MINIWORKSHOP ON MACHINE AND PHYSICS ASPECTS OF CLIC BASED FUTURE COLLIDER OPTIONS
30 August 2004, PS Auditorium, CERN

General Remarks on the Linac-Ring Type Lepton-Hadron and Photon-Hadron Colliders

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- Introduction
- Brief history
- QCD Explorer
- Second Way to TeV scale
- Conclusion

Particle Colliders

Colliding Beams:

- Hadron Colliders
- Lepton Colliders
- Lepton-Hadron Colliders

Accelerator Types:

- Ring-Ring → Hadron energy frontiers (also, μμ?, μp??)
- Linac-Linac → Lepton energy frontiers
- Linac-Ring → Lepton-hadron energy frontiers

Energy frontiers mean TeV scale at constituent level

Lepton-Hadron Colliders

- Ring-Ring type:

HERA*, e-RHIC* (EPIC* etc), “LEP”-LHC*, e-VLHC*, μp??

- Linac-Ring type:

THERA*, e-RHIC*, QCD Explorer, “NLC”-LHC, CLIC-VLHC
+ γ options

- Linac-Linac type:

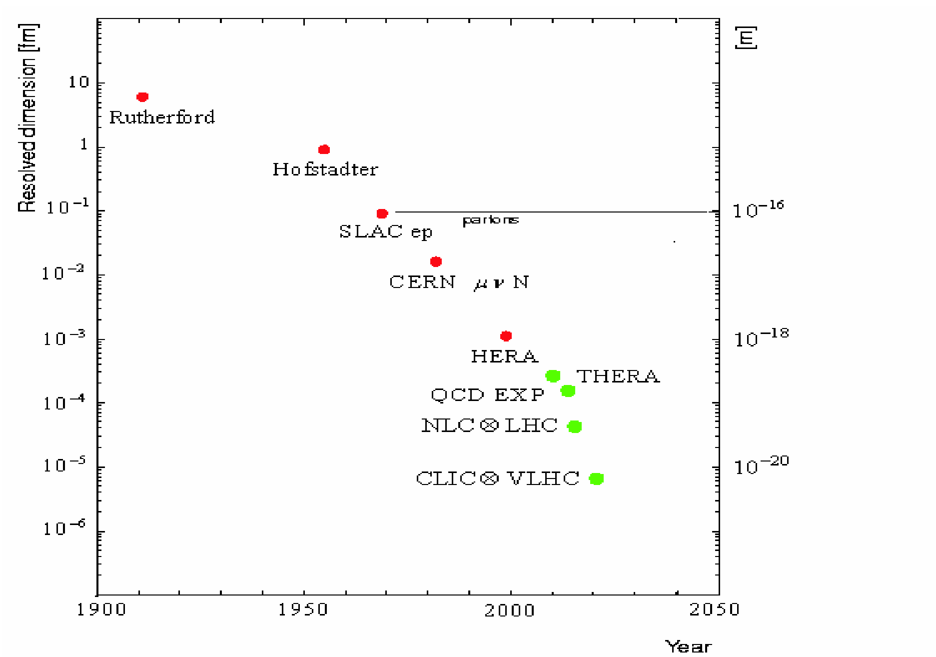
TESLA, GLC, CLIC
+ γ options

Underline denotes √s > 1 TeV

* Snowmass 2001 Working Group M5 on Lepton-Hadron Colliders

“NLC” denotes 0.5 TeV CM energy linear collider

The development of the resolution power of the experiments exploring the inner structure of matter over time from Rutherford experiment to CLIC×VLHC



REVIEWS

- B.H. Wiik, “Recent Developments in Accelerators”, Plenary Talk at EPS-HEP 93, p. 739 (22-27 July 1993, Marseille)
- S. Sultansoy, “Four Ways to TeV Scale”, Ankara 97 Workshop (9-11 April 1997), Turk. J. Phys. 22 (1998) 575; **hep-ex/0007043**
- R. Brinkmann et al., “Linac-Ring Type Colliders: Fourth Way to TeV Scale”, DESY-97-239 (1997); **physics/9712023**
- S. Sultansoy, “The Post-HERA Era: Brief Review of Future Lepton-Hadron and Photon-Hadron Colliders”, DESY-99-159 (1999); **hep-ph/9911417**
- A.K. Ciftci et al., “A Brief Review of Future Lepton-Hadron and Photon-Hadron Colliders”, **hep-ex/0106082**
- E. Arik and S. Sultansoy, “Turkish Comments on `Future Perspectives in HEP`”, **hep-ph/0302012**
- S. Sultansoy, “Linac-Ring Type Colliders: Second Way to TeV Scale”, Talk at EPS-HEP 03 (17-23 Jul 2003, Aachen, Germany), Eur Phys J C 33, so1, s1064-s1066 (2004); **hep-ex/0306034**

Two parameters are the most important ones from the physics point of view: **center-of-mass energy and luminosity**

Center-of mass energy (in TeV)

Colliders	pp	ee	ep	ep/ee
2010’s	LHC	NLC	NLC*LHC	
√s	14	0.5 → 1	3.7 → 5.3	≈ 6
2020’s	VLHC	CLIC	CLIC*VLHC	
√s	200	3 → 5	34 → 46	≈10

Therefore, **the critical issue is luminosity** !

Additional γp, eA, γA and FEL γA options

- γp option

  A.K. Ciftci et al., Nucl. Instrum. Meth. A 365 (1995) 317

- eA option

  Z.Z. Aydin et al., ICHEP 96, p.1752

- γA option

  A.K. Ciftci, S. Sultansoy and O. Yavas, NIM A 472 (2001) 72

- FEL γA option

  H. Aktas et al., NIM A 428 (1999) 271

Main problems

Bunch spacing do not coincide: ns at JLC/NLC and CLIC, 200 ns at TESLA, 25 ns at LHC etc

- Low collision frequency
- Beam sizes do not coincide

Possible solutions: change LC (or/and PS) bunch structure, special e-linac design etc

Main limitations

- Linac's beam power ($\sim f_{rep} \cdot n_b \cdot n_e$)
- Proton bunch brightness (n_p/ε_p)

In addition, we must keep under control a lot of parameters such as ΔQ_p, t_{IBS} etc

Brief History

- P.L. Csonka and J. Rees, Nucl. Instr. Meth. 96 (1971) 149
- D. Berley et al., “e-p Accelerator Subgroup Summary”, Snowmass 1982, p.303

  100 GeV e-linac on SSC, $\sqrt{s}$ = 2.8 TeV, L = 10^{32} cm^{-2} s^{-1}
  But P_e = 400 MW !

- UNK+VLEPP Physics Study Group (1986-1988):

  ep option: S. Alekhin et al., IHEP preprint 87-48, Serpukhov 1987
  γp option: S. Alekhin et al., Int. J. Mod. Phys. A 6 (1991) 21

  see, also, S. F. Sultanov, ICTP preprint IC/89/409, Trieste 1989

- M. Tigner, B. Wiik and F. Willeke, 1991 IEEE Particle Accelerator Conference, p. 2910

  “TESLA” on HERA, LHC and SSC
  L = 10^{31-32} cm^{-2} s^{-1} with P_e = 60 MW

- Ankara group, 1993 –

  Ankara Univ & Gazi Univ, see webpage
  http://bilge.science.ankara.edu.tr

- R. Brinkmann and M. Dohlus, DESY-M-95-11 (1995)

  “**dynamic focusing**”

- International Workshop on Linac-Ring Type ep and γp Colliders (9-11 April 1997, Ankara)
  Proc. in Turk. J. Phys. 22 (1998) 521-775

THERA: Electron-Proton Scattering at $\sqrt{s} \approx 1$ TeV

- H. Abramowicz et al., in TESLA TDR, v. 6, DESY-01-011, Mar 2001, 62 pp.
- The THERA Book, Eds. U. Katz, A. Levy, M. Klein and S. Schlendstedt, DESY-01-123, Dec 2001, 415 pp.
- THERA Webpage
  www.ifh.de/thera

TESLA on HERA: 0.25 TeV × 1.0 TeV
0.4 TeV × 0.4 TeV
0.8 TeV × 0.8 TeV

$L \approx 10^{31}\ cm^{-2}\ s^{-1}$

LHC and VLHC based ep colliders: e-ring vs e-linac

Y. Islamzade, H. Karadeniz, S. Sultansoy

- LHC based (hep-ex/0207013)

Comparison of LEP*LHC with the same energy Linac*LHC
E_e = 67.3 GeV and E_p = 7 TeV for both options

$L = 1.2 \cdot 10^{32}\ cm^{-2}\ s^{-1}$ for LEP*LHC (E. Keil, LHC Project Report 93, CERN, 1997) vs $L \approx 10^{32}\ cm^{-2}\ s^{-1}$ for Linac*LHC with $P_e \approx 34.5$ MW (which correspond to synchrotron radiation power at LEP)

0.5 km “CLIC” or 2 km “TESLA” vs 27 km “LEP”

- VLHC based (hep-ex/0204034)

E_e = 180 GeV, E_p = 50 TeV and $L = 1.4 \cdot 10^{32}\ cm^{-2}\ s^{-1}$ for ring option (J. Norem and T. Sen, FERMILAB-PUB-99/347, 1999)
E_e = 250 GeV, E_p = 50 TeV and $L = 3 \cdot 10^{32}\ cm^{-2}\ s^{-1}$ for linac option

Instead of constructing a 530 km e-ring in VLHC tunnel it seems more wise to construct a 2 km (10 km) e-linac with the same ep parameters

QCD Explorer

21.08.2002 First Meeting on CLIC*LHC Interface

Participants:

A. De Roeck, G. Guignard, D. Schulte, I. Wilson (CERN)

O. Cakir, S.A. Cetin, S. Sultansoy (Turkiye)

14.08.2003 Second Meeting on CLIC*LHC Interface

Participants:

A. De Roeck, G. Guignard, D. Schulte, I. Wilson,

F. Zimmermann (CERN)

E. Arik, O. Cakir, A.K. Ciftci, R. Ciftci, H. Koru, E. Recepoglu,

S. Sultansoy (Turkiye)

E_e = 70 GeV, E_p =7 TeV and $\sqrt{s}$ = 1.4 TeV

With nominal parameters of CLIC and LHC beams:

$L = 10^{28}\ cm^{-2}\ s^{-1}$

Even with this low luminosity, QCD Explorer

- will provide unique information which will be crucial for adequate interpretation of the LHC data

- The region of extremely small $x_g = 10^{-5} - 10^{-6}$ at sufficiently high Q^2 = 1-10 GeV^2 will be explored. This region is crucial for the understanding of QCD dynamics

With appropriate upgrades of CLIC and LHC beams, a luminosity of $10^{31}\ cm^{-2}\ s^{-1}$ and even $10^{32}\ cm^{-2}\ s^{-1}$ (optimistic scenario) may be achievable

LHC Project Note 333
CLIC Note 589
08.01.2004

QCD Explorer Based on LHC and CLIC

D. Schulte, F. Zimmermann

Keywords: Linac-Ring Collider, Superbunches, Luminosity, Beam-Beam Interaction, Disruption

Table 1: Beam Parameters

parameter	symbol	electrons	protons
beam energy	E_b	75 GeV	7 TeV
bunch population	N_b	4×10^9	6.5×10^{13}
rms bunch length	σ_z	35 μm (Gaussian)	9 m (uniform)
bunch spacing	L_{sep}	0.66 ns	N/A
number of bunches	n_b	154	1
(effective) pulse line density	λ	2.0×10^{10} m^{-1}	2.1×10^{12} m^{-1}
IP beta function	$\beta^*_{x,y}$	0.25 m	0.25 m
spot size at IP	$\sigma_{x,y}$	11 μm	11 μm
full length of interaction region	l	2 m	
normalized transv. rms emittances	$\gamma\epsilon_{x,y}$	73 μm	3.75 μm
collision frequency	f_{coll}	100 Hz	
luminosity	L	1.1×10^{31} cm^{-2}s^{-1}	
beam-beam shift	$\xi_{x,y}$	N/A	0.004

SM Physics Example

The importance of small x_g region (at sufficiently $Q^2 \sim 10$ GeV^2) exploration for strong interactions corresponds to the importance of the Higgs boson search for electro-weak interactions !!!

	x_g	Detector cuts
1. Fixed Target	10^{-2}	-
2. HERA	10^{-4}	10^{-3}
3. e-RHIC	10^{-3}	?
4. THERA	10^{-5}	10^{-4}
5. QCD Explorer	10^{-5}	?
6. NLC*LHC	10^{-6}	?
7. CLIC*VLHC	10^{-7}	?

Low x_g via ep → Q(bar)+Q+X (Q = c, b) at future ep colliders

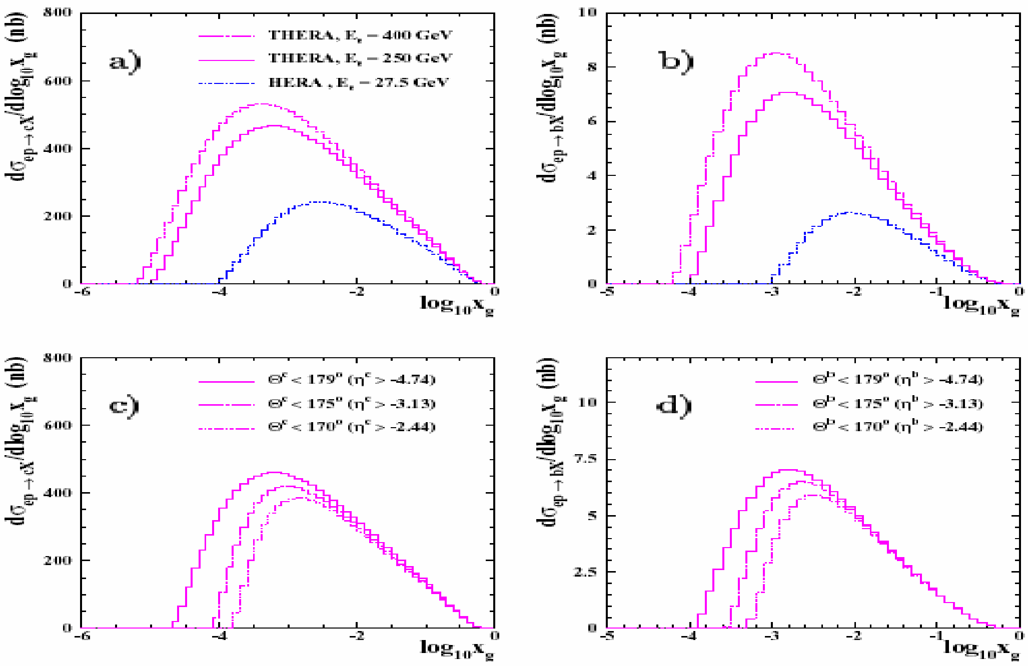


Figure 2: *The differential cross sections $d\sigma/d\log_{10} x_g$ for charm ((a) and (c)) and beauty ((b) and (d)) produced in the process of photon–gluon fusion. The cross sections were calculated within NLO QCD for $Q^2 < 1\,GeV^2$. In (a) and (b), the solid and dashed magenta curves show the predictions for THERA operation with an electron energy of 250 GeV and 400 GeV, respectively, and $E_p = 920\,GeV$. The predictions for the HERA case are indicated by the dash-dotted blue curves. In (c) and (d), the predictions for THERA with $E_e = 250\,GeV$ are shown with additional cuts $\theta^{c,b} < 179°$ (solid curves), $\theta^{c,b} < 175°$ (dashed curves) and $\theta^{c,b} < 170°$ (dash-dotted curves).*

Advantage of the γp option

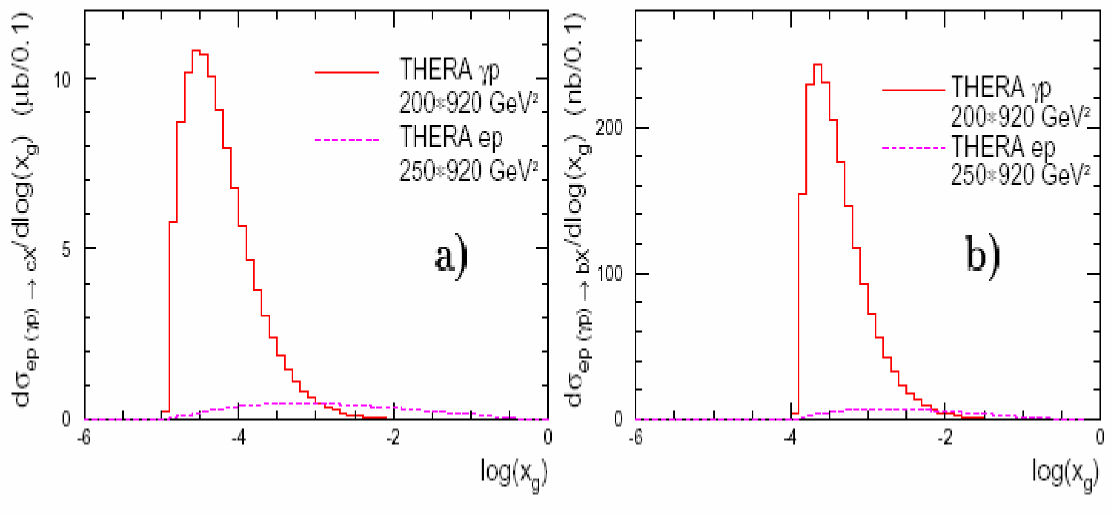


Figure 3: *Dependence of the differential cross section of (a) charm and (b) beauty production on x_g in γp and ep scattering at THERA.*

Second Way to TeV Scale

Colliders	Hadron	Lepton	Lepton-Hadron
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	1-10
2020's	VLHC	CLIC	"CLIC"×VLHC
$\sqrt{s}$, TeV	200	3	34
L, 10^{31} cm^{-2} s^{-1}	10^3	10^3	10-100

Physics targets and achievable limits (following U. Amaldi in CERN 87-07, pp. 323-352)

"Comparing the physics potentialities of two* accelerators is a formidable task for at least three obvious reasons:

i) the unknown cannot be predicted;

ii) even after having agreed on a list of 'expected' new phenomena, the relative importance is subjective;

iii) tomorrow's discovery may completely modify the 'relevance' weights given to selected phenomena"

* LHC (including LEP*LHC option) and CLIC

Summary of discovery limits for 12 different processes*

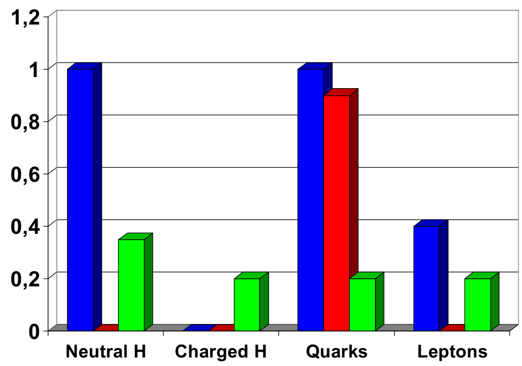
	1987	→	2003
pp	$\sqrt{s}$= 16 TeV, L= 10^{33} cm^{-2} s^{-1}	→	$\sqrt{s}$= 14 TeV, L= 10^{34} cm^{-2} s^{-1}
e^+e^-	$\sqrt{s}$= 2 TeV, L= (4) 10^{33} cm^{-2} s^{-1}	→	$\sqrt{s}$= 0.5 TeV, L= 10^{34} cm^{-2} s^{-1}
ep	$\sqrt{s}$= 1.5 TeV, L= 10^{32} cm^{-2} s^{-1}	→	$\sqrt{s}$= 3.7 TeV, L= 10^{32} cm^{-2} s^{-1} + γp option !!

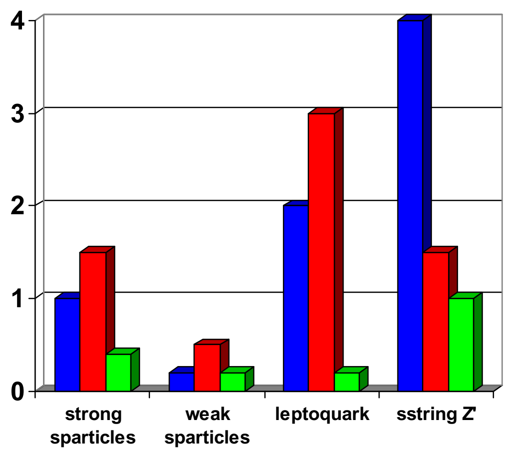
* Two principal additions during last years:

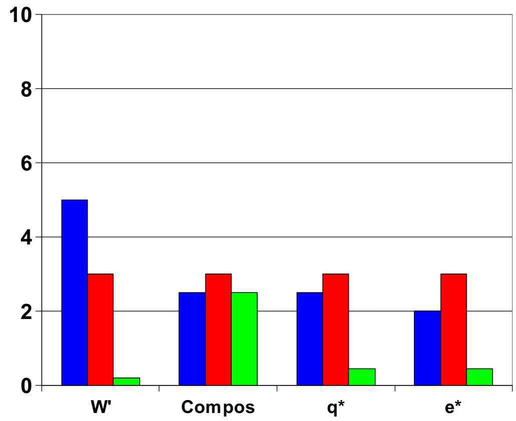
- extra dimensions (serious)
- infinite number of SUGRA points (curious)

Discovery limits in TeV
(rescaled from U. Amaldi 87)

- LHC
- Linac*LHC
- 0.5 TeV LC







- Recently, the e*→eγ signal and corresponding backgrounds are studied in details (O. Cakir, A. Yilmaz and S. Sultansoy, hep-ph/0403307). Results confirm discovery limits given in previous slide. Namely,

~0.5 TeV for ee, ~2.3 TeV for ep and ~1.9 TeV for pp.

- Discovery limits for extra dimensions are approximately:

0.5 √s for pp	7-8 TeV at LHC
10 √s for ee	5 TeV at NLC
2.5 √s for ep	7-8 TeV at NLC*LHC

Conclusion

- QCD Explorer

Two scenarios for LHC:

a) 2007-2012 "discovery period", 2012-… "precision period"

b) 2012 lumi upgrade, 2013-2015 further "discovery period", 2016-… "precision period'

Therefore, we need TeV scale ep collider before 2015.

THERA assumes the use of the HERA proton beam.

Unfortunately, 2007 is planned as close up date for HERA.

And QCD Explorer becomes the unique (realistic) opportunity!

- Energy frontier

Concerning direct search for new physics "NLC"-LHC potential exceeds that of "NLC" and is complementary to the LHC.

Recommendations

- "As a result of the workshop, *participants came to the point that it will be useful to organize two workshops, one on the machine parameters and the other on the research programs,* ***during the next year***"

  Cited from Ankara 97 Workshop's Conclusion and Recommendations

- Linac-Ring type lepton-hadron and photon-hadron colliders require more adequate attention of HEP community

- Common ICFA-ECFA-ACFA Study Group on Linac-Ring Type ep, γp, eA, γA and FEL γA Colliders

- Second International Workshop on the Linac-Ring Type Lepton-Hadron and Photon-Hadron Colliders in 2005.

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