A REVIEW OF TEV SCALE LEPTON-HADRON AND PHOTON-HADRON COLLIDERS

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Abstract

The investigation of lepton-hadron and photon-hadron collisions at TeV scale is crucial both to clarify the strong interaction dynamics from nuclei to quark-parton level and for adequate interpretation of experimental data from future hadron colliders (LHC and VLHC). In this presentation different TeV scale lepton-hadron and photon-hadron collider proposals (such as THERA, "LEP"-LHC, QCD Explorer etc) are discussed. The advantages of linac-ring type colliders has been shown comparatively.

INTRODUCTION

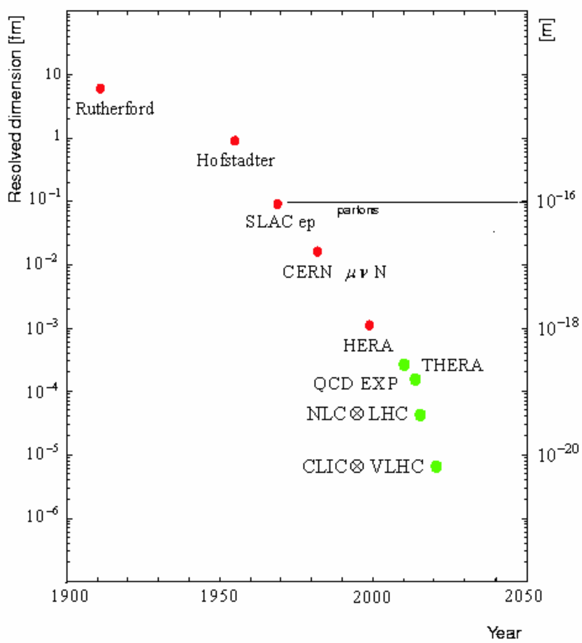

Figure 1: The development of the resolution power of the experiments exploring the inner structure of matter over time from Rutherford experiment to CLIC⊗VLHC.

It is known that lepton-hadron collisions have been playing a crucial role in exploration of deep inside of matter. For example, the quark-parton model was originated from investigation of electron-nucleon scattering. The HERA with $\sqrt{s} \approx 0.3$ TeV has opened a new era in this field extending the kinematics region by two orders both in high Q^2 and small x with respect to fixed target experiments. However, the region of sufficiently small x ($\leq 10^{-5}$) and simultaneously high Q^2 (≥ 10 GeV^2), where saturation of parton densities should manifest itself, is not currently achievable. 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 colliders are necessary for adequate interpretation of physics at future hadron colliders. Concerning LHC, which hopefully will start in 2007, a $\sqrt{s} \approx 1$ TeV ep collider will be very useful in earlier 2010's when precision era at LHC will begin.

Finally, multi-TeV center of mass energy ep colliders are competitive to future hadron and lepton colliders in search for the BSM physics.

TEV SCALE LEPTON-HADRON COLLIDERS

Today, linac-ring type machines seem to be the main way to TeV scale in lepton-hadron collisions (see [1, 2] and references therein). Construction of future linear collider or a special e-linac tangentially to existing (HERA, Tevatron, RHIC) or planned (LHC, VLHC) hadron rings will provide a number of new powerful tools in addition to ep and eA options:

- TeV scale γp [3] (see also [4]) and γA [5] colliders
- FEL-Nucleus colliders [6] (see also [7]).

Standard Type ep Colliders

There are several standard (ring-ring) type ep collider proposals with $\sqrt{s} \geq 1$ TeV. The first one is an ep option for LHC, which assumes a construction of 67.3 GeV electron ring in the LHC tunnel [8]. Concerning the VLHC based ep collider, a construction of 180 GeV e-ring in the VLHC tunnel is proposed in [9]. However, a construction of an additional e-ring in the LHC and VLHC tunnels might cause a lot of technical problems (an example is inevitable removing of the LEP from the tunnel in order to assemble the LHC). Recently, linac-ring analogues of these proposals are discussed in [10]. It is shown that linacs will give opportunity to obtain the same $\sqrt{s}$ and luminosities with much shorter lengths.

Table 1: LHC and VLHC based ep colliders: e-ring vs e-linac (for TESLA-like linac)

Collider	eLHC	eVLHC
E_e (GeV)	67.3	180
E_p (TeV)	7	50
$\sqrt{s}$ (TeV)	1.37	6
Ring circumference (km)	26.66	531
Luminosity (10^{32}cm^{-2}s^{-1})	1.2	1.4
Linac length	2.9	7.7
Luminosity (10^{32}cm^{-2}s^{-1})	1.6	2.3

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THERA, ILC-Tevatron and QCD Explorer

Three versions of TESLA-HERA based ep collisions are considered in the TESLA TDR [11]: E_e = 250 GeV and E_p = 1 TeV with L = $0.4\times10^{31}cm^{-2}s^{-1}$, E_e = E_p = 500 GeV with L = $2.5\times10^{31}cm^{-2}s^{-1}$ and E_e = E_p = 800 GeV with L = $1.6\times10^{31}cm^{-2}s^{-1}$.

Main parameters of ILC-Tevatron based lepton-hadron colliders are discussed in [12]. With nominal Tevatron parameters, the luminosity for *ep* ($e\bar{p}$) collisions is calculated to be $8\cdot10^{29}$ $cm^{-2}s^{-1}$ ($4.6\cdot10^{29}$ $cm^{-2}s^{-1}$). The THERA [10] like upgrade of the proton beam parameters (namely, σ_p=10 μm with β_p=10 cm) leads to L_{ep} = $1.2\cdot10^{31}$ $cm^{-2}s^{-1}$.

QCD Explorer assumes a collision of 75 GeV CLIC electron bunches with 7 TeV LHC proton beam [13, 14]. Super-bunch upgrade of the LHC will give opportunity to achieve L_{ep} = $1.1\cdot10^{31}$ $cm^{-2}s^{-1}$ [13]. Otherwise, a radical upgrade of CLIC beam is necessary to achieve sufficiently high luminosity [10].

In spite of approximately equal center of mass energies, QCD Explorer is more advantageous than THERA and ILC-Tevatron for exploration of small x_g region [10].

"ILC"-LHC

The center of mass energy which will be achieved at this machine (0.5 TeV "ILC" electron beam on 7 TeV energy LHC proton beam) is an order higher larger than HERA. Certainly, $L_{ep} \approx 10^{32}$ $cm^{-2}s^{-1}$ 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, $L_{ep} \approx 10^{31}$ $cm^{-2}s^{-1}$ can be achieved with super bunch structure of LHC and nominal parameters of 0.5 TeV CLIC. The ep option, which 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 γp option, the advantage in spectrum of back-scattered photons will clearly manifest itself in a search for different phenomena. Rough estimations [2] show that the total capacity of ep and γp options for BSM physics (SUSY, compositness etc) research essentially exceeds that of a 0.5 TeV linear collider. Discovery limits for different phenomena obtained by "simple" rescale of corresponding results from [15] are presented in Figure 2. Detailed study for exited electrons [16] confirms "fingertip" estimations given in the Figure.

In the case of LHC nucleus beam IBS effects in main ring are not crucial because of large 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 $L_{eA}\cdot A \approx 10^{31}$ $cm^{-2}s^{-1}$ can be achieved at least for light and medium nuclei. For γA option, limitations on luminosity due to beam-beam tune shift is removed in the scheme with deflection of electron beam after conversion [3] and sufficiently high luminosity can be achieved for heavy nuclei, too. Certainly, nuclei options of "ILC"-LHC will bring out great opportunities for QCD and nuclear physics research. For example, γA option will five an opportunity to investigate 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).

"CLIC"-VLHC

Concerning high energy frontiers, even 1 TeV e-linac will provide $\sqrt{s_{ep}}$ = 20 TeV, whereas 3 (5) TeV CLIC will give $\sqrt{s_{ep}}$ = 34 (45) TeV. Taking in mind THERA estimations one can expect $L_{ep} \approx 10^{33}$ $cm^{-2}s^{-1}$ for "İLC"-VLHC, whereas $L_{ep} \approx 10^{32}$ $cm^{-2}s^{-1}$ 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 will give opportunity to investigate a lot of particle physics phenomena in a best manner.

Table 1: Energy Frontiers

Colliders	Hadron	Lepton	Lepton-Hadron
1990's	Tevatron	SLC/LEP	HERA
√s, TeV	2	0.1/0.1 → 0.2	0.3
L, $10^{31}cm^{-2}s^{-1}$	1	0.1/1	1
2010's	LHC	"NLC"(TESLA)	"NLC"-LHC
√s, TeV	14	0.5 → 1.0(0.8)	3.7 → 5.3(4.7)
L, $10^{31}cm^{-2}s^{-1}$	10^3	10^3	1 ÷ 10
2020's	VLHC	CLIC	"CLIC"-VLHC
√s, TeV	200	3	34
L, $10^{31}cm^{-2}s^{-1}$	10^3	10^3	10 ÷ 100

CONCLUSION

The importance of linac-ring type ep colliders was emphasized by Professor B. Wiik at Europhysics HEP Conference in 1993 [17]. Following previous article [18], he argued TESLA type accelerator to be used as linac. The argument is still valid for LHC-based ep, γp, eA and γA colliders. Concerning VLHC-based ep and γp colliders, CLIC type linear accelerator seems to be advantageous, since the energy of TESLA of reasonable size is less than 1 TeV.

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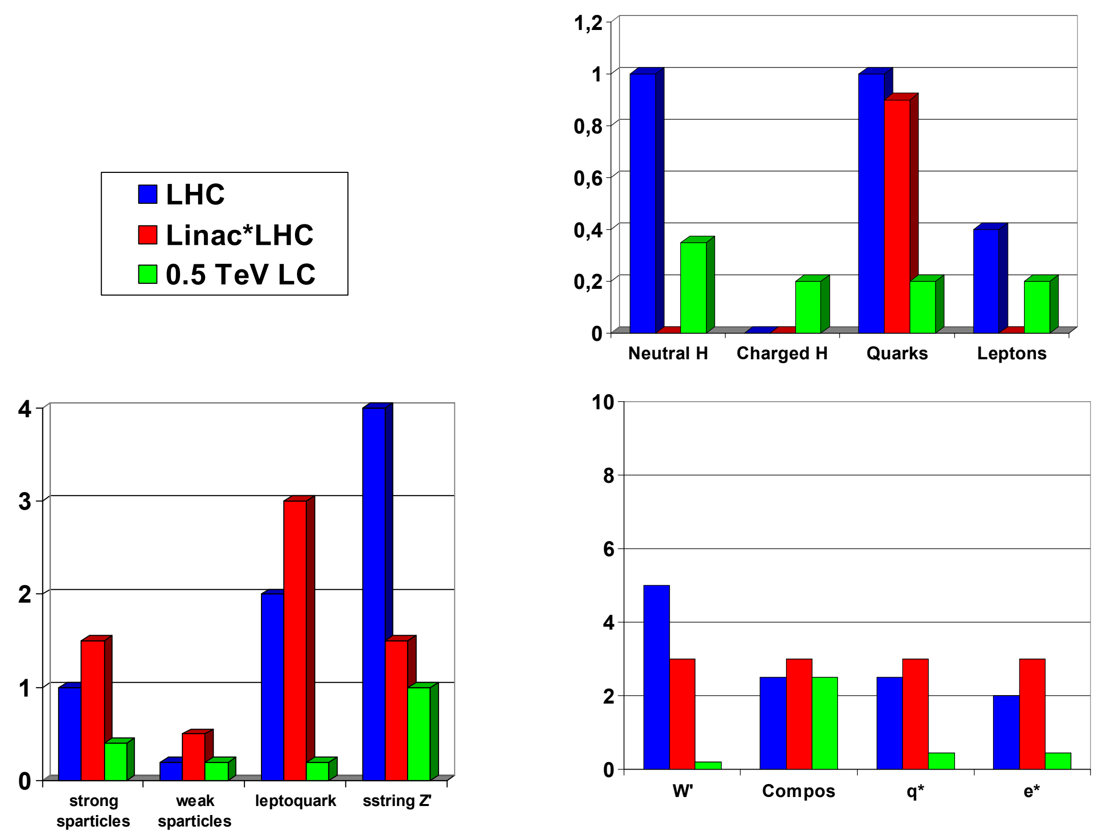

Figure 2: “Fingertip” estimations of discovery limits at the LHC (blue), ILC*LHC (red) and ILC (green). Upper-left picture contains: the neutral Higgs, a charged Higgs, the fourth SM family quarks and leptons. Down-right picture contains: strong sparticles (gluino and squarks), weak sparticles (neutralino, chargino and sleptons), leptoquark and Z’ from E_6. Down-left picture contains: W’, compositness scale, excited quarks and leptons.

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