Report on the Design Concepts for the LHeC

Max Klein
for the LHeC Study Group

ECFA, CERN, 26.11.10
Rolf Heuer: 3/4. 12. 09 at CERN: From the Proton Synchroton to the Large Hadron Collider
50 Years of Nobel Memories in High-Energy Physics
1. Grand unification? $\alpha_s$ to per mille accuracy: jets vs inclusive ultraprecision DIS programme: $N^kLO$, charm, beauty, $ep/eD$,.. 

2. A new phase of hadronic matter: high densities, small $\alpha_s$ saturation of the gluon density? BFKL-Planck scale superhigh-energy neutrino physics ($p-N$) 

3. Partons in nuclei (4 orders of magnitude extension) saturation in $eA$ ($A^{1/3}$?), nuclear parton distributions black body limit of $F_2$, colour transparency, ... 

4. Novel QCD phenomena instantons, odderon, hidden colour, sea=antiquarks (strange) 

5. Complementarity to new physics at the LHC LQ spectroscopy, eeqq Cl, Higgs, e* 

6. Complete unfolding of partonic content of the proton, direct and in QCD
| 1. | Neutron structure free of Fermi motion |
| 2. | Diffraction – Shadowing (Glauber). Antishadowing |
| 3. | Vector Mesons to probe strong interactions |
| 4. | Diffractive scattering “in extreme domains” (Brodsky) |
| 5. | Single top and anti-top ‘factory’ (CC) |
| 6. | Gluon density over 6 orders of magnitude in x |
| 7. | GPDs via DVCS |
| 8. | Unintegrated parton distributions |
| 9. | Partonic structure of the photon |
| 10. | Electroweak Couplings to per cent accuracy |

For numeric studies and plots see recent talks at DIS10, ICHEP10, EIC and LHeC Workshops [ cern.ch/lhec]

Every major step in energy can lead to new unexpected results, ep: SLAC, HERA

Requires: High energy, $e^\pm$, p, d, A, high luminosity, $4\pi$ acceptance, high precision ($e/h$)

TeV scale physics, electroweak, top, Higgs, low x unitarity
Two Options

**Ring-Ring**

Power Limit of 100 MW wall plug “ultimate” LHC proton beam

60 GeV e± beam

\[ \Rightarrow L = 2 \times 10^{33} \text{ cm}^{-2} \text{s}^{-1} \rightarrow \text{O(100) fb}^{-1} \]

HERA 0.5fb⁻¹ with 100 times less L

---

**LINAC Ring**

Pulsed, 60 GeV: \( \sim 10^{32} \)

High luminosity:

Energy recovery: \( P = P_0 / (1 - \eta) \)

\( \beta^* = 0.1 \text{m} \)

[5 times smaller than LHC by reduced \( l^* \), only one p squeezed and IR quads as for HL-LHC]

\( L = 10^{33} \text{ cm}^{-2} \text{s}^{-1} \rightarrow \text{O(100) fb}^{-1} \)
A 60 GeV Ring with 10 GeV LINAC Injector

**Lattice Design dominated by geometry:**
- forbidden space (usually DEBM) induces an asymmetric lattice
- asymmetric lattice needs to be matched to the symmetric LHC lattice
- most choices for the LHeC lattice structure are made due to integration

**Bypass Design:**
- Bypasses increase the circumference of the ring
- Compensation of the increase in circumference by placing the electron ring 0.61 cm to the inside of the LHC (Idealized Ring)

**Bypass Point 1:**
- uses the Survey Gallery
- $\Delta = 16.25$ Meter

**Bypass Point 5:**
- adjustment of the circumference by varying the separation
- $\Delta = 20.56$ Meter

5min filling time
Ring - Arc Optics and matched IR

Optics:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beam Energy</td>
<td>60 GeV</td>
</tr>
<tr>
<td>Phase Advance per FODO Cell</td>
<td>≈ 90°/60°</td>
</tr>
<tr>
<td>Cell length</td>
<td>106.881 m</td>
</tr>
<tr>
<td>Dipole Fill factor</td>
<td>0.75</td>
</tr>
<tr>
<td>Damping Partition $J_x/J_y/J_e$</td>
<td>1.5/1/1.5</td>
</tr>
<tr>
<td>Coupling constant $\kappa$</td>
<td>0.5</td>
</tr>
<tr>
<td>Horizontal Emittance (no coupling)</td>
<td>4.70 nm</td>
</tr>
<tr>
<td>Horizontal Emittance ($\kappa = 0.5$)</td>
<td>3.52 nm</td>
</tr>
<tr>
<td>Vertical Emittance ($\kappa = 0.5$)</td>
<td>1.76 nm</td>
</tr>
</tbody>
</table>

23 arc cells, $L_{\text{Cell}} = 106.881 \text{ m}$
Ring Installation Study

- Installation of an e ring is challenging
- Modifications of the existing installations will be necessary
- No show stopper

This is the big question for the ring option (interference, activation,..)
LINACs

Two 10 GeV Linacs, 3 returns, compensation for synchrotron radiation losses, recovery of power
Multibunch wakefields - ok
Emittance growth - ok
[ILC 10nm, LHeC 10μm]
36σ separation at 3.5m - ok
Fast ion instability - probably ok
   with clearing gap (1/3)
Q – probably ok (between ILC/BNL)
**LINAC Views**

- LINAC into hall
  - T12 use tentative

- LINAC when assigned to ALICE hall
  - Injector, dumps to be drawn still

- LINAC leaving hall

- initial LINAC
## Design Parameters

<table>
<thead>
<tr>
<th>electron beam</th>
<th>RR</th>
<th>LR</th>
<th>LR</th>
</tr>
</thead>
<tbody>
<tr>
<td>e- energy at IP [GeV]</td>
<td>60</td>
<td>60</td>
<td>140</td>
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<tr>
<td>luminosity $[10^{32} \text{ cm}^{-2}\text{s}^{-1}]$</td>
<td>17</td>
<td>10</td>
<td>0.44</td>
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<td>polarization [%]</td>
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<td>90</td>
<td>90</td>
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<tr>
<td>bunch population $[10^9]$</td>
<td>26</td>
<td>2.0</td>
<td>1.6</td>
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<tr>
<td>e- bunch length [mm]</td>
<td>10</td>
<td>0.3</td>
<td>0.3</td>
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<tr>
<td>bunch interval [ns]</td>
<td>25</td>
<td>50</td>
<td>50</td>
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<tr>
<td>transv. emit. $\gamma \varepsilon_{x,y}$ [mm]</td>
<td>0.58, 0.29</td>
<td>0.05</td>
<td>0.1</td>
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<tr>
<td>rms IP beam size $\sigma_{x,y}$ [$\mu$m]</td>
<td>30, 16</td>
<td>7</td>
<td>7</td>
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<tr>
<td>e- IP beta funct. $\beta^*_{x,y}$ [m]</td>
<td>0.18, 0.10</td>
<td>0.12</td>
<td>0.14</td>
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<td>full crossing angle [mrad]</td>
<td>0.93</td>
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<td>geometric reduction $H_{hg}$</td>
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<td>0.94</td>
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<td>N/A</td>
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<td>beam pulse length [ms]</td>
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<td>N/A</td>
<td>5</td>
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<td>ER efficiency</td>
<td>N/A</td>
<td>94%</td>
<td>N/A</td>
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<td>average current [mA]</td>
<td>131</td>
<td>6.6</td>
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<td>tot. wall plug power [MW]</td>
<td>100</td>
<td>100</td>
<td>100</td>
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<th>proton beam</th>
<th>RR</th>
<th>LR</th>
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<tr>
<td>bunch pop. $[10^{11}]$</td>
<td>1.7</td>
<td>1.7</td>
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<tr>
<td>tr.emit.$\gamma \varepsilon_{x,y}$ [µm]</td>
<td>3.75</td>
<td>3.75</td>
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<tr>
<td>spot size $\sigma_{x,y}$ [µm]</td>
<td>30, 16</td>
<td>7</td>
</tr>
<tr>
<td>$\beta^*_{x,y}$ [m]</td>
<td>1.8, 0.5</td>
<td>0.1</td>
</tr>
<tr>
<td>bunch spacing [ns]</td>
<td>25</td>
<td>25</td>
</tr>
</tbody>
</table>

“ultimate p beam”
1.7 probably conservative

Design also for deuterons (new) and lead (exists)

RR = Ring – Ring
LR = Linac – Ring

Parameters from 8.7.2010
New: Ring: use 1° as baseline : L/2
Linac: clearing gap: L*2/3
Synchrotron losses ≈400 MeV: 500 MV => 43 MW rated RF system (RF Feedback margin)

Efficiency: take 40% => < 100 MW mains power.

SPL like 700 MHz cavity, but at harmonic that allows 25 ns bunch spacing (40.08 MHz multiple -> 721 MHz) => Synergy with ongoing SPL cavity prototyping work. Here limitation is not gradient but input power!

- Assume 225 kW per coupler, 2 couplers per cavity, => 96 cavities (reasonable number)
- 5.2 MV/cavity only needed; SPL cavity is 25 MV/m in 5 cells length 1.06 m i.e. use 2 cell cavity.
  => 8 double cell cavities in 12 x 10 m cryomodules, Total Length 144 m, Incl. quads, vacuum, BI equipment.
- Two cavities per one 1 MW Klystron - (Less space, “Only” 48 klystrons...)

Install all cavities in the IR bypass sections
208 m available (124 + 2 *42)
6 modules at CMS bypass = 72m
2 x 3 modules at ATLAS bypass = 2 * 36m

RF Power System underground
Need 100m² per 8 cavity module in adjacent RF gallery, i.e. 7-8 m wide over the module length

Surface: Need one HV Power Converter rated 6-8 MVA per 4 klystrons on surface.. (12)

Cryogenics: Split cold boxes: on surface and underground
Energy = 3 * 20 GeV, 2 x 10 GeV Linacs, 6.6 mA, Take 721 MHz, to allow 25 ns bunches

**Take SPL type cavity @18 MV/m** (Close to BNL design for eRHIC)

- 1.06 m/cavity => 19.1 MV/cav => **1056 cavities total** (=132 x 8)
- Take 8 cavities in a 14 m cryomodule (cf SPL) => **66 cryo modules / linac**
  
  Total length = 924 m/linac + margin ~10%

- Power loss in arcs = 9.5 MW, 9 kW/cavity, Take $P_{rf} = 20$ kW/cavity with overhead for feedbacks, **total installed RF 21 MW**.

- No challenge for power couplers, power sources – could be solid state

- However, still need adjacent gallery to house RF equipment (high gradient = radiation !)
  4-5 m diameter sufficient

- Synchrotron radiation losses in arcs: need re-accelerating ‘mini’-linacs

- Future: could **hardware prototyping be initiated, on SC cavities**, - good synergy with SPL Proton Driver study which is well underway. => Possibility of test of ERL concept at CERN?
Linac-Ring Cryogenics

CW operation, 18 MV/m
2 K thermal load: 37 W/m (for active length)
2 K total thermal load: 42 kW @ 2 K
Electric power: 30 MW (with a COP of 700)

Cooling requirements dominated by dynamic losses at 2 K
(other loads neglected here for simplicity)

Lay-out is based on LHC cryogenic principles
with split cold boxes (surface cold box and underground cold box with cold compressors).

Refrigerator units of approx. 5 kW @ 2 K
assumed. To be designed. Technology and experience: LHC, CEBAF (JLAB).
Ring Dipole Magnets

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

<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>5.38</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>

5m long
(35 cm)$^2$
slim + light
for installation

BINP &
CERN
prototypes
Dipole Prototype - BINP

3408 grain oriented steel
0.35 mm thick laminations

laminations of alternated rolling

same results for the two alternatives

Reproducibility of injection field is below 0.1 Gauss!
Status of CERN Dipole Prototype

- interleaved, low-coercivity iron ($H_c < 25 \text{ A/m}$)
- low resistance conductor, air cooled
- two turns only, bolted bars
- 400 mm long models with different types of iron

- design completed
- spacers under manufacture (phenolic)
- NiFe 50 steel ($H_c = 3 \text{ A/m}$) as reference
- low carbon iron ($H_c = 20 \text{ A/m}$) is available
- first model expected before Christmas

### Magnet Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beam Energy [GeV]</td>
<td>70</td>
</tr>
<tr>
<td>Magnetic Length [m]</td>
<td>5.45</td>
</tr>
<tr>
<td>Magnetic field [Gauss]</td>
<td>874</td>
</tr>
<tr>
<td>Number of magnets</td>
<td>3080</td>
</tr>
<tr>
<td>Vertical aperture [mm]</td>
<td>40</td>
</tr>
<tr>
<td>Pole width [mm]</td>
<td>150</td>
</tr>
<tr>
<td>Number of coils</td>
<td>2</td>
</tr>
<tr>
<td>Number of turns/coil</td>
<td>1</td>
</tr>
<tr>
<td>Current [A]</td>
<td>1500</td>
</tr>
<tr>
<td>Conductor section [mm$x$mm]</td>
<td>92$x$43</td>
</tr>
<tr>
<td>Conductor material</td>
<td>aluminum</td>
</tr>
<tr>
<td>Magnet Inductance [mH]</td>
<td>0.15</td>
</tr>
<tr>
<td>Magnet Resistance [mΩ]</td>
<td>0.2</td>
</tr>
<tr>
<td>Power per magnet [W]</td>
<td>450</td>
</tr>
<tr>
<td>Cooling</td>
<td>air</td>
</tr>
</tbody>
</table>
### Ring-Arc Quadrupoles Linac

<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>1.0</td>
<td>Meters</td>
</tr>
<tr>
<td>Field gradient @ 60 GeV</td>
<td>10.28 (QF) - 8.40 (QD)</td>
<td>T/m</td>
</tr>
<tr>
<td>Number of magnets</td>
<td>368 + 368</td>
<td></td>
</tr>
<tr>
<td>Aperture radius</td>
<td>30 mm</td>
<td></td>
</tr>
<tr>
<td>Total length</td>
<td>1.2 meters</td>
<td></td>
</tr>
<tr>
<td>Weight</td>
<td>700 kg</td>
<td></td>
</tr>
<tr>
<td>Number of turns/pole</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>Current @ 10.28 T/m</td>
<td>430 A</td>
<td>Ampere</td>
</tr>
<tr>
<td>Conductor material</td>
<td>copper</td>
<td></td>
</tr>
<tr>
<td>Current density</td>
<td>2 A/mm²</td>
<td></td>
</tr>
<tr>
<td>Magnet inductance</td>
<td>4 mH/mm²</td>
<td></td>
</tr>
<tr>
<td>Magnet resistance</td>
<td>8 mH/mm²</td>
<td></td>
</tr>
<tr>
<td>Power @ 60 GeV</td>
<td>1500 Watt</td>
<td></td>
</tr>
<tr>
<td>Cooling</td>
<td>water</td>
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</tr>
</tbody>
</table>

Table 3.3: Main parameters of arc quadrupole magnets for the RR Option.

Figure 3.3: Arc quadrupole magnets for the RR Option

<table>
<thead>
<tr>
<th>Number of magnets</th>
<th>72</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aperture radius [mm]</td>
<td>20</td>
</tr>
<tr>
<td>Field gradient [T/m]</td>
<td>4.4</td>
</tr>
<tr>
<td>Magnetic Length [mm]</td>
<td>500</td>
</tr>
<tr>
<td>Weight [kg]</td>
<td>150</td>
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<tr>
<td>Number of turns/pole</td>
<td>18</td>
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<tr>
<td>Current [A]</td>
<td>40</td>
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<tr>
<td>Conductor material</td>
<td>Copper</td>
</tr>
<tr>
<td>Current density [A/mm²]</td>
<td>1.5</td>
</tr>
<tr>
<td>Resistance [mΩ]</td>
<td>60</td>
</tr>
<tr>
<td>Power [kW]</td>
<td>0.1</td>
</tr>
<tr>
<td>Inductance [mH]</td>
<td>9</td>
</tr>
<tr>
<td>Cooling</td>
<td>air</td>
</tr>
</tbody>
</table>
Final Proton Quadrupoles

<table>
<thead>
<tr>
<th>NbTi: 6700 A, 248 T/m at 88% LL</th>
<th>NbTi: 4500 A, 145 T/m, 3.6 T at 87%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nb3Sn: 8600 A, 311 T/m, at 83% LL</td>
<td>Nb3Sn: 5700 A, 175 T/m, 4.7 T at 82% on LL</td>
</tr>
<tr>
<td>(Four layer coil !)</td>
<td></td>
</tr>
<tr>
<td>23 mm aperture</td>
<td>46 mm (half) aperture</td>
</tr>
<tr>
<td>87 mm septum</td>
<td>63 mm septum (space for p and e-beams)</td>
</tr>
<tr>
<td>0.03 T, 3.5 T/m in e-beam pipe</td>
<td>0.37 T, 18 T/m</td>
</tr>
<tr>
<td>0.09 T, 9 T/m in e-beam pipe</td>
<td>0.5 T, 25 T/m</td>
</tr>
</tbody>
</table>

NbTi at 1.8 K, Nb3Sn at 4.2 K

3 beams in horizontal plane

Focus and deflect
Double Solenoid Detector

- 2 big Solenoids +5T/-1.5T outside HCAL (evaluated by H. Ten Kate)
  saving ~10kTons steel for return yoke (~10M$)
- superior muon track measurement in between the 2 magnets

Fwd/Bwd asymmetry in energy deposited and thus in technology [W/Si vs Pb/Sc.]
Present dimensions: LxD =17x10m² [CMS 21 x 15m², ATLAS 45 x 25 m²]
Taggers at -62m (e), 100m (γ,LR), -22.4m (γ,RR), +100m (n), +420m (p)
Track Detector Concept

(down to 1 degree)

Baseline:
Si Tracker - Pixel, Strip, outer layer straw tubes?

Track Angles

Angles for inner cone radius 4.9cm

Angles for radius 4.9cm

Forward and backward (red) disks to be removed for the High Luminosity - High Q^2 running (RR-option)

Alternative technologies: MAPS, DEPFET, GOSSIP^* (talk of H.van de Graf)

^*Gas On Slimmed Silicon Pixels (or Strixels/Pads) - NIKHEF
Beam Pipe Design

72mm x 58mm elliptical pipe
0.8mm thick Beryllium

72mm x 58mm elliptical pipe
1.2mm thick Beryllium

Equivalent Stress Contours
+ Deformed/Undefomed Shapes

Minimum thickness for Be, elliptical (constant geometry) pipe in order of 1mm

Also studied conical design (a la LHCb)
### LHeC_DRAFT_Timeline

Based on LHC constraints, ep/A programme, series production, civil engineering etc

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<td>Prototyping- testing</td>
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<td>Production main components</td>
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<td>Operation</td>
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**Variations on timeline:**

- Production of main components can overlap with civil engineering
- Installation can overlap with civil engineering
- Additional constraints from LHC operation not considered here
- In any variation, a start by 2020 requires launch of prototyping of key components by 2012
Organisation for the CDR

Scientific Advisory Committee

Guido Altarelli (Rome)
Sergio Bertolucci (CERN)
Stan Brodsky (SLAC)
Allen Caldwell -chair (MPI Munich)
Swapan Chattopadhyay (Cockcroft)
John Dainton (Liverpool)
John Ellis (CERN)
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Alexander Skrinsky (Novosibirsk)
Anthony Thomas (Jlab)
Steven Vigor (BNL)
Frank Wilczek (MIT)
Ferdinand Willeke (BNL)

Steering Committee

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Emmanuelle Perez (CERN)
Wesley Smith (Wisconsin)
Bernd Surrow (MIT)
Katsuo Tokushuku (KEK)
Urs Wiedemann (CERN)
Frank Zimmermann (CERN)

Working Group Convenors

Accelerator Design [RR and LR]
Oliver Bruening (CERN),
John Dainton (CI/Liverpool)

Interaction Region and Fwd/Bwd
Bernhard Holzer (DESY),
Uwe Schneekloth (DESY),
Pierre van Mechelen (Antwerpen)

Detector Design
Peter Kostka (DESY),
Rainer Wallny (U Zurich),
Alessandro Polini (Bologna)

New Physics at Large Scales
George Azuelos (Montreal)
Emmanuelle Perez (CERN),
Georg Weiglein (Durham)

Precision QCD and Electroweak
Olaf Behnke (DESY),
Paolo Gambino (Torino),
Thomas Gehrmann (Zuerich)
Claire Gwennlan (Oxford)

Physics at High Parton Densities
Nestor Armesto (Santiago),
Brian Cole (Columbia),
Paul Newman (Birmingham),
Anna Stasto (MSU)

Referees of CERN

QCD/electroweak:
Guido Altarelli, Alan Martin, Vladimir Chekalyan

BSM:
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eas/low x
Al Mueller, Raju Venugopalan, Michele Arneodo

Detector
Philipp Bloch, Roland Horisberger

Interaction Region Design
Daniel Pitt, Mike Sullivan

Ring-Ring Design
Kurt Huebner, Sasha Skrinsky, Ferdinand Willeke

Linac-Ring Design
Reinhard Brinkmann, Andy Wolski, Kaoru Yokoya

Energy Recovery
Georg Hofstatter, Ilan Ben Zvi

Magnets
Neil Marx, Martin Wilson

Installation and Infrastructure
Sylvain Weisz
Final Remarks

**The CDR draft is currently being written** (140 pages on svn) by perhaps 100 authors.

November 12/13: 3rd LHeC Workshop. December and January for completion and updates
February/March for referees to comment, followed by updating the CDR
Cost estimate organised by CERN

Print in spring 2011

**Issues of present concern and attention:** Coherence, plots, text for all chapters.
Detailed IR layout with masks and absorbers – finalisation of detector concept
Understanding and write-up of necessary R+D steps

For the continuation of the project, a new mandate/expressions of interest by ECFA and NuPECC are essential, which allow to adapt the organisation of the further work, together with CERN.

**The Ring** (which has Linac elements) has high lumi with both charges, reserve for high luminosity and estimated lepton polarisation between 25 and 40%. It looks easier to build but is hard to install.

**The Linac** (which has arcs..) with ER has high lumi for $e^-$ and $>80\%$ polarisation, yet is much less luminous for $e^+$. It is challenging to build but easier to install.

It has been decided early on to first conclude the design work and then choose L vs R. This is not unrelated to the LHC. The CDR also has a section on a 140 GeV straight LINAC, which would need more than 100 MW to exceed $10^{32}$ luminosity (and thus extraordinary physics reasons to be built).

**The detector** will and can be based on ‘existing’ technology, but it needs 10 years too.

The LHeC is worth an intensified, broadened effort, but cannot ignore the pace of the LHC clock.
Thanks

To the many experts in engineering, accelerators, detectors, experimental physics, software, theory and politics for their engagement in this project, which was launched in 2007 by the SPC, CERN and ECFA and approaches completion of its first phase in the attempt to reach the real world.

Particular thanks to the directors of CERN, to ECFA and NuPECC for their attention and support.

Personal thanks to Patricia Mage, to my Liverpool colleagues for extending their understanding of academic freedom to my ‘hobby’ and many old and new friends.
2 solenoid detector concept

Elliptical Pixel Tracker
inner-$g_x$ = 9.5 cm
inner-$g_y$ = 7.0 cm
2.4 cm active radius

Fwd Tracker - active Thickness 8 cm each
Si-Pix/Si-Strip/SiGas Tracker:
inner R = 48.6 cm, outer R = 61.3 cm
Planes 1-5:
$z_i$ = 140, 210, 280, 340, 370 cm

Barrel Tracker - active Radius 2.5 cm each
1. layer: inner R = 9.8 cm, outer R = 11.3 cm
2. layer: r = 21.3 cm
3. layer: r = 33.6 cm
4. layer: r = 46.3 cm
5. layer: r = 59.8 cm

4 Cone structured Fwd/Barrel Si-Pix/Si-Strip/SiGas Tracker:
$R_w$ = 4.86 cm
7.5 cm active thickness

Dipoles ±0.5T
Solenoid 3.5T
Solenoid -1.5T
Ring-Ring Cryogenics (basics)

For the CMS and ATLAS bypasses are considered:
1. LHC type cryomodules (400 MHz)
2. SPL type cryomodules (704 MHz)

Cryogenics requirements
1. 4.5 K operation. Two cryoplants of approx. 10 kW @ 4.5 K each. El. power approx. 5 MW total.
2. 2 K operation. The installed power of the cryoplants is a function of acc. field (to be determined). (El. power comparable to 1.)

Injector:
12 ILC (XFEL) cryomodules.
Intermittent operation.
Operation temp. 2K.
Cryoplant of modest size (0.2 kW @ 2 K)
Time Considerations for an LHeC Installation:

- **LHC upgrade plans:**
  - HiLumi upgrade planned for 2020 with goal of
    - an average luminosity of $5 \times 10^{34} \text{ cm}^{-2} \text{ sec}^{-1}$
    - an integrated luminosity of $250 \text{ fb}^{-1}$ per year and
    - a total of $3000 \text{ fb}^{-1}$ over the lifetime of the LHC.
  - With the HiLumi parameters the LHC will reach the lifetime goal of $3000 \text{ fb}^{-1}$ by 2030 to 2035 depending on the efficiency of the HiLumi commissioning performance ramp up.
  - Aiming for a minimum of 10 years of exploitation for the LHeC this requires start of LHeC operation by about 2020
  - Based on the experience of other projects (e.g. LEP, XFEL and LHC), a large facility like the LHeC will require 1-2 years of installation; ca. 3 years of production including pre-series production; plus ca 1-2 years of test bench operation of the key components
  - Total installation time of 5 to 7 years.
Civil Engineering Requirements

**Energy recovery linac option for linac-ring design:**

- Total tunnel length of ca. 10km (similar to 500 GeV CLIC option):
  - 4 years for civil engineering
  - 2 years of service installation (piping, cabling, EL general services)
  - 2 years of actual machine installation
  - Total of 6 years with partial overlap of some of these activities
    (Not counting any time for legal preparations for construction on communal property!)

**Bypass for ring-ring option:**

- Total tunnel length of ca. 2km (ca. 500 on either side of experiment)
  - But also requires two access shafts (safety)
  - Requires dedicated alcoves for Klystrons and RF system
- Perhaps slightly shorter intervention time as for Linac-Ring options
- Total of 5 years with partial overall of some of these activities
  (Civil engineering for injector complex not considered here)
# CDR in 2010/2011

<table>
<thead>
<tr>
<th>Month</th>
<th>Event Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>April</td>
<td>DIS and QCD Workshop at Florence (DIS10)</td>
</tr>
<tr>
<td>May</td>
<td>KEK IPAC</td>
</tr>
<tr>
<td></td>
<td>NuPECC at Madrid → LHeC on Long Range Plan (Roadmap)</td>
</tr>
<tr>
<td>June</td>
<td>CERN SPC → Reported to Council</td>
</tr>
<tr>
<td>July</td>
<td>ICHEP at Paris</td>
</tr>
<tr>
<td>October</td>
<td>Dipole Prototype (Novosibirsk) successfully tested</td>
</tr>
<tr>
<td>December</td>
<td>Completion/editing of CDR</td>
</tr>
<tr>
<td>January</td>
<td></td>
</tr>
<tr>
<td>February</td>
<td>Refereeing</td>
</tr>
<tr>
<td>March</td>
<td></td>
</tr>
<tr>
<td>April/May</td>
<td>Update and Print</td>
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</tbody>
</table>
**Strong Coupling Constant**

Simulation of $\alpha_s$ measurement at LHeC

- $\alpha_s$ least known of coupling constants
- Grand Unification predictions suffer from $\delta\alpha_s$
- DIS tends to be lower than world average
- LHeC: per mille accuracy indep. of BCDMS.
- Challenge to experiment and to h.o. QCD

<table>
<thead>
<tr>
<th>DATA</th>
<th>exp. error on $\alpha_s$</th>
</tr>
</thead>
<tbody>
<tr>
<td>NC e$^+$ only</td>
<td>0.48%</td>
</tr>
<tr>
<td>NC</td>
<td>0.41%</td>
</tr>
<tr>
<td>NC &amp; CC</td>
<td><strong>0.23% :=</strong>$(1)$</td>
</tr>
<tr>
<td>$\gamma_h &gt; 5^\circ$</td>
<td>0.36% :=$(2)$</td>
</tr>
<tr>
<td>+BCDMS</td>
<td>0.22%</td>
</tr>
<tr>
<td>+BCDMS</td>
<td>0.22%</td>
</tr>
<tr>
<td>stat. *= 2</td>
<td>0.35%</td>
</tr>
</tbody>
</table>

Extension of kinematic range by 3-4 orders of magnitude into saturation region (with p and A) Like LHeC ep without HERA.. (e.g. heavy quarks in A)
Single top and anti-top Production in Charged Currents

\[ e^- p \rightarrow \nu X \]

\[ W^- s \rightarrow c \]

\[ W^- b \rightarrow t \]

\[ e^+ p \rightarrow \bar{\nu} X \]

\[ W^+ s \rightarrow c \]

\[ W^+ b \rightarrow t \]

LHeC is a single top and single tbar quark 'factory'

CC t cross section O(5)pb

CC events for 10 fb\(^{-1}\)
Interaction Region

Small crossing angle of about 1 mrad to avoid first parasitic crossing (L x 0.77) (Dipole in detector? Crab cavities? Design for 25ns bunch crossing [50ns?] Synchrotron radiation – direct and back, absorption ... recall HERA upgrade...)

Focus of current activity

1\textsuperscript{st} sc half quad (focus and deflect)
separation 5cm, \(g=127T/m\), MQY cables, 4600 A

2\textsuperscript{nd} quad: 3 beams in horizontal plane
separation 8.5cm, MQY cables, 7600 A