Linac-Ring type Colliders: Energy vs Lumi

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ATLAS, LHeC and FCC Collaborations, CERN

* with A. Akay, U. Kaya, B Ketenoglu and B. Oner

What is the science of tomorrow? Pretty awesome!

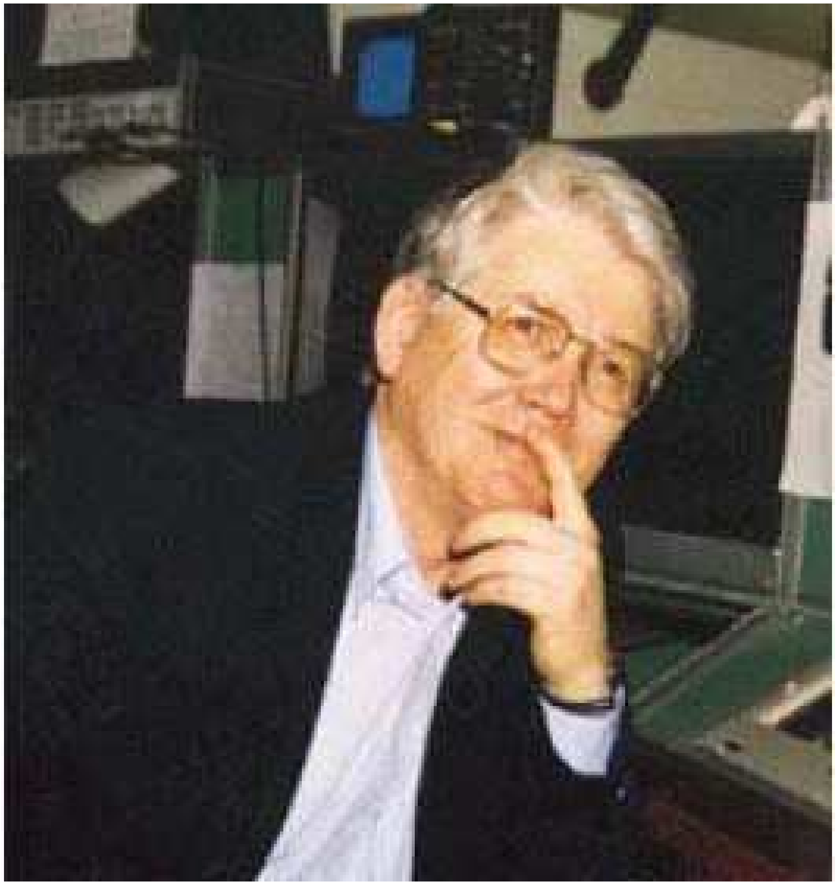
"Power of particles of the substance" engaged in the business ...

Mehmet Akif ERSOY, Safahat (1919); great poet and philosopher
The author of the words of the Turkish National Anthem

- Turkey is an Associate Member of CERN since April 2015
- Azerbaijan has applied for associate membership in September 2015

Dedicated to the memory of Professors Engin Arık and Bjorn Wiik

1948 - 2007



1937 -1999

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Introduction

Classification of colliders

ECFA presentation
25.11.2010, CERN

1. Colliding particles
- hadrons
- leptons
- lepton-hadron

2. Collider schemes
- ring-ring
- linear
- linac-ring

The ring-ring colliders are the most advanced ones from technology point of view and are widely used around the (developed) world.

The linear (linac-linac) colliders are less familiar; however, a lot of experience is gained through Standard Linear Collider (SLC) operation and ILC/CLIC related workout.

The linac-ring colliders require more R&D.

S. SULTANSOY 25.11.2010 CERN 4

Linac-ring type colliders: two directions*

Lepton-hadron and photon-hadron colliders:

UNK+VLEPP (Mid 1980's) → THERA (End 1990's) → LHeC → Energy Frontier / QCD Explorer

THERA → eRHIC/EIC/ELIC

Factories:

B-factory (Grosse-Wiesmann) → c-τ-factory → Super-Charm factory (TAC project)

c-τ-factory → ϕ-factory (Ankara group)

* For details and ref's see: A. Akay, H. Karadeniz and S. Sultansoy, Review of Linac-Ring-Type Collider Proposals, Int. J. Mod. Phys. A 25 (2010) 4589

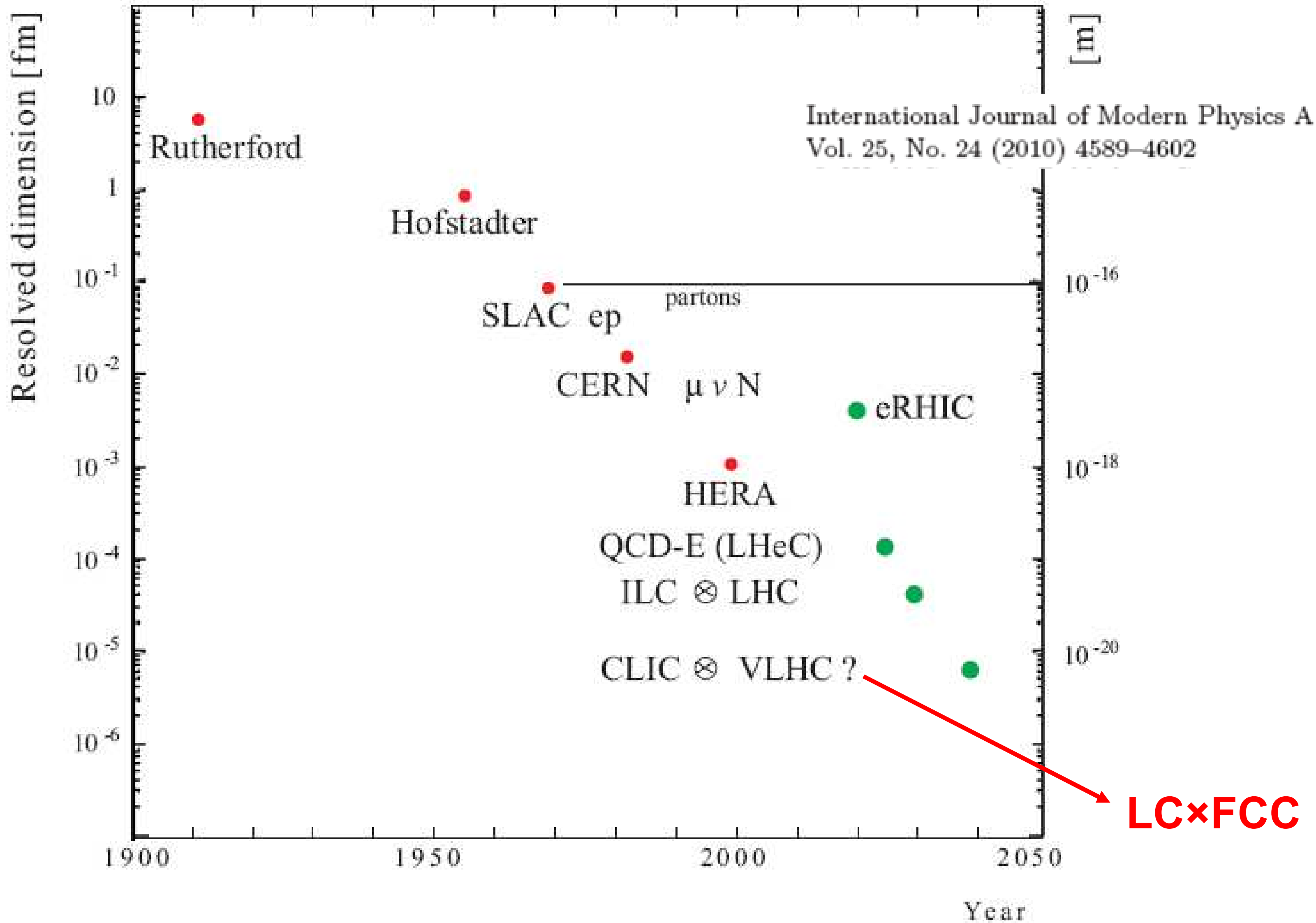


Fig. 1. The development of the resolution power of the experiments exploring the inner structure of matter over time from Rutherford experiment to CLIC ⊗ VLHC.

International Journal of Modern Physics A
Vol. 25, No. 24 (2010) 4589–4602

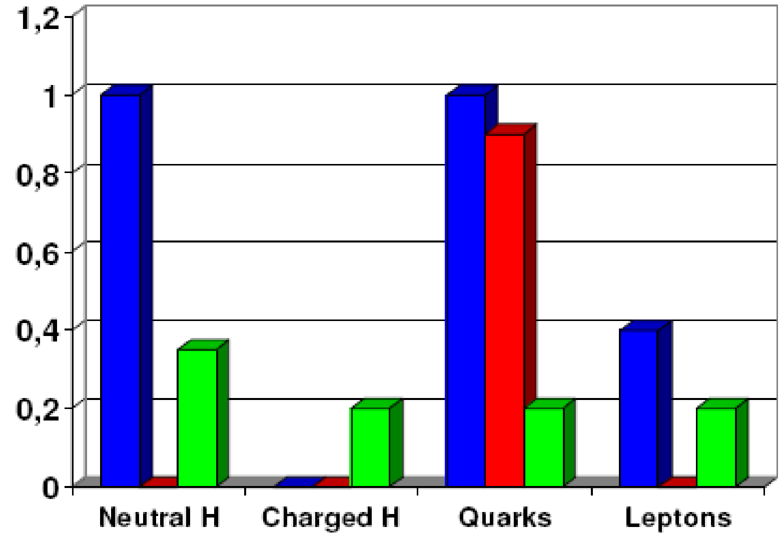
2.5. *Energy frontier (CERN)*

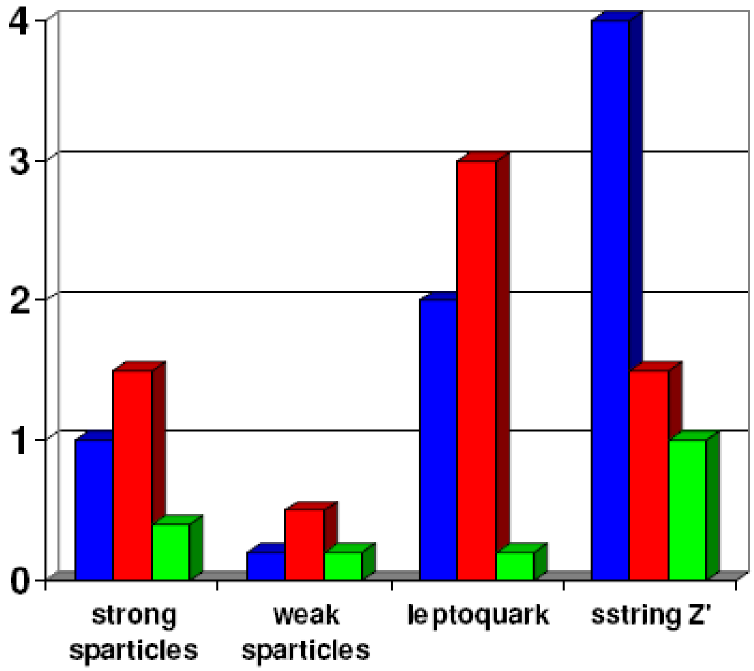
If $E_c \geq 500$ GeV, LHC based *ep* colliders are named as energy frontier. These high energies are inconvenient to use energy recovery. Nevertheless, $L = 10^{32}$ cm^{-2}s^{-1} seems to be achievable with pulsed linac.[41] It is useful to compare physics search potential of three colliders which can be considered as energy frontiers in foreseen future. Namely,

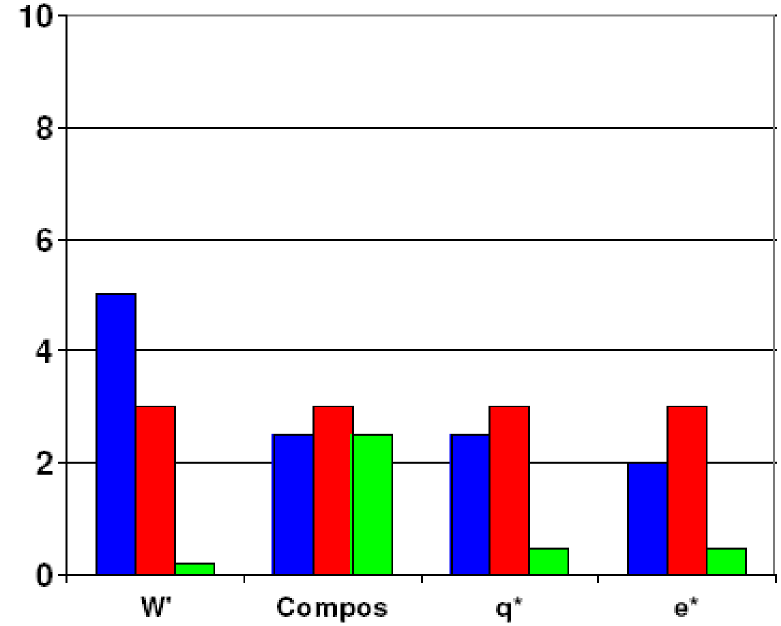
(i) $\sqrt{s} = 14$ TeV *pp* collider with $L = 10^{34}$ cm^{-2}s^{-1} (LHC);
(ii) $\sqrt{s} = 0.5$ TeV e^+e^- collider with $L = 10^{34}$ cm^{-2}s^{-1} (ILC);
(iii) $\sqrt{s} = 3.7$ TeV *ep* collider with $L = 10^{32}$ cm^{-2}s^{-1} ("ILC" $\times$ LHC).

Rough estimations[14] show that the total capacity of *ep* and γp options for BSM physics (SUSY, compositeness, etc.) research essentially exceeds that of 0.5 TeV linear collider.

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







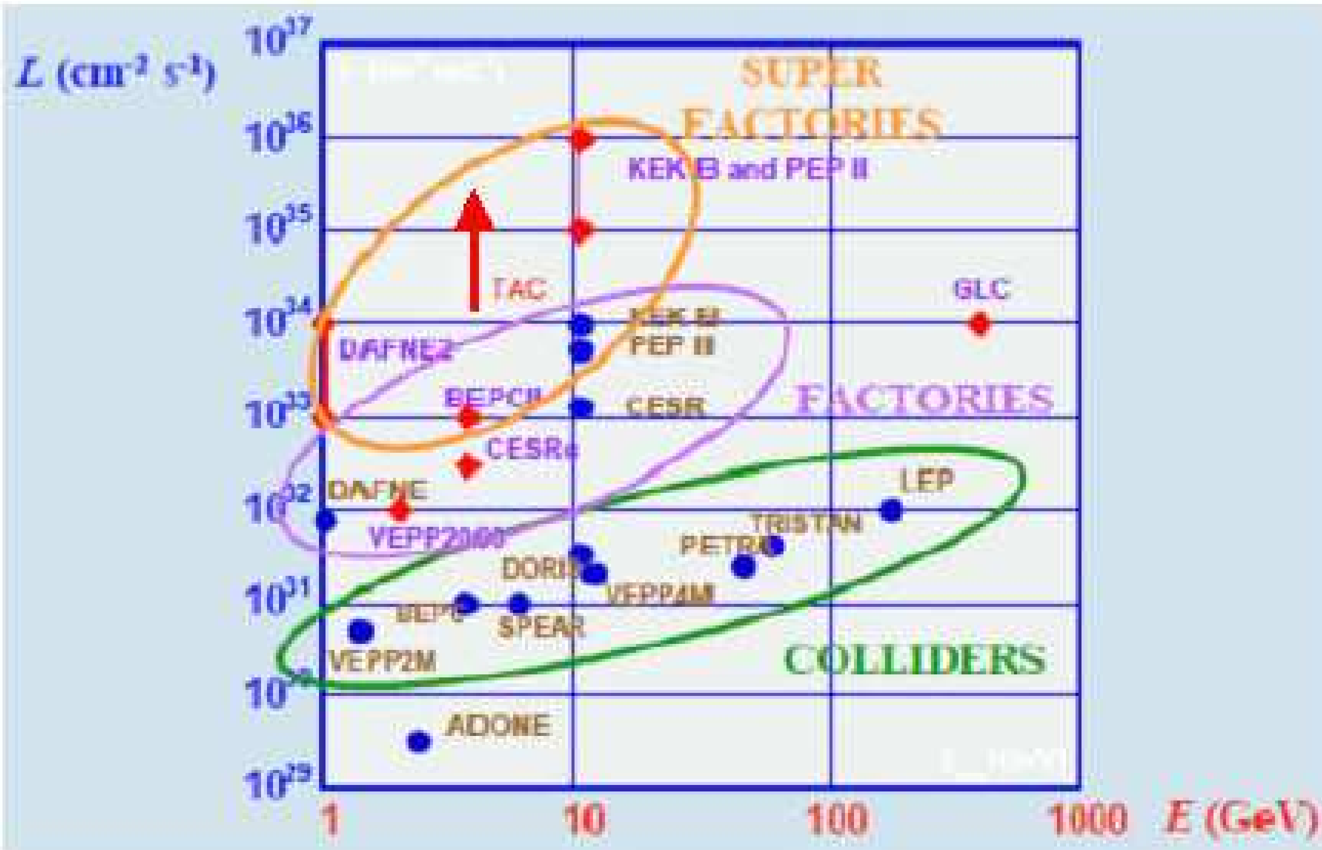


Fig. 2. Past, present and future e^+e^- colliders.

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2.1. *UNK+VLEPP (IHEP, Protvino)*

In 1980's there were two projects of energy frontier collider in the former USSR, namely, $\sqrt{s} = 6$ TeV proton–proton collider UNK and $\sqrt{s} = 2$ TeV linear electron–positron collider VLEPP. The construction of the first one started at IHEP (Protvino, Moscow region), and the second one was planned at BINP (Novosibirsk). In mid-1980's, the construction of VLEPP tangential to UNK was proposed in order to provide additional opportunity to handle energy frontier ep (Ref. 8) and γp (Ref. 9) colliders.

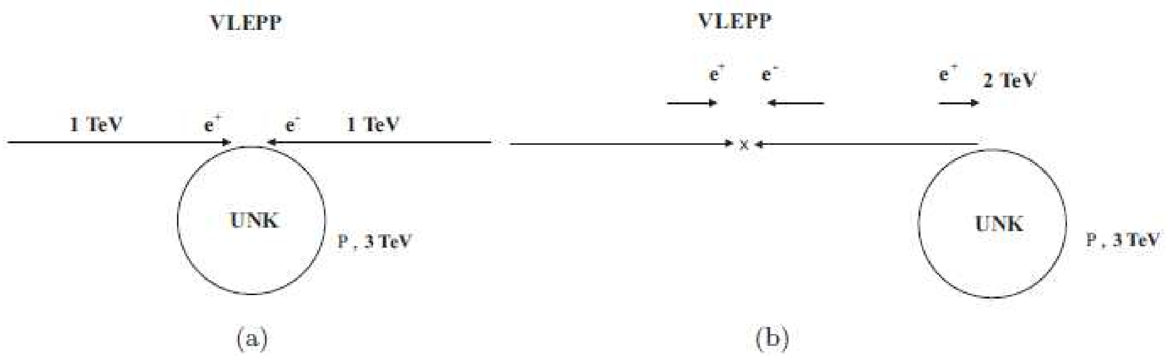

Fig. 3. (a) Symmetric version of ep (γp) collider; (b) asymmetric version.[11]

Note that this consideration was the main scientific reason for moving VLEPP from Novosibirsk to Protvino. Unfortunately, in the final design, VLEPP placement was chosen to cross the UNK ring, instead of tangential placement. Obviously, this choice eliminated ep and γp options (clear indication of the collapse of Eastern Block).

Reason(s) for this slide - similar situation for:

- **LHeC and FCC-eh (similar, but fortunately, not the same)**
- **TAC Super-Charm factory (ufortunately, the same)**

The LHeC project: e-ring revisited

Brief history of the LHC based ep colliders

1980'ies: LEP+LHC

1990'ies: LC+LHC or OPL+LHC

2000'ies: 'LEP'+LHC was resurrected

2010'ies: ERL60+LHC

2020'ies: LC+LHC will return

LC – Linear Collider
OPL – One Pass Linac
ERL – Energy Recovery Linac

Actually THERA was intended as a preparatory step toward LC + LHC
see Section 2.2 in International Journal of Modern Physics A
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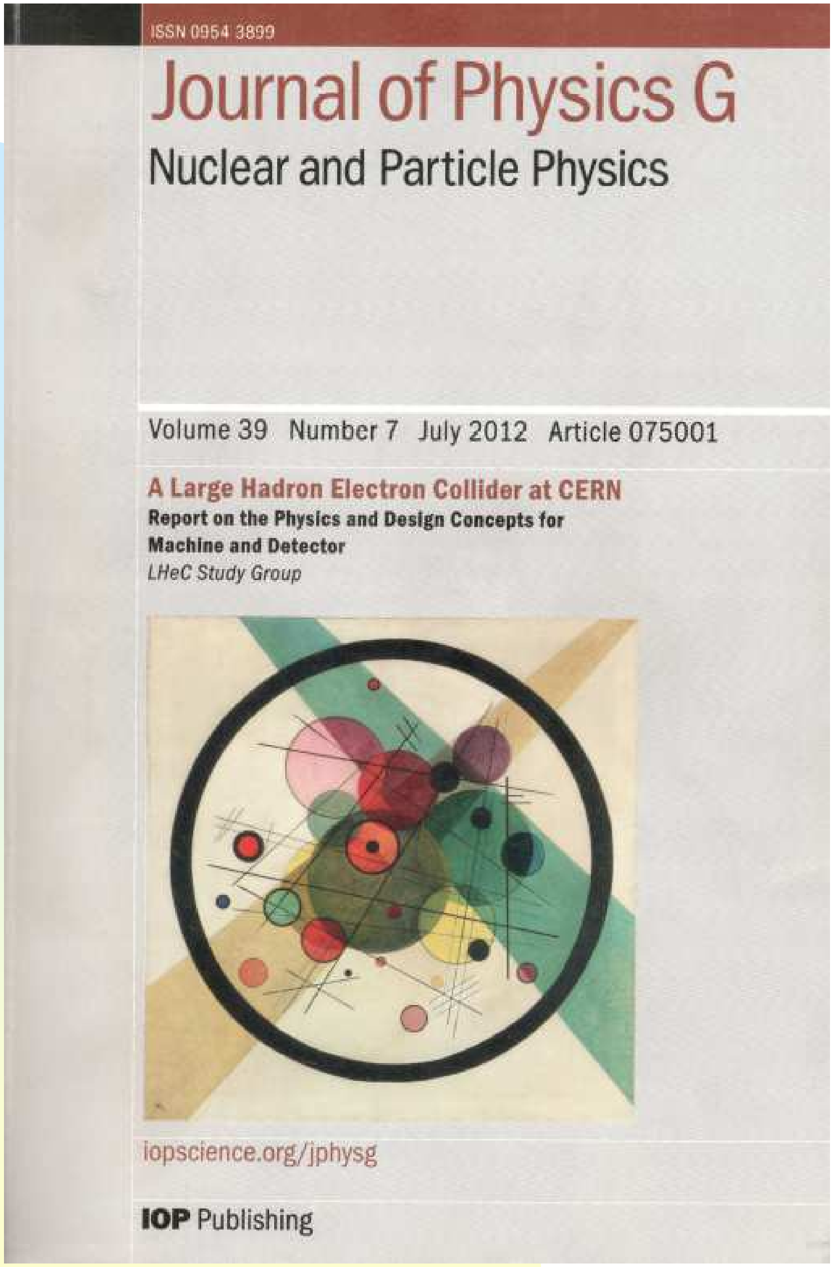


Accelerator Chapter

Ring-ring collider : pp 224-315
(wasting time and energy)

Linac-ring collider: pp 316-387
The lion's share is devoted to ERL60
OPL - less than 5 pages

Wall-plug power 100 MW for both LR

$L = 10^{33}$ cm^{-2} s^{-1} for RR and ERL60
(energy recovery efficiency 90%)

$L = 10^{32}$ cm^{-2} s^{-1} for 60 GeV OPL
Actually $L = 10^{33}$ cm^{-2} s^{-1} for 60 GeV OPL using «dynamic focusing»

J. Phys. G: Nucl. Part. Phys. **39** (2012) 075001 LHeC CDR

Total length ~ 9 km

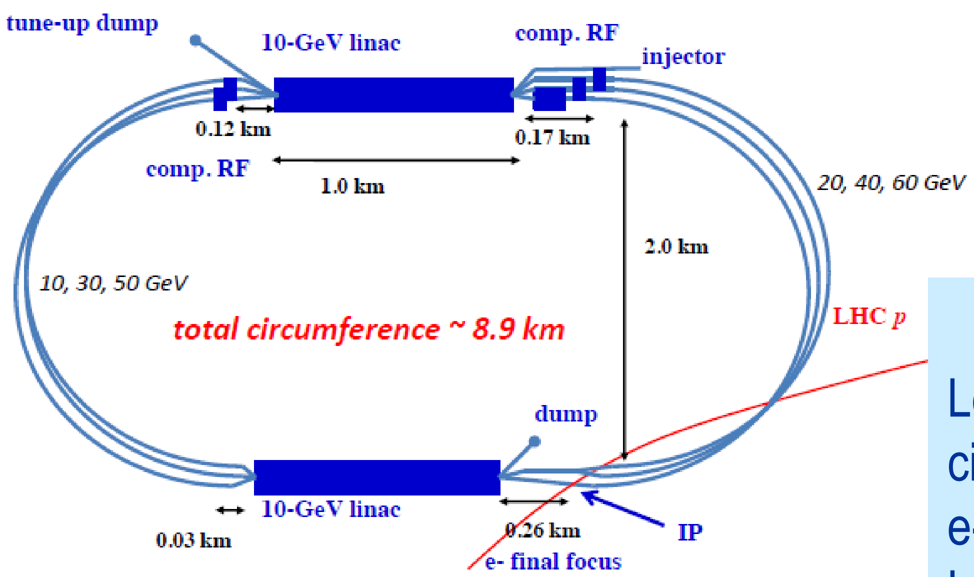


Figure 7.5: LHeC ERL layout including dimensions.

Item	Electrical Power [MW]
Main linac cryopower	18.0
Microphonics control	22.2
Extra RF to compensate SR losses	24.1
Extra-RF cryopower	1.6
Electron injector	6.4
Arc magnets	3.0
Total	75.3

Table 7.2: ERL power budget.

e-ring revisited

Let us consider **'normal' e-ring** with 9 km circumference and 60 GeV energy. With e-beam paramaters similar to those of the LHeC RR option **$L = 10^{33}$ cm^{-2} s^{-1} is achieved with SR power 80 MW !!!**

9 km linac
8 km active length

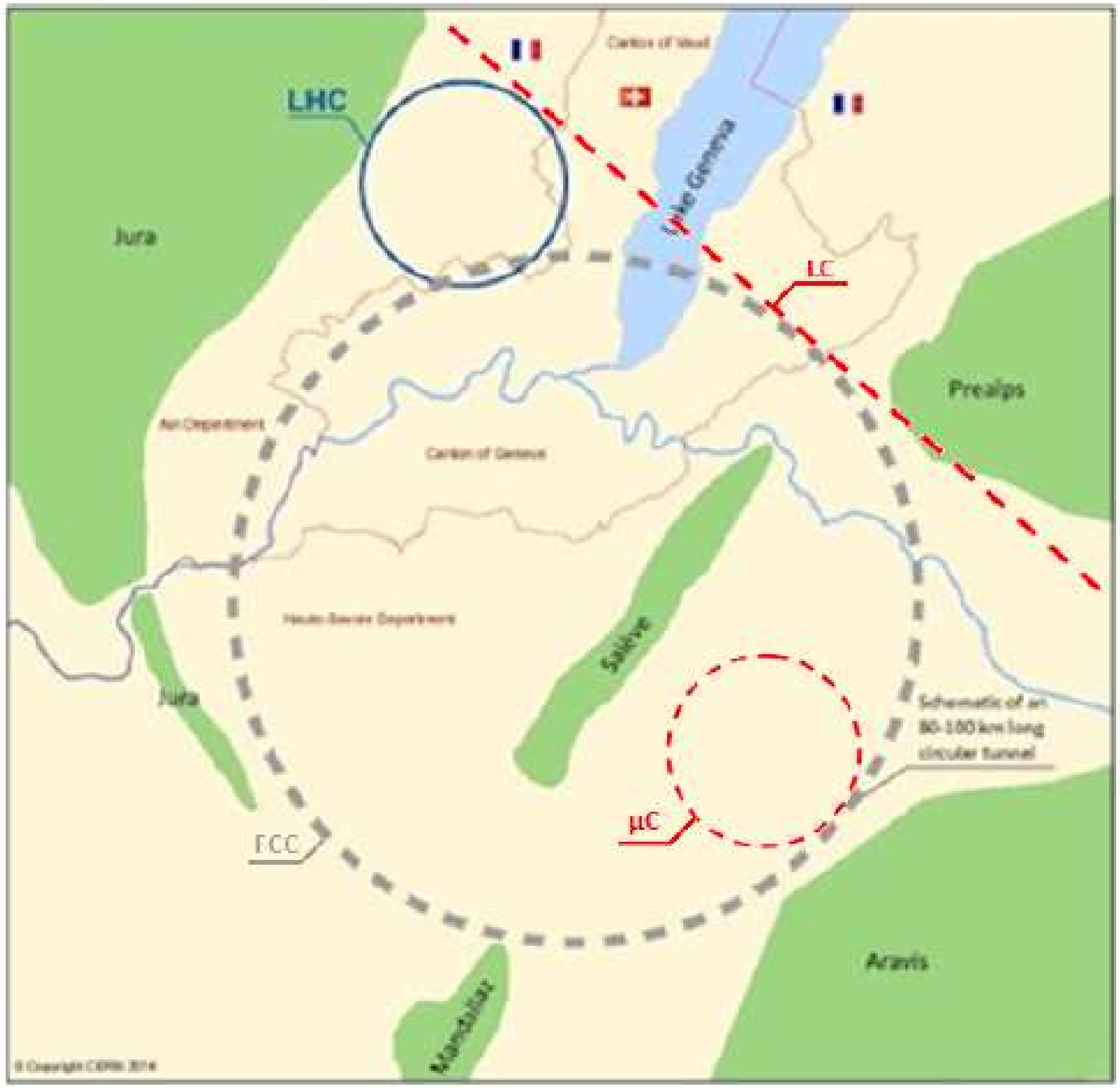
20 MeV/m: 180 GeV, $L = 3\times10^{32}$ cm^{-2} s^{-1} , $\sqrt{s}$ = 2.3 TeV
35 MeV/m: 280 GeV, $L = 2\times10^{32}$ cm^{-2} s^{-1} , $\sqrt{s}$ = 2.9 TeV

FCC/SppC based lepton-hadron and photon-hadron colliders

Construction of future electron-positron colliders (or dedicated electron linac) and muon colliders tangential to Future Circular Collider will give opportunity to **utilize highest energy proton and nucleus beams** for **lepton-hadron** and **photon-hadron** collisions.

LC×FCC = LC + FCC
+ ep + eA
+ $\gamma p + \gamma A + \mathrm{FEL}\,\gamma A$

$\mu C \times FCC = \mu C + FCC$
$+ \mu p + \mu A$



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Future circular collider based lepton–hadron and photon–hadron colliders: Luminosity and physics

CrossMark

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A B S T R A C T

Construction of future electron–positron colliders (or dedicated electron linac) and muon colliders (or dedicated muon ring) tangential to Future Circular Collider (FCC) will give opportunity to utilize highest energy proton and nucleus beams for lepton–hadron and photon–hadron collisions. Luminosity values of FCC based ep, μp, eA, μA, γp and γA colliders are estimated. Multi-TeV center of mass energy ep colliders based on the FCC and linear colliders (LC) are considered in detail. Parameters of upgraded versions of the FCC proton beam are determined to optimize luminosity of electron–proton collisions keeping beam–beam effects in mind. Numerical calculations are performed using a currently being developed collision point simulator. It is shown that $L_{ep} \sim 10^{32}$ cm^{-2} s^{-1} can be achieved with LHeC-like upgrade of the FCC parameters. Moreover, "dynamic focusing" scheme could provide opportunity to handle $L_{ep} \gtrsim 10^{33}$ cm^{-2} s^{-1}.

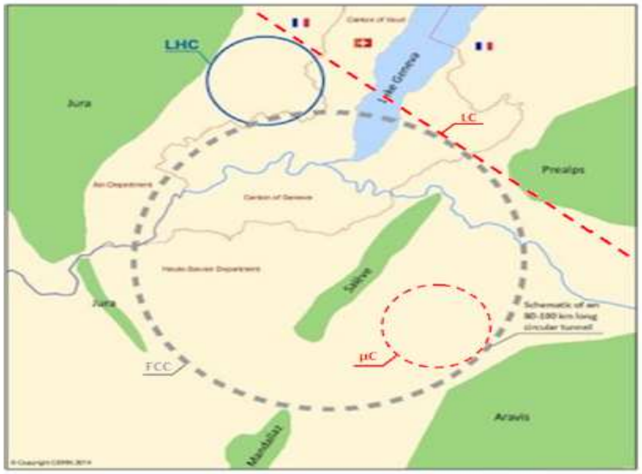

Table 1
Energy frontier colliders: colliding beams vs. collider types.

Colliders	Ring–Ring	Linac–Linac	Linac–Ring
Hadron	+		
Lepton ($e^- e^+$)		+	
Lepton ($\mu^- \mu^+$)	+		
Lepton–hadron (eh)			+
Lepton–hadron (μh)	+		
Photon–hadron			+

Y.C. Acar et al.

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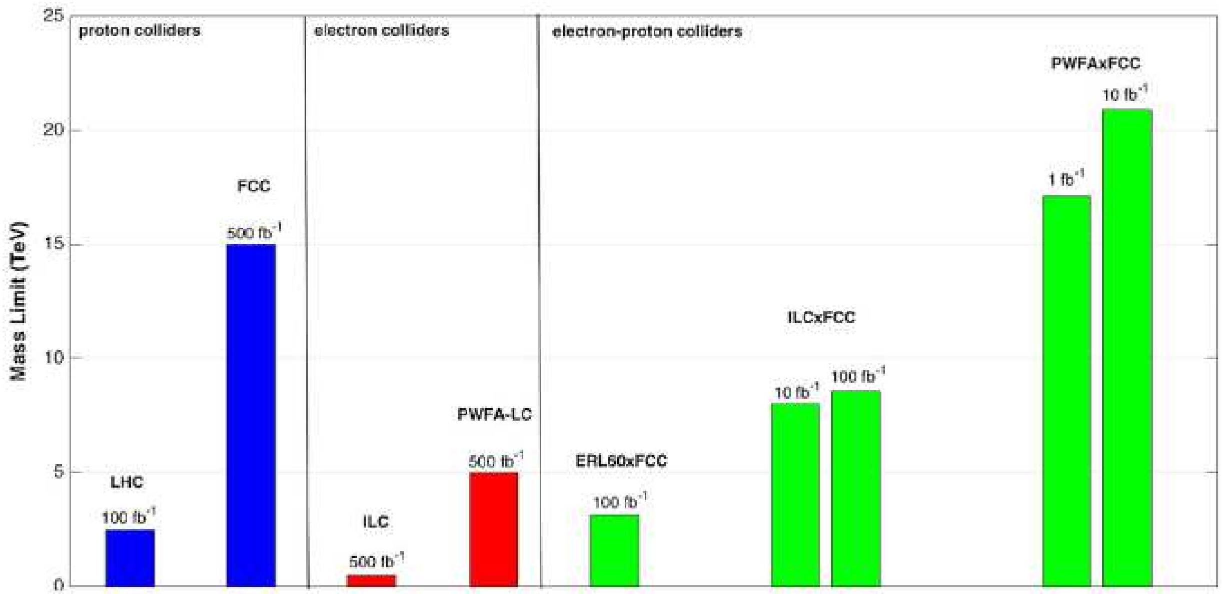

Fig. 2. Discovery limits for color octet electron at different pp, e^+e^- and ep colliders [46]. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

LC×FCC based γp and γA colliders

These machines can be **realised only on the base of linac-ring type** ep and eA colliders
$\sqrt{s}(\gamma p) \sim 0.9\sqrt{s}(ep)$ and $L(\gamma p) \sim 0.6L(ep)$

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Nuclear Instruments and Methods in Physics Research A 365 (1995) 317–328
NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A

Main parameters of TeV energy γp colliders

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Department of Physics, Faculty of Sciences, Ankara University, 06100 Tandoğan, Ankara, Turkey

Received 20 February 1995

Abstract
The main parameters of TeV energy γp colliders have been investigated for HERA+LC, LHC+TESLA and LHC+e-Linac proposals in detail. In this research, the luminosity of γp collisions and the helicity of the high energy γ beam for these colliders are studied in terms of the distance between the conversion region and the collision point as well as γp invariant mass. The main design problems are also discussed.

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Nuclear Instruments and Methods in Physics Research A 576 (2007) 287–293
NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A
www.elsevier.com/locate/nima

Conversion efficiency and luminosity for gamma-proton colliders based on the LHC-CLIC or LHC-ILC QCD explorer scheme

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A.K. Çiftçi et al./Nucl. Instr. and Meth. in Phys. Res. A 365 (1995) 317–328

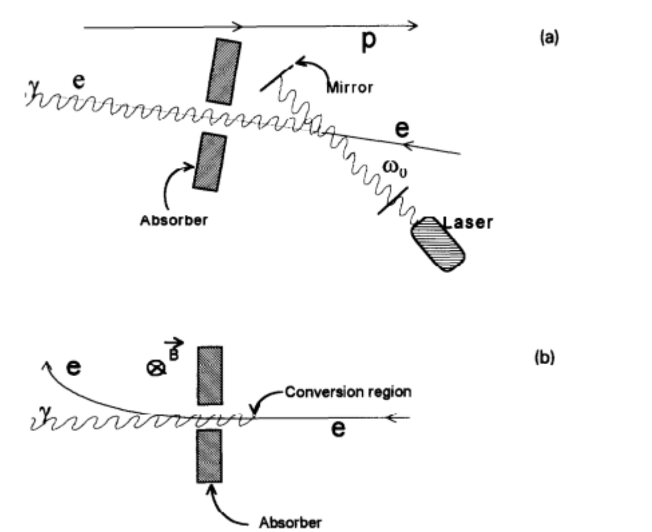
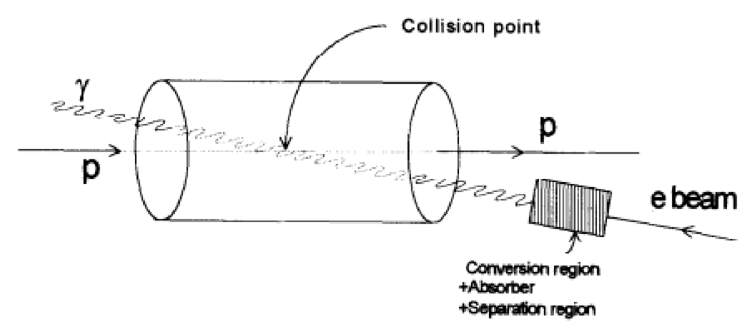


Fig. 16. Schematic view of the part of the design between the conversion region and the detector. (a) Horizontal plane, (b) vertical plane.



According to VMD γA means $\boldsymbol{\rho}$A collider.
Formation of the quark-gluon plasma at very high temperatures but relatively low nuclear density

FEL γA colliders

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Nuclear Instruments and Methods in Physics Research A 428 (1999) 271–275
NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A
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New tool for "old" nuclear physics: FEL γ-nucleus colliders

H. Aktaş[a], N. Büget[b], A.K. Çiftçi[a,*], N. Meriç[a], S. Sultansoy[b,c], Ö. Yavaş[b]

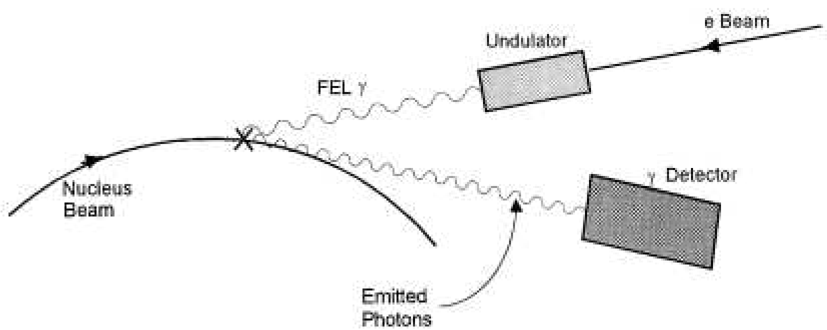

Fig. 1. General schematic view of the proposed design.

Effective tool for nuclear spectroscopy…

keV energy FEL photons will be seen as a «laser» beam in the MeV energy range in the rest frame of the nucleus.

In the nucleus rest frame the energy of FEL photon is multiplied by $2\gamma(\mathrm{N})$, where $\gamma(\mathrm{N})$ is the Lorentz factor of the nucleus:
$\gamma(\mathrm{N}) \sim 3000$ for LHC
$\gamma(\mathrm{N}) \sim 20{,}000$ for FCC

Excited nucleus will turn to the ground state at a distance $l = \gamma(\mathrm{N})\tau(\mathrm{N})c$ from the collision point, where $\tau(\mathrm{N})$ is the lifetime of the excited state in the nucleus rest frame and c is the speed of light. As an example, for the 4847.2 keV excitation of 208Pb nucleus at FCC l=4×10(-4) m. Therefore, the detector should be placed close to the collision region. The 5 MeV energy photons emitted in the rest frame of the nucleus will be seen in the detector as high energy photons with energies up to 200 GeV.

Hindawi
Advances in High Energy Physics
Volume 2017, Article ID 4021493, 6 pages
https://doi.org/10.1155/2017/4021493

Research Article

SppC Based Energy Frontier Lepton-Proton Colliders: Luminosity and Physics

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Main parameters of Super proton-proton Collider (SppC) based lepton-proton colliders are estimated. For electron beam parameters, highest energy International Linear Collider (ILC) and Plasma Wake Field Accelerator-Linear Collider (PWFA-LC) options are taken into account. For muon beams, 1.5 TeV and 3 TeV center of mass energy muon collider parameters are used. In addition, ultimate μp collider which assumes construction of additional 50 TeV muon ring in the SppC tunnel is considered. It is shown that luminosity values exceeding 10^{32} cm^{-2} s^{-1} can be achieved with moderate upgrade of the SppC proton beam parameters. Physics search potential of proposed lepton-proton colliders is illustrated by considering small Björken x region as an example of SM physics and resonant production of color octet leptons as an example of BSM physics.

3.1. Small Björken x. As mentioned above, investigation of extremely small x region ($x < 10^{-5}$) at sufficiently large Q^2 (>10 GeV^2), where saturation of parton density should manifest itself, is crucial for understanding of QCD basics. Smallest achievable x at lp colliders is given by Q^2/S. For LHeC with $\sqrt{s} = 1.3$ TeV minimal achievable value is $x = 6 \times 10^{-6}$. In Table 9, we present smallest x values for different SppC based lepton-proton colliders (E_p is chosen as 68 TeV). It is seen that proposed machines has great potential for enlightening of QCD basics.

TABLE 9: Attainable Björken x values at $Q^2 = 10$ GeV^2.

E_l (TeV)	0.5	5	1.5	50
x	7×10^{-8}	7×10^{-9}	2×10^{-8}	7×10^{-10}

3.2. Color Octet Leptons. Color octet leptons (l_8) are predicted in preonic models with colored preons [31]. There are various phenomenological studies on l_8 at TeV energy scale colliders [32–39]. Resonant production of color octet electron (e_8) and muon (μ_8) at the FCC based lp colliders (http://collider-reach.web.cern.ch/collider-reach) have been considered in [40] and [41], respectively. Performing similar

It should be noted that FCC/SppC based lp colliders have great potential for search of a lot of BSM phenomena, such as excited leptons (see [45] for μ^*), contact interactions, and R-parity violating SUSY.

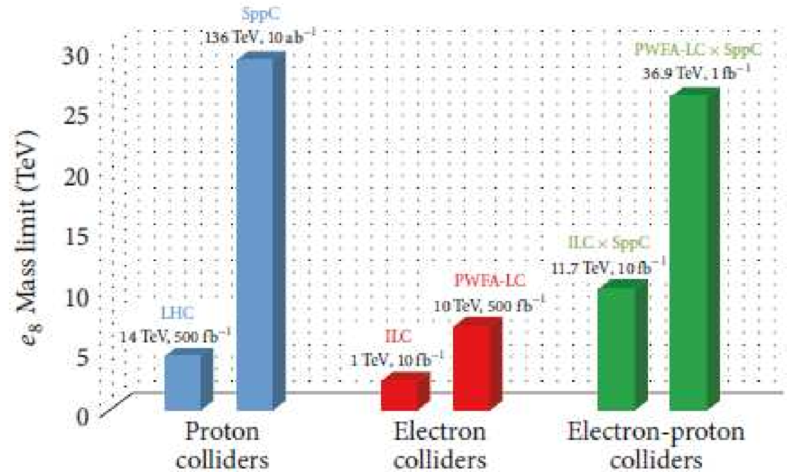

FIGURE 2: Discovery mass limits for color octet electron at different pp, e^+e^-, and ep colliders.

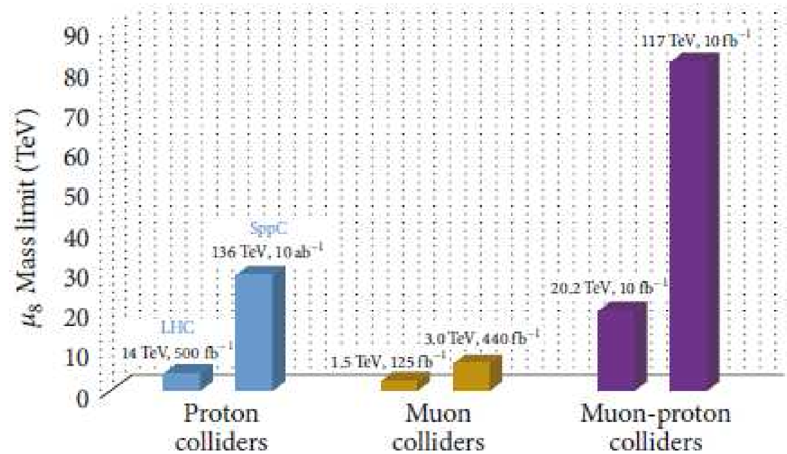

FIGURE 3: Discovery mass limits for color octet muon at different pp, $\mu^+\mu^-$, and μp colliders.

Why leptogluons ?

More than 50 fundamental particles and **26 free parameters** in the minimal SM3 indicates that the Standard Model is manifestation of **more fundamental theory.**

Physics met similar situation two times in the past:

Stages	1870s-1930s	1950s-1970s	1970s-2020s	
Fundamental Constituent Inflation	Chemical Elements	Hadrons	Quarks, leptons	
Systematic	Periodic Table	Eight-fold Way	Flavor democracy?	⇒ **Family replication**
Confirmed Predictions	New elements	New Hadrons	Fourth family?	⇒ **e8, μ8, q6 ...**
Clarifying Experiments	Rutherford	SLAC DIS	LHC?	⇒ **or rather FCC**
Building Blocks	Proton, neutron, electron	Quarks	Preons?	
Energy Scale	MeV	GeV	TeV?	
Impact on Technology	Exceptional	Indirect	Exceptional?	

- Periodic Table of the Elements was clarified by Rutherford's experiment
- Hadron inflation has resulted in quark model
- This analogy implies the preonic structure of the SM fermions

Answer: in models with colored preons leptogluons have the same status as excited leptons and quarks

The TAC project

ECFA EUROPEAN COMMITTEE FOR FUTURE ACCELERATORS
EIGHTY-EIGHTH PLENARY ECFA MEETING
25-26 November 2010, CERN

THE CORNESTONE OF THE TAC PROJECT: LINAC-RING TYPE SUPER-CHARM FACTORY

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S. SULTANSOY 25.11.2010 CERN 1

Introduction

- Accelerator technology ➲ a generic technology ➲ locomotive of the development in almost all fields of science and technology.
- Accelerator technology should become widespread all over the world.
- Existing situation: a large portion of the world (the South Hemisphere, Mid-East and Central Asia) is poor on the accelerator technology.
- Worldwide strategy covering developing countries is needed (under the leadership of ICFA, ECFA, ACFA)

S. SULTANSOY 25.11.2010 CERN

Birth of TAC

Region means: Mid East + Balkans + Caucasus + Central Asia

Doğa – Tr. J. of Physics
17 (1993), 591 – 597.

Regional Project for Elementary Particle Physics Linac-Ring Type c-τ-Factory *

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Received 25.1.1993

Abstract

Linac-ring type e^+e^- collider with $\sqrt{s} = 3 - 5$ GeV is proposed as the regional project for elementary particle physics. It is shown that modern accelerator technology makes it possible to achieve luminosity $\mathcal{L} = 10^{34} cm^{-2}s^{-1}$. The possible physical goals of this machine in investigation of charmed particles, τ-lepton and ψ properties is briefly discussed.

1. Introduction

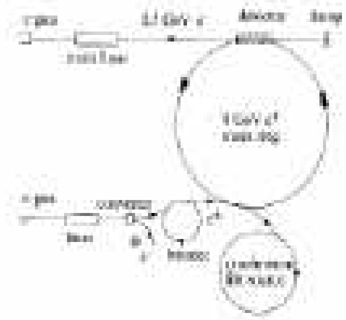

Figure 1. The proposed scheme for linac-ring c-τ factory

Table 1. Basic parameters of linac-ring c-τ factory

Parameters	e^--linac		e^+-ring
Energy (GeV)	0.5		8.0
$\sqrt{s}$ (GeV)		4	
Radius (m)	-		100
Length (m)	50		-
Particles per bunch, n (10^{10})	0.1		10
Collision rate, f_c (MHz)		30	
Bunches per ring, k	-		60
Current, I (mA)	.5		500
Energy loss/turn, ΔE (MeV)	-		3.6
Power (MW)	2.5		> 1.7
Beam size at IP, $\sigma_{x,y}$ (μm)	1		1
$\beta^*_{x,y}$ at IP (cm)	-		0.25
Bunch length, σ_z (cm)	0.1		0.2
Luminosity, $\mathcal{L}(cm^{-2}s^{-1})$		$2.4 \cdot 10^{34}$	

d) Synchrotron radiation. There are two possibilities: 1) to use the main positron ring as the source of synchrotron radiation; 2) to construct a new ring for this purpose. Let

c–τ–factory proposals in 1990's

- Ring–Ring: Spain (1991), JINR and BINP (1994)

  $$L = 10^{33} cm^{-2} s^{-1}$$

- Linac–Ring: Ankara group (1993)

  $$L = 10^{34} cm^{-2} s^{-1}$$

Before Crab–Waist scheme (2006) LR seemed to provide about 10 times higher Lumi.

S. SULTANSOY 25.11.2010 CERN 7

ICFA Statement on a Tau Charm Factory 31 January 1996

ICFA has noted that several intensive workshops have been held on the physics potential of a tau–charm factory. This collider is intended to operate at a luminosity of 10^{33} $cm^{-2}s^{-1}$, one hundred times the luminosity of the Beijing Electron–Positron Collider. The conclusion of these workshops is that a tau–charm factory can address issues concerning the tau, charmed particles, and light quark spectroscopy in a unique manner. Many of the issues can only be addressed by a tau–charm factory and cannot be fully addressed by B factories now under construction, or by high energy fixed target experiments.

There has been strong interest in a tau–charm factory by physicists from all regions of the world. Physicists from two nations, China and Russia, are seriously developing plans to construct such a facility. ICFA is pleased to note that the Chinese government has awarded funds of 5 million Yuan to the Institute of High Energy Physics in Beijing for the purpose of designing a tau–charm factory.

S. SULTANSOY 25.11.2010 CERN

ICFA Statement on a Tau Charm Factory 31 January 1996 (cont.)

ICFA is pleased that international workshops on a tau–charm factory have been held over the past several years and that there are plans to hold additional ones in the future. In addition, the ICFA Beam Dynamics Panel is in the process of establishing a subpanel to assist in identifying and solving the beam dynamics issues associated with a tau–charm factory. ICFA supports the planning that must be done in advance of the construction of such a facility, and supports its construction, since there is ample justification for one such facility.

ICFA looks forward to the day when a tau–charm factory can begin operation, and encourages exploitation open to an international team in accordance with the existing ICFA Guidelines for Utilization of Major Regional Experimental facilities for High Energy Particle Physics.

BEPC II srarted in 2008

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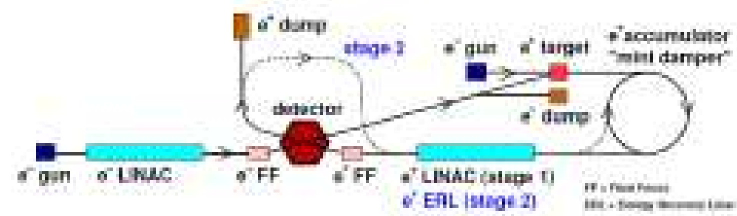
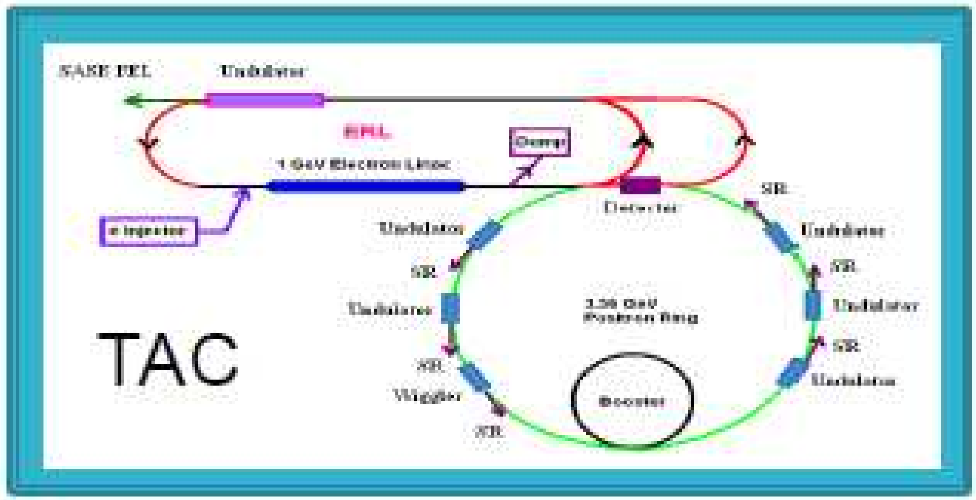
c–τ–factory proposals 2010



A. Schöning / Nuclear Physics B (Proc. Suppl.) 169 (2007) 387–392

All three proposals promise

$$L = 10^{35} cm^{-2} s^{-1}$$



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Tentative parameter list for TAC Super-C Factory

Positron ring	
Positron beam energy (GeV)	**3.56**
Number of positrons per bunch (10^{11})	2
Beta functions at IP β_x / β_y (mm)	80/5
Normalized emittances $\varepsilon_x^N / \varepsilon_y^N$ (μm)	110/0.36
σ_x / σ_y (μm)	36/0.5
σ_z (mm)	5
Beam-beam tune shift	0.012/0.13
Energy loss / turn (MeV)	0.7
Number of buches, n_b	300
Revolution frequency (MHz)	0.5
Circumference, C (m)	600
Beam current (A)	4.8

Electron ERL	
Electron beam energy (GeV)	1
Number of electrons per bunch (10^{10})	2
Beta functions at IP β_x / β_y (mm)	80/5
Normalized emittances $\varepsilon_x^N / \varepsilon_y^N$ (μm)	31/0.1
σ_x / σ_y (μm)	36/0.5
σ_z (mm)	5
Disruption Dx/Dy	0.33/60
Beam current (A)	0.48
Collider Parameters	
Crossing angle (mrad)	34
Collision frequency (MHz)	150
Luminosty	$1.4 \cdot 10^{34}$

Studies for reducing Dy are continuing

Further Lumi increase could be achieved by:
- increasing collision frequency
- shortening electron bunches with subsequent use of "dynamic focusing" (Brinkmann-Dohlus, DESY-M-95-11 (1995))

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Physics at Super-Charm Factory

- τ option is weak.
  SuperB vs Super-c-τ: 2.5 times lower σ, but 10 times higher L
- Basic operation at $\Psi(3S)$
- Energy asymmetry is essential for time-dependent CPV analysis
  - Boost examples from *B*-factories are:
  - KEKB, the boost is $\beta\gamma = 0.43$.
  - PEP-II, used a slightly larger boost $\beta\gamma = 0.55$.

In TAC/PF, the boost is $\beta\gamma = 0.68$.

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Outlook

For Charm Factory

Benchmark physics processes should be reviewed for a factory with asymmetrical beam energies.

Various synergy options within the TAC project should be evaluated.

TAC SR (same e+ ring vs dedicated ring, sharing infrastructure)

TAC FEL (time, infrastructure, expertise etc... sharing)

International collaborations with similar projects will be mutually beneficial:

LHeC LR option, eRHIC LR option

For TAC in general

1 GeV SNS (based on TAC PA) is mandatory.

ADS studies (based on TAC PA) should be intensified.

Strong international cooperation opportunities should be seized.

We are seeking ECFA support for LR type colliders in general and for TAC project in particular.

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Conclusions and recommendations

ERL ('classical') is mandatory for TAC Super-Charm Factory, nesessary for EIC (e-RHIC etc), may be useful for LHeC

OPL/LC advantages:

- **possibility for energy upgrade**
- ***γp* and *γp* colliders**
- **electron, positron and photon polarization**

ERL60 as sole option for LHeC (2014) is incorrect decision
ERL60 as sole option for FCC-eh (2017) is more than incorrect decision

LHeC and FCC-eh studies should be disentangled !!!

TAC Super-Charm factory related work was de-facto stopped in 2003. These studies should be restarted.

Finally:
In 1990'ies the majority of papers on Linac-Ring type colliders had Ankara and/or Baku address , After 2000 ~ half of papers. Therefore, our comments and recomendations should not be ignored.

For correct Euro-HEP strategy we need:

- Systematic study (accelerator, physics and detector aspects) for the FCC based ep, eA, μp, μA, γp, γA and FEL γA colliders.

- Comparison of physics search potentials of hadron, lepton and lepton-hadron colliders for different BSM phenomena.

In order to do these:

- FCC subgroup on lh and γh colliders (may be DESY leaded) a'la FCC-ee.

- Dedicated Workshops a'la FCC-ee etc.

In this content comparison of

ERL60×FCC with $\sqrt{s} = 3.46$ TeV and $L = 10^{34\text{-}35}$ cm^{-2} s^{-1}

ILC×FCC with $\sqrt{s} = 10$ TeV and $L = 10^{33\text{-}34}$ cm^{-2} s^{-1}

PWFA-LC×FCC with $\sqrt{s} = 30$ TeV and $L = 10^{32\text{-}33}$ cm^{-2} s^{-1}

will be useful.

FCC based lh and γh colliders, especially γA option, will provide deeper understanding of QCD basics and in general strong interactions from quark to nuclei level.

FCC based ep (μp) collider will be powerful tool for BSM physics connected to first (second) family leptons and quarks.

….

Thank You for your attention.

Any questions or comments?

This work is supported by TÜBİTAK under grant No 114F337

Appendix 1: Second Way to TeV Scale

Eur Phys J C **33**, s01, s1064–s1066 (2004)
Digital Object Identifier (DOI) 10.1140/epjcd/s2004-03-1716-2

EPJ C direct
electronic only

Linac-ring type colliders: Second way to TeV scale

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Published Online: 3 March 2004 – © Springer-Verlag / Società Italiana di Fisica 2004

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.

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.

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	$10 \div 100$

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AU-HEP-99/02
October 1999

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The post-HERA era: brief review of future lepton-hadron and photon-hadron colliders

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Institute of Physics, Academy of Sciences, Baku, Azerbaijan

Abstract

Options for future *lp*, *lA*, *γp*, *γA* and FEL *γA* colliders are discussed.

CONTENTS

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[physics.acc-ph] 12 Dec 1997

Linac-Ring Type Colliders: Fourth Way To TeV Scale

R. Brinkmann[a], A. K. Çiftçi[b], S. Sultansoy[b,c], Ş. Türköz[b], F. Willeke[a], Ö. Yavaş[b], M. Yılmaz[d]

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The present status of suggested linac-ring type *ep* and γp colliders is reviewed. The main parameters of these machines as well as *e*-nucleus and γ-nucleus colliders are considered. It is shown that sufficiently high luminosities may be achieved with a reasonable improvement of proton and electron beam parameters.

Tr. J. of Physics
22 (1998) , 575 – 594.

International Workshop on Linac-Ring Type *ep* and γp Colliders

Four Ways to TeV Scale

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Abstract

Four known types of colliders, which may give an opportunity to achieve TeV center of mass energies in the near future (10-15 years), are discussed. Parameters of the linac-ring type *ep* and γp machines are roughly estimated. Some speculations on TeV scale physics are given. The physics goals of the TeV energy *ep* and γp colliders are considered.

Ankara workshop 1997
http://journals.tubitak.gov.tr/physics/issue.htm?id=175

Plenary ECFA – CERN (25-26 November 2010)

https://indico.cern.ch/event/111130/contribution/27/material/slides/1.pdf

Classification of colliders

1. Colliding particles
- hadrons
- leptons
- lepton-hadron

2. Collider schemes
- ring-ring
- linear
- linac-ring

The ring-ring colliders are the most advanced ones from technology point of view and are widely used around the (developed) world.

The linear (linac-linac) colliders are less familiar; however, a lot of experience is gained through Standard Linear Collider (SLC) operation and ILC/CLIC related workout.

The linac-ring colliders require more R&D.

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Linac-ring type colliders: two directions*

Lepton-hadron and photon-hadron colliders:

UNK+VLEPP (Mid 1980's) → THERA (End 1990's) → LHeC → Energy Frontier / QCD Explorer

THERA (End 1990's) → eRHIC/EIC/ELIC

Factories:

B-factory (Grosse-Wiesmann) → c-τ-factory → Super-Charm factory (TAC project)

c-τ-factory → ϕ-factory (Ankara group)

* For details and ref's see: A. Akay, H. Karadeniz and S. Sultansoy, Review of Linac-Ring-Type Collider Proposals, Int. J. Mod. Phys. A 25 (2010) 4589

International Journal of Modern Physics A
Vol. 25, No. 24 (2010) 4589–4602

DOI: 10.1142/S0217751X10049165

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www.worldscientific.com

REVIEW OF LINAC–RING-TYPE COLLIDER PROPOSALS

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There are three possible types of particle colliders schemes: familiar (well-known) ring–ring colliders, less familiar but sufficiently advanced linear colliders, and less familiar and less advanced linac–ring-type colliders. The aim of this paper is twofold: to present a possibly complete list of papers on linac–ring-type collider proposals and to emphasize the role of linac–ring-type machines for future HEP research.

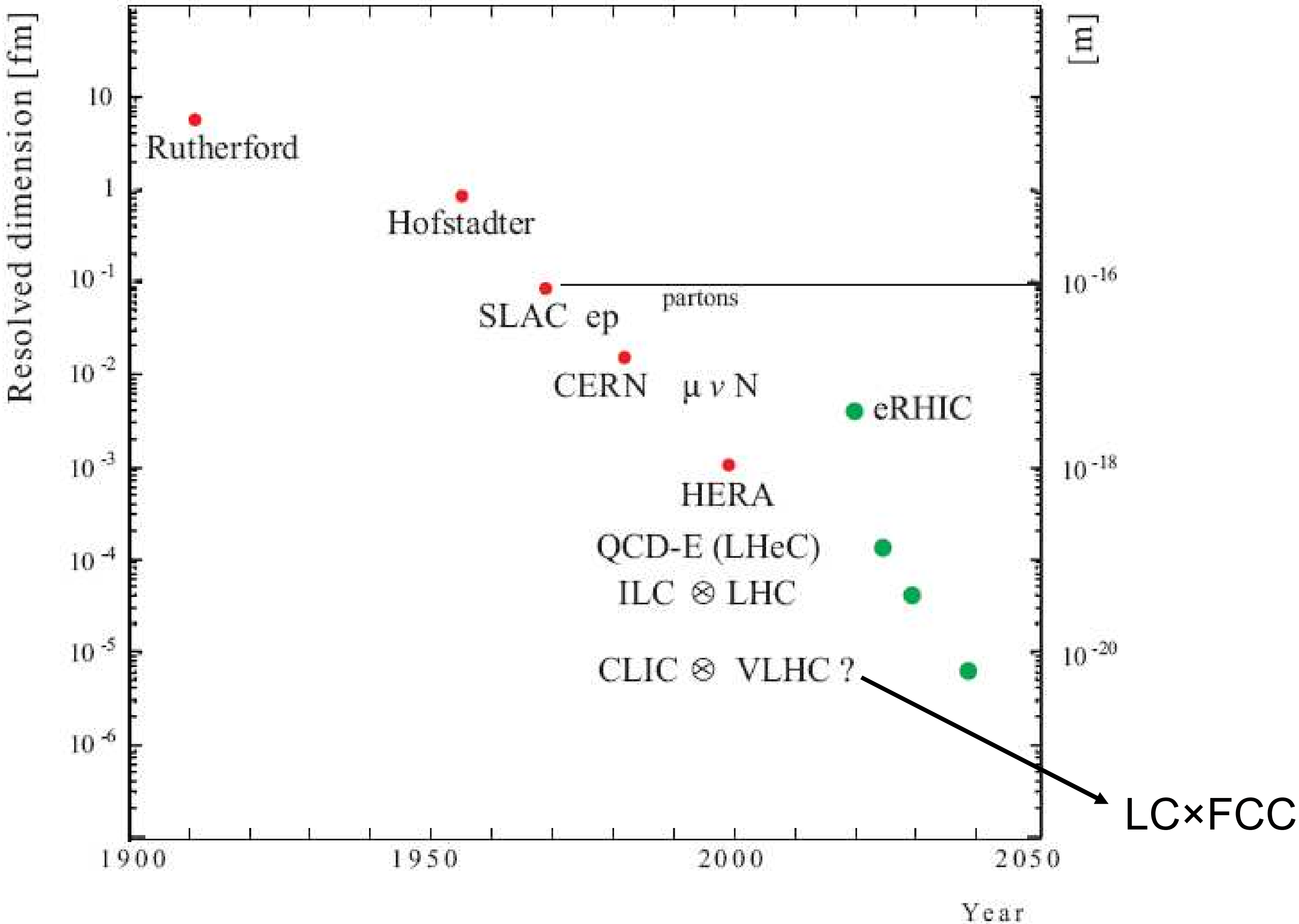


Fig. 1. The development of the resolution power of the experiments exploring the inner structure of matter over time from Rutherford experiment to CLIC ⊗ VLHC.

Forty years ago, John Rees[2] proposed a collision of 20 GeV SLAC electron beam with 3 GeV stored positrons in order to handle 15.5 GeV center-of-mass energy electron–positron collisions with a luminosity of 5×10^{29} cm^{-2}s^{-1}. Two years later, this proposal was reconsidered in Ref. 3 keeping in mind 2 GeV stored electrons (or positrons) which corresponds to 12.6 GeV center-of-mass energy with

a luminosity of 2.4×10^{29} cm^{-2}s^{-1}. Both proposals were considered as possible upgrades for SLAC accelerator.[4] In the subsequent 15 years, only one paper on this subject was published.[5] The purpose was to choose a linear collider option for SLAC upgrade: the SLC construction began in 1983 and completed in 1989. In 1979, linac–ring scheme was considered merely as an alternative to SSC-based ring–ring-type of 140 GeV+20 TeV electron–proton collider (Ref. 6; see also Ref. 7).

The idea was reborn in mid-1980's when it was proposed to combine linear electron–positron and ring-type proton colliders to realize additional TeV scale lepton–hadron collider option. Namely, it was proposed to construct VLEPP tangentially to UNK.[8] This scheme would provide an opportunity to handle TeV scale γp colliders too.[9] This line went on by THERA, EIC/EPIC and QCD-E/LHeC projects (for references see the corresponding sections below). An important stage in this direction was made at the International Workshop held in Ankara in 1997.[10] Reviews on the subject can be found in Refs. 11–15 and 1.

Another line deals with particle factories (Fig. 2): in 1988 Grosse-Wiesmann proposed linac–ring-type B-factory.[16–19] In 1993, linac–ring-type charm-tau factory was proposed as the regional project for Turkey and abroad.[20] The last stage of this line is represented by Super Charm Factory as part of the Turkic Accelerator Complex (TAC) Project.[21]

The present review is organized as follows. In Sec. 2, the main parameters of linac–ring-type lepton–hadron collider proposals are considered, namely, UNK + VLEPP, THERA, eRHIC, EIC, QCD Explorer (LHeC linac–ring option) and energy frontier. Photon–hadron colliders which would be constructed on the base of these colliders are considered in Sec. 3. Section 4 is devoted to proposals of linac–ring-type particle factory. Finally, in Sec. 5 some concluding remarks and recommendations are presented.

Table 2. Planned and possible *ep* colliders (as for 1989[11]).

Machine	$\sqrt{s}$, TeV	E_e, TeV	E_p, TeV	n_e, 10^{10}	n_p, 10^{10}	Coll. rate, f (Hz)	L, 10^{30} cm^{-2}s^{-1}
Standard *ep* machines							
HERA	0.3	0.03	0.82	3.48	10	10^7	15
LHC+LEPI	1.3	0.05	8	8.2	30	5×10^6	200
LHC+LEPII	1.8	0.1	8	8.2	30	5×10^6	10
UNK+e-ring	0.6	0.03	3	—	—	—	100
SSC+e-ring	2.8	0.1	20	—	—	—	100
New type *ep* machines[a]							
UNK+VLEPPI	2.4	0.5	3	20	100	100	1÷10
UNK+VLEPPII	3.5	1	3	20	100	100	1÷10
UNK+VLEPP[b]	4.9	2	3	20	100	100	1÷10
LHC+CLIC[b]	8	2	8	0.5	100	6×10^3	10÷100
LHC+CLIC[c]	4.8	0.7	8	0.6	100	10^4	10÷100
SSC+LSC[b]	28	10	20	0.08	100	8×10^4	100
LHC+e-linac[d]	3	0.3	8	0.08	100	5×10^5	5×10^3
SSC+e-linac[d]	8	0.8	20	0.05	100	5×10^5	10^4
Electron–proton linacs[e]							
VLEPP+p10	2	1	1	20	20	100	1÷10
LSC+p10	10	5	5	0.08	0.08	8×10^4	100

[a]Given parameters corresponds to *ep* collisions in the proton ring.
[b]Asymmetric version (see Fig. 3(b)).
[c]*ep* version of Linac-LEP Collider with $\sqrt{s} = 0.5$ TeV proposed by C. Rubbia (see Ref. 24).
[d]P. Grosse-Wiesmann's proposal: electron linacs parameters are optimized for *ep* collisions (see Ref. 16).
[e]One shoulder of the e^+e^- linac can be used for acceleration of protons, if 10 GeV proton ring is added at its beginning.

2.4. *QCD Explorer (LHeC linac–ring option, CERN)*

QCD Explorer means to construct a moderate energy electron linac (50–100 GeV) tangentially to LHC ring. This construction will provide opportunity to utilize highest energy hadron beams for lepton–hadron collisions. QCD Explorer has two main goals:

(i) to get more precise data on PDF's which will be necessary for adequate interpretation for future LHC data;
(ii) to enlighten fundamentals of QCD.

For this purpose, the technologies for electron–positron colliders, which have developed up to now can be used or new technologies can be created.

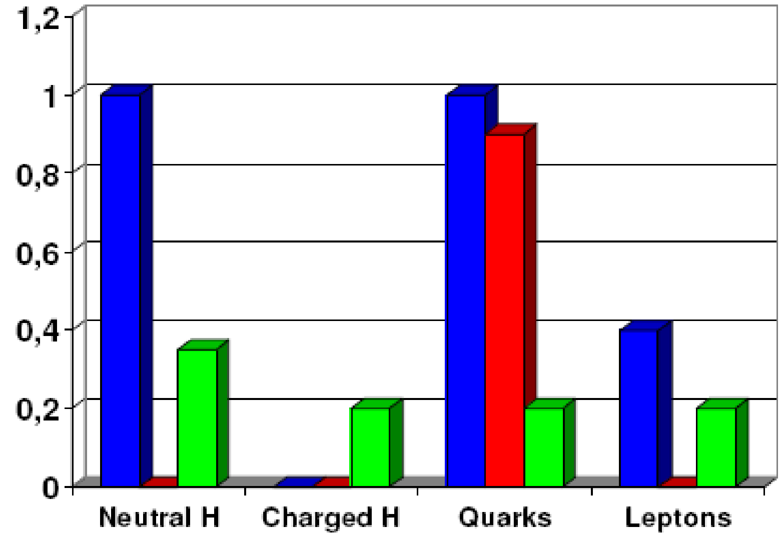
2.5. *Energy frontier (CERN)*

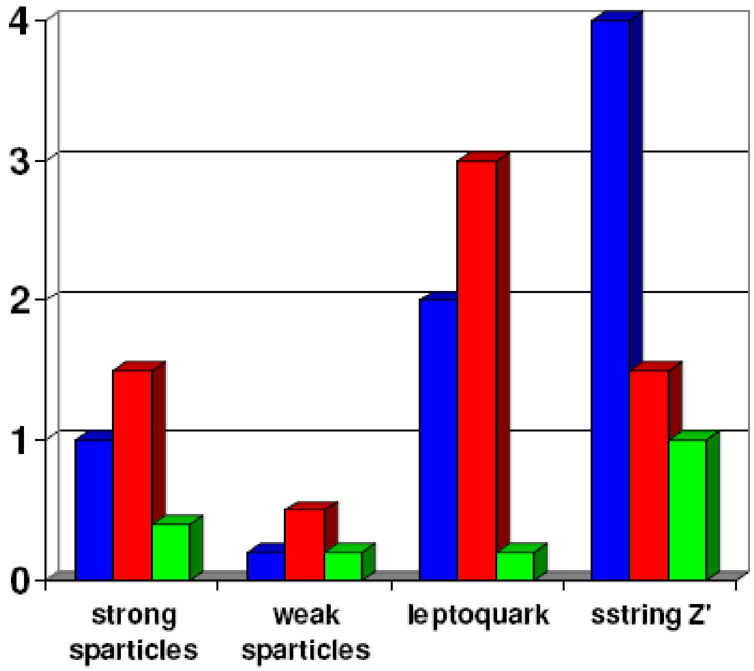
If $E_c \geq 500$ GeV, LHC based ep colliders are named as energy frontier. These high energies are inconvenient to use energy recovery. Nevertheless, $L = 10^{32}$ cm^{-2}s^{-1} seems to be achievable with pulsed linac.[41] It is useful to compare physics search potential of three colliders which can be considered as energy frontiers in foreseen future. Namely,

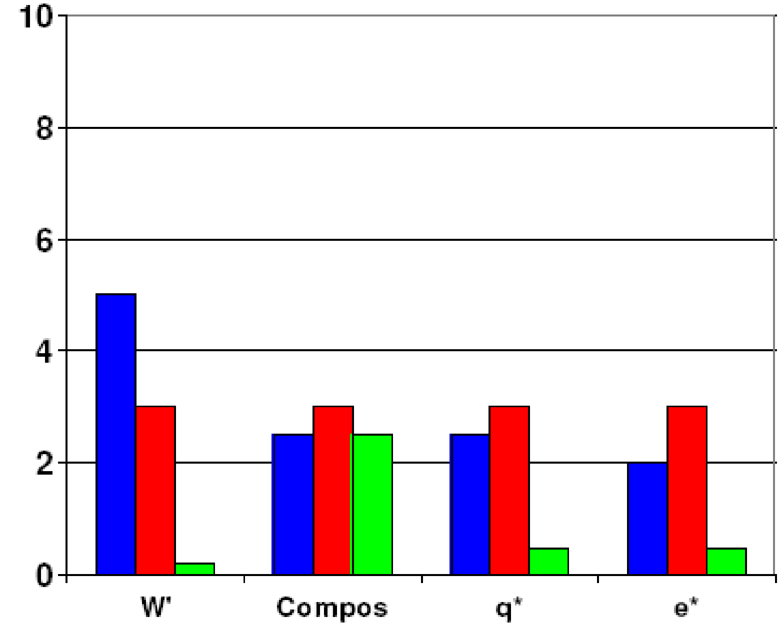
(i) $\sqrt{s} = 14$ TeV pp collider with $L = 10^{34}$ cm^{-2}s^{-1} (LHC);
(ii) $\sqrt{s} = 0.5$ TeV e^+e^- collider with $L = 10^{34}$ cm^{-2}s^{-1} (ILC);
(iii) $\sqrt{s} = 3.7$ TeV ep collider with $L = 10^{32}$ cm^{-2}s^{-1} ("ILC" $\times$ LHC).

Rough estimations[14] show that the total capacity of ep and γp options for BSM physics (SUSY, compositeness, etc.) research essentially exceeds that of 0.5 TeV linear collider.

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







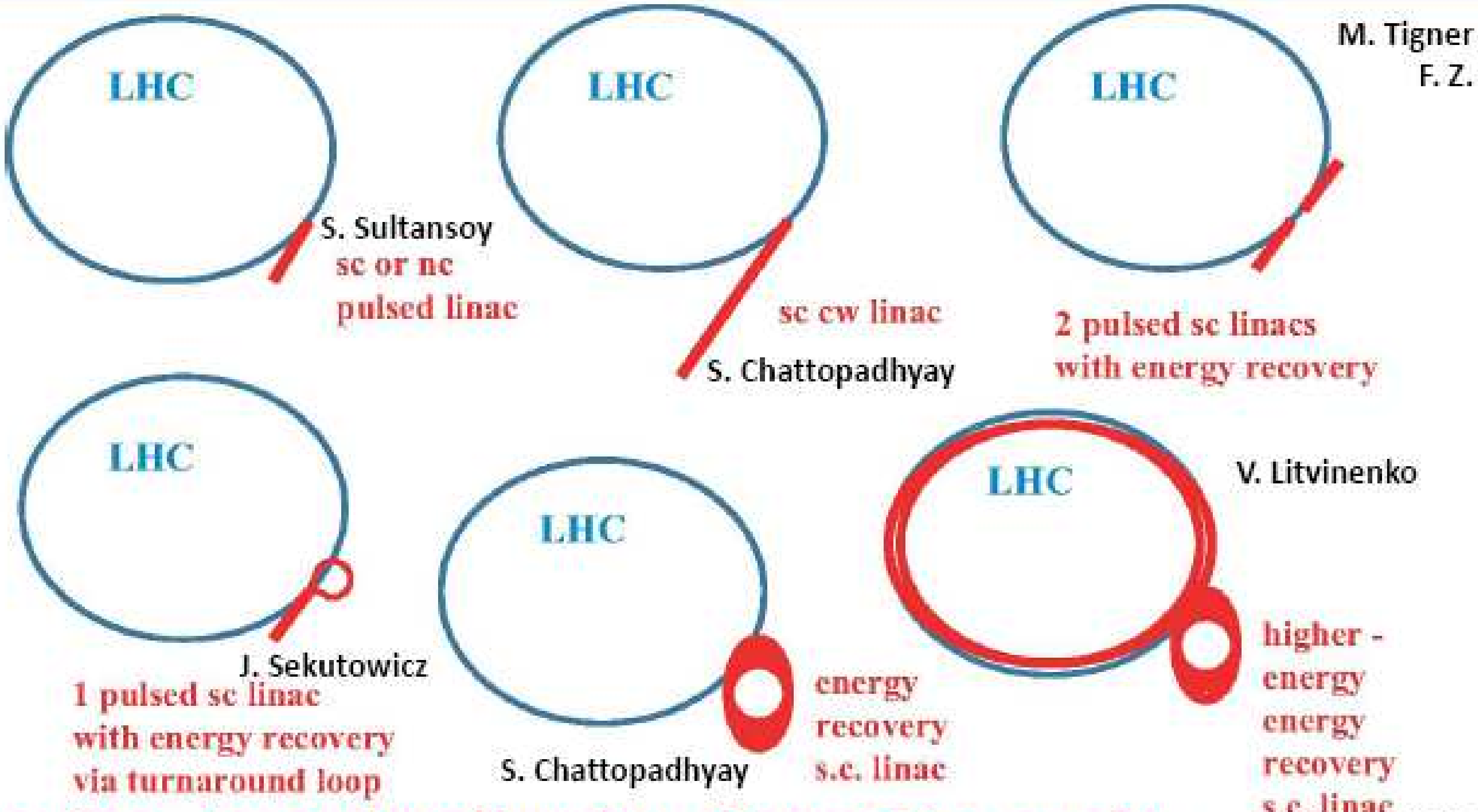
(F. Zimmermann, 1st ECFA-CERN LHeC Workshop, 02.09.2008)

LR e-p motivation

- colliding 7 TeV p's with 25-140 (-300) GeV e-'s:
  - → extending LHC discovery reach
  - → enabling LHC precision physics
- history: - Ankara workshop 1997, Turkish JP, 22, 7 (1998)
  - -S. Sultansoy, Aachen 2003, EPJ C33: S1064 (2004)
  - -D.Schulte,F.Zimmermann, EPAC'04 (CLIC-1/LHC p s-bunch)
  - -H. Aksakal et al, NIM A576: 287 (2007) (CLIC & ILC vs LHC)
  - - S. Chattopadhyay: ***cw!, ERL!*** (2007), A. Eide's report (2008)
  - -V. Litvinenko, CERN AB Form 11 March 2008
  - -F. Zimmermann et al, EPAC'08
  - -J. Skrabacz' report (2008)
- e- linac offers several distinct advantages
  e.g.: separation from LHC, high beam quality, synergies

(F. Zimmermann, 1st ECFA-CERN LHeC Workshop, 02.09.2008)

LR scenarios



s.c. linac , long trains of bunches, 25-ns or 50-ns spacing, matching LHC p beam (*PLACET: stable*); long pulse or cw → high luminosity; optional energy recovery → higher luminosity; 1.3 GHz (ILC) or 700 MHz (SPL)

LHeC/QCD-E:

A Large Hadron electron Collider at CERN. Webpage:
http://lhec.web.cern.ch/
Mirror site:
http://www.ep.ph.bham.ac.uk/exp/LHeC/

CDR is published in Journal of Physics G: Nuclear and Particle Physics
Volume 39, Number 7, July 2012.