The center of mass energies which will be achieved at different options of this machine are an order larger than those at HERA and ~3 times larger than the energy region of THERA and LEP*+LHC. In principle, luminosity values are ~7 times higher than those of corresponding options of HERA complex due to higher energy of protons.

Center of mass energy and luminosity for ep option are $\sqrt{s} = 5.29$ TeV and $L_{ep} = 10^{32}$ cm$^{-2}$s$^{-1}$, respectively; and additional factor of 3-4 can be provided by the “dynamic” focusing scheme [14]. A further increase will require cooling at injector stages. This machine, which will extend both the $Q^2$-range and x-range by more than two order of magnitude comparing to those explored by HERA, has a strong potential for both SM and BSM research. Few examples are: the discovery limit for the first generation leptoquarks is $m = 3$ TeV; the discovery limit for SUSY particles is $m_f + m_{\tilde{g}} = 1.5$ TeV and covers all six SUGRA points, which are used for SUSY analyses at LHC [15]; excited electron will be copiously produced up to $m_{e^*} = 3.5$ TeV etc.

In the case of $\gamma p$ option, the advantage in spectrum of backscattered photons and sufficiently high luminosity (for details see [4,13]), $L_{ep} = 10^{32}$ cm$^{-2}$s$^{-1}$ at $z = 0$, will clearly manifest itself in searching of different phenomena.

The physics search potential of $\gamma p$ colliders is reviewed in [9]. The $\gamma p$ option will essentially enlarge the capacity of the Linac*LHC complex. For example, thousands of di-jets with $p_t > 500$ GeV and hundred thousands of single W bosons will be produced, hundred millions of $h\bar{b}$ and $c\bar{c}$ pairs will give opportunity to explore the region of extremely small $x_g (~10^{-6}-10^{-7})$ etc. Concerning the BSM physics:

- linac-ring type $\gamma p$ colliders are ideal are machines for $u^*$, $d^*$, and $Z_8$ search (the discovery limits are $m_{u^*} = 5$ TeV, $m_{d^*} = 4$ TeV, $m_{Z_8} = 4$ TeV)
- the fourth SM family quarks (the discovery limits are $m_{u_4} = 1$ TeV and $m_{d_4} = 0.8$ TeV) will be copiously produced, since their masses are predicted to be in the region 300-700 GeV with preferable value $m_{u_4} = m_{d_4} = 640$ GeV (see [16] and references therein)
- because of parameter inflation, namely more than 160 observable free parameters in the three family MSSM (see [17] and references therein), SUSY should be realized at preonc level. Nevertheless, the discovery limits for different channels are: $m_{\tilde{W}} + m_{\tilde{q}} = 1.8$ TeV, $m_{\tilde{g}} + m_{\tilde{q}} = 1.6$ TeV, $m_{\tilde{g}} + m_{\tilde{q}} = 0.5$ TeV, $m_{\tilde{g}} + m_{\tilde{q}} = 1.5$ TeV.
In the case of LHC nucleus beam, IBS effects in main ring are not crucial because of large value of $\gamma_A$. 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 $L_{cA}=10^{31} cm^{-2}s^{-1}$ can be achieved at least for light and medium nuclei [11]. For electron-carbon and electron-Pb collisions, one has $L_{eC}=10^{31} cm^{-2}s^{-1}$ and $L_{ePb}=10^{30} cm^{-2}s^{-1}$, correspondingly. This machine will extend both the $Q^2$-range and $x$-range by more than two orders of magnitude with respect to the region, which can be explored by HERA based eA collider.

In the case of $\gamma A$ collider, limitation on luminosity due to beam-beam tune shift is removed in the scheme with deflection of electron beam after conversion [4]. As it is shown in [13], $L_{cC}=0.8 \times 10^{31} cm^{-2}s^{-1}$ and $L_{cPb}=10^{30} cm^{-2}s^{-1}$ at $z=5m$. Center of mass energy of Linac*LHC based $\gamma A$ collider corresponds to $E_{cm}=2.1 GeV$. Proposed set of parameters can be found in [21]. One can see that linac-ring type $\gamma A$ collider will produce $\sim 4 \times 10^8$ $e^+e^-$ pair working year, which exceeds by two order the statistics obtained at LEP and CLEO up to now.

5. **LINAC-RING TYPE PARTICLE FACTORIES**

5.1. **Phi Factory**

It is well known that, center of mass energy and luminosity are two important parameters from the point of view of particle physics. In order to make a linac-ring type $\phi$ factory feasible, its luminosity should exceed $10^{35} cm^{-2}s^{-1}$. We have presented sets of parameters for a linac-ring type $\phi$ factory in [18]. About $4 \times 10^{11}$ events per working year ($10^7$ s) is expected. For main parameters and rates of $\phi$ decays at a linac-ring type $\phi$ factory see ref. [19].

5.2. **Charm Factory**

Recently CLEO-c [20] has been approved in order to explore the charm sector starting early 2003. Expected machine performance will be $L=3 \times 10^{32} cm^{-2}s^{-1}$ at $\sqrt{s}=3.77 GeV$. We present proposed parameters for linac-ring type charm factory [21] and show that $L=10^{33-34} cm^{-2}s^{-1}$ can be achieved. Expected numbers of $\Psi(3S)$ per working year is about $10^{10}$. Let us mentioned that $D\bar{D}$ mode is the dominant one for $\Psi(3S)$ decays. An additional advantage of the proposed charm factory is the asymmetric kinematics. This feature will be important in investigations of $D^0\bar{D}^0$ oscillations and CP-violation in charmed particle decays.

5.3. **Tau Factory**

The maximum cross section of the process $e^+e^-\rightarrow \tau^+\tau^-$ is $\sigma=3.56 \, nb$ at $\sqrt{s}=4.2 \, GeV$. In difference from $\phi$ and charm factories, in the case of $\tau$ factory we have consider the symmetric option ($E_{\tau^-} = E_{\tau^+} = 2.1 GeV$). Proposed set of parameters can be found in [21]. One can see that linac-ring type $\tau$ factory will produce $\sim 4 \times 10^8$ $\tau^+\tau^-$ pair working year, which exceeds by two order the statistics obtained at LEP and CLEO up to now.

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