On the LHeC Project
http://cern.ch/lhec

P. Kostka - for the LHeC Study Group

NEW TRENDS IN HIGH-ENERGY PHYSICS
(experiment, phenomenology, theory)

Alushta, Crimea, Ukraine, September 3 - 10, 2011

The project is intended to become part of European deliberation of future directions of particle physics.

It must be seen in the context of the LHC and the results there; it will substantially enrich and extend its physics program and further exploits the investment made in the LHC.
New Terascale Facility

- Electrons of 60-140 GeV collide with LHC protons of 7000 GeV
- ep design $L \approx 10^{33}$ cm$^{-2}$s$^{-1}$ with $E_{cms}$ in the range of 1-2 TeV
  - exceeding the integrated luminosity at HERA by 2 orders of magnitude and the kinematic range by a factor of 20 in $(Q^2; x^{-1})$
Exciting Physics Program

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  - exceeding the integrated luminosity at HERA by 2 orders of magnitude and the kinematic range by a factor of 20 in \((Q^2; x^{-1})\)

- Physics complementing the LHC

- High precision deep inelastic scattering (DIS)

- Address important questions in strong and electroweak interactions

- Includes electron-ion (eA) scattering into a \((Q^2; x^{-1})\) 4 orders of magnitude extended compared to previous lepton-nucleus DIS experiments.

Selected Highlights

- \(\alpha_s\) measured to per mille
  \(\rightarrow\) Grand unification of the couplings

- Complete unfolding of proton structure
  \(\rightarrow\) Maximise the potential of LHC

- Saturation at low \(x\)
  \(\rightarrow\) Study in pQCD regime

- eA - nuclear structure functions
  \(\rightarrow\) Complementary to e.g. EIC

- Heavy flavour factory, precision tests of the treatment of mass in pQCD
  \(\rightarrow\) Understand the fits

- Leptoquarks, excited electrons, Higgs
  \(\rightarrow\) Complementary to LHC searches
Deep Inelastic e/μ p Scattering

Physics

eQ states
GUT ($\delta a_s=0.1\%$)
Excited fermions
Hot/cold spots
Single top Higgs
PDFs
Multi-Jets
DVCS
Unintegrated partons
Saturation
Vector Mesons
IP - graviton
Odderon
NC couplings
$\sin^2\Theta$
Beauty
Charm
Partons in nuclei
Shadowing

...
Accelerator Concept(s)

LH C
Add $e^\mp$ (polarised) on genuine p/A beams and running *simultaneously* with LHC program
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**Ring-Ring (RR)**
First considered 1984: LEP x LHC

**Difficulties:**
building e ring into LHC tunnel,
synchrotron radiation and
limitations of energy
Add $e^\mp$ (polarised) on genuine p/A beams and running simultaneously with LHC program. 

**Ring-Ring (RR)**
First considered 1984: LEP x LHC
Difficulties: building e ring into LHC tunnel, synchrotron radiation and limitations of energy

**Linac-Ring (LR)**
THera (DESY)
low interference with LHC, higher electron energy, lower lumi at reasonable power
Add $e^\mp$ (polarised) on genuine p/A beams and running simultaneously with LHC program

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The LHeC Ring-Ring

Challenging: bypassing the main LHC Detectors

For the CDR the bypass concepts were decided to be confined to ATLAS and CMS. LHCb bypass may be similar.

**Figure 7.1:** Schematic Layout of the LHeC: In grey the LEP tunnel now used for the LHC, in red the LHC extensions. The two LHeC bypasses are shown in blue. The RF is installed in the central straight section of the two bypasses. The bypass around Point 1 hosts in addition the injection.
Challenging: bypassing the main LHC Detectors

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The e-injector is a 10 GeV sc linac in triple racetrack configuration.

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Bypassing CMS: 20m distance to Cavern

Bypassing ATLAS: 100m wo survey gallery

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The LHeC Ring-Ring

Challenging: Installation with LHC circumference

requires:
support structure with efficient installation and compact magnets (Novosibirsk, CERN dipole-prototypes)

LHeC Ring Dipole Magnet
.12-.8T
1.3kA
0.8MW

5m long (35cm)²
slim + light for installation
The LHeC Ring-Ring
Integration in the LHC tunnel
The LHeC Ring-Ring

Integration in the LHC tunnel

RF Installation in IR4

Cryo link in IR3

IP2
The LHeC Ring-Ring
Integration in the LHC tunnel

- RF Installation in IR4
- Cryo link in IR3
- Arc Cell Design – Double FODO

- No interference with LHC
- Meets design parameters
- Synchrotron radiation energy loss < 50 MW (maximum dipole filling)
- 2 quadrupoles families
- Reasonable sextupole strength and length
Maximum energy with the Ring-Ring arrangement could reach about 120 GeV - however, many parameters to be extreme - rf power and synchrotron radiation effects increase $\propto E^4_e$.
The LHeC Linac-Ring
The LHeC Linac-Ring

LR LHeC: recirculating * linac with e± energy recovery, or straight linac

*) bypassing own IP
Baseline Linac-Ring Option

Super Conducting Linac with Energy Recovery & high current (> 6mA)

Two 1 km long sc Linacs (10GeV) in cw operation (Q ≈ 1010)

Relatively large return arcs
ca. 9 km underground tunnel installation
total of 19 km bending arcs
same magnet design as for RR option: > 4500 magnets
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required for high luminosity, the linac must be based on superconducting (SC) radiofrequency (RF) technology. The development and industrial production of its components can exploit synergies with numerous other advancing SC-RF projects around the world, such as the DESY XFEL, eRHIC, ESS, ILC, CEBAF upgrade, CESR-ERL, JLAMP, and the CERN HP-SPL.
Ring-Ring Option

Luminosity $10^{33}\text{cm}^{-2}\text{s}^{-1}$ rather ‘easy’ to achieve
Electrons and Positrons
Energy limited by synchrotron radiation
Polarisation ~30%
Magnets, Cryosystem: no major R+D, just D
10 GeV Injector possibly using ILC type cavities
Interference with the proton machine
Bypasses for LHC experiments (~3km tunnel)

LINAC-Ring Option

Luminosity $10^{33}\text{cm}^{-2}\text{s}^{-1}$ possible to achieve for $e^-$ with ERL
Positrons require E recovery AND recycling, L+ < L-
Energy limited by synchrotron radiation in racetrack mode
Polarisation ‘easy’ for $e^-$ ~90%, rather difficult for $e^+$
721 MHz Cavities: Synergy with SPL, ESS, XFEL, ILC, eRHIC
Cryo: fraction of LHC cryo system
Smaller interference with the proton machine
Bypass of own IP
Extended dipole at ~1m radius in detector
Shafts on CERN territory (~9km tunnel below St Genis for IP2)
**Ring-Ring Option**

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**LINAC-Ring Option**

Luminosity $10^{33}\text{cm}^{-2}\text{s}^{-1}$ possible to achieve for e⁻ with ERL
*Positrons require E recovery AND recycling, L+ < L-
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Extended dipole at ~1m radius in detector
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**RR:** electrons beam circulates in the existing LHC tunnel

**LR:** less invasive with respect to the existing LHC, needs the construction of a new linear accelerator complex
LR Interaction Region

Special attention is devoted to the interaction region design, which comprises beam bending, direct and secondary synchrotron radiation, vacuum and beam pipe demands.

- **Dipoles around the IP** (2 x 9m, 0.3T)
  make electrons collide head-on with $p$-beam 2 & safely extract the disrupted electron beam.

- Simulation of SR load in the IR and design of absorbers / masks
  shielding SR from backscattering into the detector & from propagating with $e^\pm$ beam.

- Beam pipe design - **space for SR fan** - tracking/calorimetry close to the IP / beam line (goal: 1°-179°)

Figure 9.14: LHeC interaction region with a schematic view of synchrotron radiation. Beam trajectories with $5\sigma$ and $10\sigma$ envelopes are shown.

3 beams, head-on collisions

Photon Number Density at the IP

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**Photon Number Density at the IP**

- **3 beams**, head-on collisions

- **Beam pipe design** - **space for SR fan** - tracking/calorimetry close to the IP / beam line (goal: 1°-179°)
RR Beam Optics and Detector Acceptance

- **High Acceptance**
  - first e beam magnet placed at \(z= \pm 6.2\)m
  - \(L \sim 7.3 \times 10^{32} \text{ cm}^{-2} \text{ s}^{-1}\) \((1° < \theta < 179°)\)

- \(L \sim 1.3 \times 10^{33} \text{ cm}^{-2} \text{ s}^{-1}\) \((10° < \theta < 170°)\)
- **High Luminosity**
- Low \(\beta^*\) magnets near the IP (HERA2) \((at z= \pm 1.2\)m\)

- Detector flexible accommodating both HA / HL
  - (forward / backward tracker & calorimeter end-caps)

RR: 1mrad crossing angle \((25\text{ns bunch spacing}; avoiding parasitic interactions)\);
LR: head on \((but dipoles for beam separation over full detector length + beyond)\)

Consequences on detector design:

- **RR Lower Lumi, Low Q^2 access \(\rightarrow High\) Acceptance detector 1° - 179°
- **RR Higher Lumi, High Q^2 access \(\rightarrow High\) Luminosity detector 10° - 170° aperture
RR Beam Optics and Detector Acceptance

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  - ↓ factor ~ 2 only

- **Luminosity**
  - $L \sim 1.3 \times 10^{33} \text{ cm}^{-2} \text{ s}^{-1}$ ($10^\circ < \theta < 170^\circ$)
  - High Luminosity
  - Low $\beta^*$ magnets near the IP (HERA2) (at z= ±1.2m)

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- **RR Higher Lumi, High $Q^2$ access** → **High Luminosity detector** 10$^\circ$ - 170$^\circ$ aperture
The LHeC Detector Concept(s)

• High Precision
  resolution, calibration, low noise at low y, tagging of b,c;
  based on the recent detector developments, using settled technology, 
  avoiding R&D programs.

• Modular and flexible - accommodating the HA/HL physics programs (RR); 
  High modularity - “fast” detector construction above ground; access.

• Small radius and thin beam pipe optimized in view of aperture 
  (1-179° acceptance for low $Q^2$, high $x$ access), 
  synchrotron radiation and background production.

• Affordable - comparatively reasonable cost.
LR detector in the r-z plane

dipole (radius \(\sim 0.6\text{m}, 0.3\text{T}\)) and solenoid (3.5T) placement between the electromagnetic and the hadronic calorimeters.

The IP is surrounded by a central tracker system, large forward and backward tracker telescopes and sets of calorimeters.

Detector dimensions \(z\approx14\text{m}, \text{ diameter } \varnothing\approx9\text{m}\).
LR detector in the r-z plane
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Detector dimensions z≈14m, diameter ∅≈9m.

RR option only (no dipole) - High Acceptance
Option studied also where the larger solenoid surrounds the hadronic calorimetry.

Magnetic field outside the solenoid (3.5T) is ≈1.5T;
Volume instrumented with 3 multilayers of muon chambers.

The overall dimensions of this detector configuration are about 11m length and 8m diameter.
The baseline configuration (LR case).

Central barrel:
- silicon pixel detector (CPT)
- silicon tracking detectors (CST, CFT/CBT)
- electromagnetic calorimeter (EMC)
- surrounded by the magnets (Solenoid, Dipoles)
- hadronic calorimeter (HAC)

Backward silicon tracker (BST)
- energy measured in the BEC and BHC calorimeters

Forward silicon tracking (FST)
- and calorimetry (FEC, FHC) measuring TeV energy final states
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Detector design
- follow BP shape (CPT/CST shown)

Linac-Ring - beam pipe
inner-$R_{\text{circ}}$=2.2cm
inner-$R_{\text{elliptical}}$=10.cm
The baseline configuration (LR case).

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Main detector for the RR
- luminosity maximised by low $\beta$ quadrupole magnets

The forward/backward tracking has been removed and the outer calorimeter inserts have been moved nearer to the interaction point.

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For numeric studies and plots see recent talks at
DIS10, DIS11, ICHEP10, EPS11, IPAC11, …
EIC and LHeC Workshops
at [http://cern.ch/lhec](http://cern.ch/lhec)
of course: CDR to be published (more then 500 pages yet)
CERN Medium Term Plan
draft as of July 2011, from [724]

Not yet approved!

## LHeC Tentative Time Schedule

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Machine only

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We base our estimates for the project timeline on the experience of other projects, such as (LEP, LHC and LINAC4 at CERN and the European XFEL at DESY and the PSI XFEL). In
## Next Steps of the LHeC Project

### 2011
1. Complete CDR Draft ✓
2. Workshop on positron intensity (20.5.11 at CERN) ✓
4. Update and Print and Hand in to ECFA/NuPECC/CERN
5. Workshop on Linac vs Ring (Fall 2011) [main features, R+D design]

### 2011/12
1. Participation in European Strategy Process (EPS Grenoble ... 2012 conclusion)
2. Update physics programme when LHC Higgs/SUSY results consolidate (DIS12)
3. Form an international accelerator development group based at CERN
4. Build an LHeC Collaboration for preparation of LoI on the Detector

**Predicting is difficult, in particular when it concerns the future (V. Weisskopf)**

**but there is a project and a plan and so there shall be a future for DIS at the energy frontier**
Conclusions

• Both machine variants RR/LR could be realised in time for the HL LHC running (~2023)
  - some R&D / prototyping necessary (LR mostly);
  - synergies with other projects

• The detector ensuring the physics program
  - high precision; first simulations promising
  - flexible/modular
  - using available technology

• New and exciting physics of DIS in $e^{\mp}_{\text{polarized}} \cdot \frac{p}{A}$ at CERN

• Thanks to my colleagues from whom I have taken slides/details and with whom I’m enjoying the LHeC adventure

• … the LHeC is already half built (J.Engelen)
Fruitfully Collider Triumvirate at Terascale

The TeV Scale [2010-2035..]

pp
- W, Z, top
- Higgs??
- New Particles??
- New Symmetries?
- LHC

ep
- High Precision QCD
- High Density Matter Substructure??
- eq-Spectroscopy??
- LHeC

New Physics

e^+e^-
- tt
- Higgs??
- New Spectroscopy??
- ILC/CLIC

Max Klein, Liverpool

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No one could work full time on LHeC
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Accelerator: Participating Institutes
HERA – an unfinished programme

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<th>Topic</th>
<th>Details</th>
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<td>Low x: DGLAP seems to hold though ln1/x is large Gluon Saturation not proven</td>
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<td>High x: would have required much higher luminosity [u/d ?, xg ?]</td>
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<td>Strange quark density ?</td>
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<td>Neutron structure not explored</td>
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<td>Nuclear structure not explored</td>
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<td>New concepts introduced, investigation just started:</td>
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<td>-parton amplitudes (GPD's, proton hologram)</td>
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<td>-diffractive partons</td>
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<td>-unintegrated partons</td>
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<td>Partonic structure of the photon</td>
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<td>Instantons not observed</td>
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<td>Odderons not found</td>
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<td>...</td>
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<tr>
<td>Fermions still pointlike</td>
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<td>Lepton-quark states (as in RPV SUSY) not observed</td>
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High Precision Gluon Measurements

NLO QCD “Fits” of LHeC simulated data

HERA + LHeC
$F_2 + F_L$
$Q^2 = 2 \text{ GeV}^2$
Heavy Flavour @ LHeC

Events per 10 fb−1 Lumi

- charm γp: $10^{10}$
- charm DIS: $10^8$
- beauty γp: $4 \times 10^6$
- beauty DIS: $4 \times 10^5$
- CC e+p: $10^5$
- sW → c: $10^3$
- sW → c\bar{c}: Obtained with PYTHIA, RAPGAP and LEPTO
- tt γp DIS: $10^{-3}$

LHeC is a flavour factory
Inclusive diffraction: new possibilities

- Studies with 1 degree acceptance,
- Constraints on diffractive-PDFs
- Factorization (tests) in much bigger kinematics range.
- Diffraction is much more sensitive to the semi-hard regime.
- Enhanced sensitivity to nonlinear/saturation effects.

Figure 6.34: Diffractive DIS kinematic ranges in $Q^2$ and $\beta$ of HERA and of the LHeC for different electron energies $E_e = 20, 50, 150$ GeV at $x_{F} = 0.01$ (left plot), and $x_{F} = 0.0001$ (right plot). In both cases, 1° acceptance is assumed for the scattered electron and the typical experimental restriction $y > 0.01$ is imposed. No rapidity gap restrictions are applied.
The LHeC will dramatically expand the coverage of nuclear DIS measurements.

- Nuclear PDF’s

Access to saturation scales $Q_s^2 \sim 5 \text{ GeV}^2$ – at $b = 0$. 

DIS 2011, Brian A. Cole, Columbia Univ.
Figure 6.18: Predictions from different models for the nuclear modification factor, Eq. (6.5) for Pb with respect to the proton, for $F_2(x, Q^2 = 5 \text{ GeV}^2)$ (plot on the left) and $F_L(x, Q^2 = 5 \text{ GeV}^2)$ (plot on the right) versus $x$, together with the corresponding LHeC pseudodata. Dotted lines correspond to the nuclear PDF set EPS09 [153], dashed ones to nDS [405], solid ones to HKN07 [406], dashed-dotted ones to FGS10 [407] and dashed-dotted-dotted ones to AKST [302]. The band corresponds to the uncertainty in the Hessian analysis in EPS09 [153].
### Design Parameters

**Draft CDR - 5th August 2011**

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<th>LR</th>
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<td>60</td>
<td>140</td>
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<td>luminosity [10\textsuperscript{32}cm\textsuperscript{-2}s\textsuperscript{-1}]</td>
<td>17</td>
<td>10</td>
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<td>polarization [%]</td>
<td>40</td>
<td>90</td>
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<td>26</td>
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<td>transv. emit. $\gamma\epsilon_{x,y}$ [mm]</td>
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<td>0.05</td>
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<td>e\textsuperscript{-} IP beta funct. $\beta_{x,y}^\ast$ [m]</td>
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*)“ultimate p beam” - 1.7 probably conservative
Design also for deuterons (new) and lead (exists)

\textsuperscript{*} but high energy ERL not impossible; RR=Ring-Ring, LR=Linac-Ring
## Summary of Machine Parameters

### Parameters of the RR and RL configurations.

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<td>$e^- (e^+)$ per bunch $N_e [10^9]$</td>
<td>20 (20)</td>
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<tr>
<th>collider</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Lum $e^- p (e^+ p) [10^{32} \text{cm}^{-2} \text{s}^{-1}]$</td>
<td>9 (9)</td>
</tr>
<tr>
<td>bunch spacing [ns]</td>
<td>25</td>
</tr>
<tr>
<td>rms beam spot size $\sigma_{x,y} [\mu m]$</td>
<td>30,16</td>
</tr>
<tr>
<td>crossing angle $\theta [\text{mrad}]$</td>
<td>1</td>
</tr>
<tr>
<td>$L e_N = A L e_A [10^{32} \text{cm}^{-2} \text{s}^{-1}]$</td>
<td>0.3</td>
</tr>
</tbody>
</table>

### Components of the electron accelerators.

<table>
<thead>
<tr>
<th>magnets</th>
<th>Ring</th>
<th>Linac</th>
</tr>
</thead>
<tbody>
<tr>
<td>beam energy [GeV]</td>
<td>60</td>
<td></td>
</tr>
<tr>
<td>number of dipoles</td>
<td>3080</td>
<td>3600</td>
</tr>
<tr>
<td>dipole field [T]</td>
<td>0.013 - 0.076</td>
<td>0.046 - 0.264</td>
</tr>
<tr>
<td>total nr. of quads</td>
<td>866</td>
<td>1588</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>RF and cryogenics</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>number of cavities</td>
<td>112</td>
</tr>
<tr>
<td>gradient [MV/m]</td>
<td>11.9</td>
</tr>
<tr>
<td>RF power [MW]</td>
<td>49</td>
</tr>
<tr>
<td>cavity voltage [MV]</td>
<td>5</td>
</tr>
<tr>
<td>cavity $R/Q [\Omega]$</td>
<td>114</td>
</tr>
<tr>
<td>cavity $Q_0$</td>
<td>-</td>
</tr>
<tr>
<td>cooling power [kW]</td>
<td>5.4@4.2 K</td>
</tr>
</tbody>
</table>

The LHeC may be realised either as a ring-ring (RR) or as a linac-ring (LR) collider.
Accelerator: Ring - Ring

Workpackages as formulated in 2008, now in the draft CDR

Baseline Parameters and Installation Scenarios
Lattice Design [Optics, Magnets, Bypasses]
IR for high Luminosity and large Acceptance
rf Design [Installation in bypasses, Crabs?]
Injector Complex [Sources, Injector]
Injection and Dump
Cryogenics – work in progress
Beam-beam effects
Impedance and Collective Effects
Vacuum and Beam Pipe
Integration into LHC
e Beam Polarization
Deuteron and Ion Beams

LHeC Ring Dipole Magnet

.12-.8T
1.3kA
0.8MW

5.3m long
(35 cm)²
slim + light(er)
3080 magnets
Prototypes:
BINP-CERN
Baseline Parameters [Designs, Real photon option, ERL]
Sources [Positrons, Polarisation]
Rf Design
Injection and Dump
Beam-beam effects
Lattice/Optics and Impedance
Vacuum, Beam Pipe
Integration and Layout
Interaction Region
Magnets
Cryogenics

Linac (racetrack) inside the LHC for access at CERN Territory
U=U(LHC)/3=9km

1056 cavities
66 cryo modules per linac
721 MHz, 19 MV/m CW
Similar to SPL, ESS, XFEL, ILC, eRHIC, Jlab
21 MW RF power
Cryo 29 MW for 37W/m heat load
Magnets in the 2 * 3 arcs:
600 - 4m long dipoles per arc
240 - 1.2m long quadrupoles per arc
Ring: Dipole + Quadrupole Magnets

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beam Energy</td>
<td>10-60</td>
<td>GeV</td>
</tr>
<tr>
<td>Magnetic Length</td>
<td>5.35</td>
<td>Meters</td>
</tr>
<tr>
<td>Magnetic Field</td>
<td>0.127-0.763</td>
<td>Tesla</td>
</tr>
<tr>
<td>Number of magnets</td>
<td>3080</td>
<td></td>
</tr>
<tr>
<td>Vertical aperture</td>
<td>40</td>
<td>mm</td>
</tr>
<tr>
<td>Pole width</td>
<td>150</td>
<td>mm</td>
</tr>
<tr>
<td>Number of turns</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Current @ 0.763 T</td>
<td>1300</td>
<td>Ampere</td>
</tr>
<tr>
<td>Conductor material</td>
<td>copper</td>
<td></td>
</tr>
<tr>
<td>Magnet inductance</td>
<td>0.15</td>
<td>milli-Henry</td>
</tr>
<tr>
<td>Magnet resistance</td>
<td>0.16</td>
<td>milli-Ohm</td>
</tr>
<tr>
<td>Power @ 60 GeV</td>
<td>270</td>
<td>Watt</td>
</tr>
<tr>
<td>Total power consumption @ 60 GeV</td>
<td>0.8</td>
<td>MW</td>
</tr>
<tr>
<td>Cooling</td>
<td>air or water</td>
<td>depends on tunnel ventilation</td>
</tr>
</tbody>
</table>

Table 3.2: Main parameters of bending magnets for the RR Option.

BINF & CERN prototypes

736 magnets
1.2 m long

5m long (35 cm)$^2$
slim + light for installation
High Energy Frontier (Colliders)

• Recent Progress
  - Tevatron
  - RHIC
  - LHC

• Future Directions
  - Future Ion Colliders
  - HL-LHC
  - ILC/CLIC
  - electron-hadron colliders
  - HE-LHC
  - Neutrinos (Intensity Frontier)
  - Muon collider
Ad personam Issues (1)

• The physics output from the LHC will be decisive
• If 500GeV cm is sufficient:
  – ILC500; almost ready to go with construction (>200MW of electrical power, capital cost)
  – CLIC500; staged version, several years technical development needed (>200MW of electrical power, capital cost)
• If 1000GeV is needed and sufficient
  – ILC1000; at the upper energy limit of this technology (~400MW Electrical power, serious issue, capital cost, 50km)
  – CLIC1000; staged version, several years technical development needed (~400MW Electrical power is a serious issue)
• If 3000GeV is needed and sufficient
  – CLIC3000; maximum energy imaginable, still some major feasibility issues (560MW of electrical power would make this highly undesirable for the ecologists + operational costs)
• If even higher energies are needed
  – HE-LHC; aggressive R&D for high field sc magnets needed, SPS upgrade, injection/extraction systems, synchrotron radiation...
  – Muon collider; many as yet unsolved technical issues (list too long to record), but very interesting accelerator physics... very long term
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• The physics output from the LHC will be decisive
  • If 500GeV cm is sufficient:
    – ILC500; almost ready to go with construction (>200MW of electrical power, capital cost)
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  • If 1000GeV is needed and sufficient
    – ILC1000; at the upper energy limit of this technology (capital cost, 50km)
    – CLIC1000; staged version, several years technical development needed (power is a serious issue)
  • If 3000GeV is needed and sufficient
    – CLIC3000; maximum energy imaginable, still some major feasibility issues (560MW of electrical power would make this highly undesirable for the ecologists + operational costs)
  • If even higher energies are needed
    – HE-LHC; aggressive R&D for high field sc magnets needed, SPS upgrade, injection/extraction systems, synchrotron radiation...
    – Muon collider; many as yet unsolved technical issues (list too long to record), but very interesting accelerator physics… very long term

Aggressive R&D needed to increase the efficiency wall-plug to beam
Summary (2)

• If e-p is interesting as a **complimentary** project:
  • LHeC (RR): certainly technically do-able. Integration presents major challenges, impact on the LHC operation is a major concern. By-passes are not trivial
  • LHeC (LR): luminosity \((10^{33})\) may be difficult to achieve, ERL a major challenge but is very interesting due to synergy with many other projects.

All these projects need continuing accelerator R&D so that the right decision can be made when the time comes to identify the next energy frontier accelerator (collider). We need to keep our choices open.
### NuPECC – Roadmap 5/2010: New Large-Scale Facilities

<table>
<thead>
<tr>
<th>Facility</th>
<th>Phase</th>
<th>2010</th>
<th>2015</th>
<th>2020</th>
<th>2025</th>
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<tbody>
<tr>
<td>FAIR</td>
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<tr>
<td>PANDA</td>
<td>R&amp;D</td>
<td>Construction</td>
<td>Commissioning</td>
<td>Exploitation</td>
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<td>CBM</td>
<td>R&amp;D</td>
<td>Construction</td>
<td>Commissioning</td>
<td>Exploitation</td>
<td>SIS300</td>
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<td>NuSTAR</td>
<td>R&amp;D</td>
<td>Construction</td>
<td>Commissioning</td>
<td>Exploitation</td>
<td>NESR FLAIR</td>
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<td>PAX/ENC</td>
<td>Design Study</td>
<td>R&amp;D</td>
<td>Tests</td>
<td>Construction/Commissioning</td>
<td>Collider</td>
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<td>SPIRAL</td>
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<td>2</td>
<td>R&amp;D</td>
<td>Constr./Commission.</td>
<td>Exploitation</td>
<td>150 MeV/u Post-accelerator</td>
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<tr>
<td>HIE-ISOLODE</td>
<td>Constr./Commission.</td>
<td>Exploitation</td>
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<td>Injector Upgrade</td>
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<td>SPES</td>
<td>Constr./Commission.</td>
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<tr>
<td>EURISOL</td>
<td>Design Study</td>
<td>R&amp;D</td>
<td>Preparatory Phase / Site Decision</td>
<td>Engineering Study</td>
<td>Construction</td>
</tr>
<tr>
<td>LHeC</td>
<td>Design Study</td>
<td>R&amp;D</td>
<td>Engineering Study</td>
<td>Construction/Commissioning</td>
<td></td>
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