Perspectives on DIS and the LHeC

DIS
Design Report
Relations to LHC and EIC
Next Steps

Max Klein (University of Liverpool)

XX Workshop on Deep Inelastic Scattering, Bonn, 30.3.2012

I. Deep Inelastic Scattering

2 mile LINAC at Stanford (“a bold extrapolation of existing technology” – R. Taylor)
\[ \text{DIS} \rightarrow \text{SU}_{2,L} \times \text{U}_1 \times \text{SU}_{3,c} \]

\[ F_2 \]

\[ \begin{array}{c}
\text{Scaling:} \\
\text{Partons}
\end{array} \]

\[ Q^2 / \text{GeV}^2 \]

\[ \text{Valence and Sea} \]

\[ \text{Scaling Violation - Gluon} \]

\[ \text{SLAC}/\text{GGM} \]

\[ 0.29 \pm 0.05 \]

\[ = (e_u^2 + e_d^2) / 2 \]

\[ \text{PV: } Q_W \]

\[ I_3^R(e) = 0 \]

\[ \theta_W \]

\[ \sin^2 \theta_W \]

\[ \text{SLAC-MIT} \]

\[ \alpha_s \approx 0.113 \quad (\text{AM+MV}) \]

Many DIS experiments in the US and Europe were crucial to establish the SM gauge theory. No problem to justify 10 experiments …
Before HERA (1989)

Table III-1: Major recent Muon Experiments.

<table>
<thead>
<tr>
<th>MUON EXPERIMENTS</th>
<th>BCDMS</th>
<th>BFP</th>
<th>EMC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Target</td>
<td>C and H₂</td>
<td>Fe</td>
<td>H₂ D₂ Fe</td>
</tr>
<tr>
<td>Energy</td>
<td>100 - 280</td>
<td>93, 215</td>
<td>120 - 280</td>
</tr>
<tr>
<td>x-range</td>
<td>.06 - .80</td>
<td>.08 - .65</td>
<td>.03 - .65</td>
</tr>
<tr>
<td>Q²-range</td>
<td>25 - 280</td>
<td>5 - 220</td>
<td>3 - 200</td>
</tr>
<tr>
<td># events</td>
<td>C: 680K</td>
<td>690K</td>
<td>Fe: 1080K</td>
</tr>
<tr>
<td>R(x, Q²)</td>
<td>Expt.</td>
<td>0.0</td>
<td>0.0</td>
</tr>
</tbody>
</table>

Table III-2: Major recent charged-current Neutrino Experiments.

<table>
<thead>
<tr>
<th>NEUTRINO EXPERIMENTS</th>
<th>BEBC</th>
<th>CCFRR</th>
<th>CDHSW</th>
<th>CHARM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Target</td>
<td>Ne H</td>
<td>Fe</td>
<td>Fe</td>
<td>Marble</td>
</tr>
<tr>
<td>Energy</td>
<td>10 - 200</td>
<td>30 - 250</td>
<td>30 - 300</td>
<td>10 - 200</td>
</tr>
<tr>
<td>x-range</td>
<td>.025 - .80</td>
<td>.02 - .65</td>
<td>.02 - .65</td>
<td>.02 - .55</td>
</tr>
<tr>
<td>Q²-range</td>
<td>2 - 70</td>
<td>1 - 200</td>
<td>0.2 - 200</td>
<td>0.2 - 100</td>
</tr>
<tr>
<td>R(x, Q²)</td>
<td>R(QCD)</td>
<td>R(QCD)</td>
<td>R(QCD)</td>
<td>0.1</td>
</tr>
<tr>
<td># Events</td>
<td>25K</td>
<td>170K</td>
<td>940K</td>
<td>160K</td>
</tr>
<tr>
<td>SU(3) symmetry</td>
<td>c = ε = 0</td>
<td>c = ε = 0</td>
<td>c = ε = 0</td>
<td></td>
</tr>
<tr>
<td>Charm</td>
<td>slow rescale: m = 1.5</td>
<td>No correction</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1 Wu-Ki Tung², J. G. Morfin, H. Schellman, S. Kunori, A. Caldwell, F. Olness
Colliders explored the Fermi Energy Scale

**Tevatron** to find SUSY and BSM; **LEP/SLC** to find SUSY and the Higgs; **HERA** to find Lepto-Quarks

**NNLO!**

**M**

\[ M_Z = 91.1876 \pm 0.0021 \text{ GeV} \] (PDG2010)

probable legacy plots/numbers

Practical end of HERA xg sensitivity
II. Conceptual Design of the LHeC

Project
Physics
Accelerator
Detector

LHeC Talks at this workshop
N.Armesto, A.Bunyatian, O.Behnke, R.Godbole, P.Newman, A.Polini, D.Schulte, A.Stasto, R.Tomas
A Large Hadron Electron Collider at CERN

Report on the Physics and Design Concepts for Machine and Detector

LHeC Study Group

THIS IS THE VERSION FOR REFEREEING, NOT FOR DISTRIBUTION

LHeC-Note-2011-003 GEN

Draft LHeC Design Report
530 pages now refereed
Publication imminent
LHeC Study Group

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About 180 Experimentalists and Theorists from 60 Institutes
Tentative list of those who contributed to the CDR

Supported by
CERN, ECFA, NuPECC

http://cern.ch/lhec
Project Development

2007: Invitation by SPC to ECFA and by (r)ECFA to work out a design concept

2008: First CERN-ECFA Workshop in Divonne (1.-3.9.08)

2009: 2nd CERN-ECFA-NuPECC Workshop at Divonne (1.-3.9.09)

2010: Report to CERN SPC (June)
      3rd CERN-ECFA-NuPECC Workshop at Chavannes-de-Bogis (12.-13.11.10)
      NuPECC puts LHeC to its Longe Range Plan for Nuclear Physics (12/10)

2011: Draft CDR (530 pages on Physics, Detector and Accelerator) (5.8.11)
      refereed and being updated

2012: Discussion of LHeC at LHC Machine Workshop (Chamonix)
      Publication of CDR – European Strategy
      New workshop (June14-15, 2012)
Organisation for CDR

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Raju Venugopalan (BNL)
Michele Arneodo (INFN Torino)
Why an ep/A Experiment at TeV Energies?

1. For resolving the quark structure of the nucleon with p, d and ion beams
   - QPM symmetries, quark distributions (complete set from data!), GPDs, nPDFs, γ..

2. For the development of perturbative QCD
   - N^kLO (k≥2) and h.o. eweak, HQs, jets, resummation, factorisation, diffraction

3. For mapping the gluon field
   - Gluon for ~10^-5 < x <1 , J/ψ, F_2^{c,b}, … unintegrated gluon

4. For searches and the understanding of new physics
   - GUT (α_s to 0.1%), LQs RPV, Higgs, PDFs4LHC, top in DIS, instanton, odderon,..?

5. For investigating the physics of parton saturation
   - Non-pQCD (chiral symm. breaking, confinement), black disc limit, saturation border..

..For providing data which could be of use for future experiments [Proposal for SLAC ep 1968]
Precision measurement of gluon density to extreme $x \to \alpha_s$

Low $x$: saturation in ep? Crucial for QCD, LHC, UHE neutrinos!

High $x$: $xg$ and valence quarks: resolving new high mass states!

Gluon in Pomeron, odderon, photon, nuclei.. Local spots in p?

Heavy quarks intrinsic or only gluonic?
**Strong Coupling Constant**

\[ \alpha_s \text{ least known of coupling constants} \]
Grand Unification predictions suffer from \[ \delta \alpha_s \]

**DIS tends to be lower than world average**
Recently challenged by MSTW and NNPDF – jets??

**LHeC: per mille - independent of BCDMS.**

Challenge to experiment and to h.o. QCD →
A genuine DIS research programme rather than one outstanding measurement only.

<table>
<thead>
<tr>
<th>case</th>
<th>cut ([Q^2 \text{ in GeV}^2])</th>
<th>relative precision in %</th>
</tr>
</thead>
<tbody>
<tr>
<td>HERA only (14p)</td>
<td>(Q^2 &gt; 3.5)</td>
<td>1.94</td>
</tr>
<tr>
<td>HERA+jets (14p)</td>
<td>(Q^2 &gt; 3.5)</td>
<td>0.82</td>
</tr>
<tr>
<td>LHeC only (14p)</td>
<td>(Q^2 &gt; 3.5)</td>
<td>0.15</td>
</tr>
<tr>
<td>LHeC only (10p)</td>
<td>(Q^2 &gt; 3.5)</td>
<td>0.17</td>
</tr>
<tr>
<td>LHeC only (14p)</td>
<td>(Q^2 &gt; 20.)</td>
<td>0.25</td>
</tr>
<tr>
<td>LHeC+HERA (10p)</td>
<td>(Q^2 &gt; 3.5)</td>
<td>0.11</td>
</tr>
<tr>
<td>LHeC+HERA (10p)</td>
<td>(Q^2 &gt; 7.0)</td>
<td>0.20</td>
</tr>
<tr>
<td>LHeC+HERA (10p)</td>
<td>(Q^2 &gt; 10.)</td>
<td>0.26</td>
</tr>
</tbody>
</table>

Two independent QCD analyses using LHeC+HERA/BCDMS
\( F_{2}^{\text{charm}} \) and \( F_{2}^{\text{beauty}} \) from LHeC

**Hugely extended range and much improved precision**
will pin down heavy quark behaviour at and away from thresholds
How can we use the LHC for ep/A?
Storage Ring

\[ L = \frac{N_p \gamma}{4\pi \epsilon_{pn}} \cdot \frac{I_e}{\sqrt{\beta_{px} \beta_{py}}} \]

\[ N_p = 1.7 \cdot 10^{11}, \epsilon_p = 3.8 \mu m, \beta_{px(y)} = 1.8(0.5) m, \gamma = \frac{E_p}{M_p} \]

\[ L = 8.2 \cdot 10^{32} \text{cm}^{-2} \text{s}^{-1} \cdot \frac{N_p 10^{-11}}{1.7} \cdot \frac{m}{\sqrt{\beta_{px} \beta_{py}}} \cdot \frac{I_e}{50 \text{mA}} \]

\[ I_e = 0.35 \text{mA} \cdot P \{ \text{MW} \} \cdot (100/E_e[\text{GeV}])^4 \]

---

L vs \( E_e \)

Energy Recovery Linac

\[ L = \frac{1}{4\pi} \cdot \frac{N_p}{\epsilon_p} \cdot \frac{1}{\beta_x^*} \cdot \gamma \cdot \frac{I_e}{e} \]

\[ N_p = 1.7 \cdot 10^{11}, \epsilon_p = 3.8 \mu m, \beta^* = 0.2 m, \gamma = 7000 / 0.94 \]

\[ L = 8 \cdot 10^{31} \text{cm}^{-2} \text{s}^{-1} \cdot \frac{N_p 10^{-11}}{1.7} \cdot \frac{0.2}{\beta^*/m} \cdot \frac{I_e}{\text{mA}} \]

\[ I_e = mA \cdot \frac{P_E / \text{MW}}{E_e / \text{GeV}}, P_E = P / (1 - \eta), \eta \approx 0.95 \]
Bypassing ATLAS

Civil Engineering studied and reviewed internally and by CH company Amber. Both for ring and for linac options.
Two 10 GeV energy recovery Linacs, 3 returns, 720 MHz cavities
Linac Characteristics

**U_{LHeC} = U_{LHC} / 3 : 1.5 \times HERA**

Tunneling: 150m per week – 60 weeks

Two 1km linacs with 59 cryomodules of 8 cavities each \( \rightarrow \) 1000 cavities

Multibunch wakefields - ok
Emittance growth - ok
[ILC 10nm, LHeC 10 \( \mu \)m]
36 \( \sigma \) separation at 3.5m - ok
Fast ion instability - probably ok with clearing gap (1/3)

Figure 10.11: View on the ERL placed inside the LHC ring and tangential to IP2. TI2 is the injection line into the LHC. The insert shows the view towards IP2, which currently houses the ALICE experiment, from the direction of the protons colliding with the electron beam incoming from behind.
Prototypes from BINP and CERN: function to spec's

### TABLE II REPRODUCIBILITY OF MAGNETIC FIELD OVER 8 CYCLES

<table>
<thead>
<tr>
<th>Model</th>
<th>Low field</th>
<th>High fields</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model 1 (NiFe steel)</td>
<td>$5 \times 10^{-5}$</td>
<td>$4 \times 10^{-5}$</td>
</tr>
<tr>
<td>Model 2 (Low carbon steel)</td>
<td>$6 \times 10^{-5}$</td>
<td>$6 \times 10^{-5}$</td>
</tr>
<tr>
<td>Model 3 (Grain oriented 3.5% Si steel)</td>
<td>$4 \times 10^{-5}$</td>
<td>$6 \times 10^{-5}$</td>
</tr>
</tbody>
</table>

**Standard Deviation from Average**

<table>
<thead>
<tr>
<th>Model</th>
<th>Low field</th>
<th>High fields</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model 1 (NiFe steel)</td>
<td>$3 \times 10^{-5}$</td>
<td>$3 \times 10^{-5}$</td>
</tr>
<tr>
<td>Model 2 (Low carbon steel)</td>
<td>$4 \times 10^{-5}$</td>
<td>$5 \times 10^{-5}$</td>
</tr>
<tr>
<td>Model 3 (Grain oriented 3.5% Si steel)</td>
<td>$2 \times 10^{-3}$</td>
<td>$4 \times 10^{-3}$</td>
</tr>
</tbody>
</table>

5.35 m
0.013-0.08 T
~200 kg/m
 Components and Cryogenics

Table 2: Components of the Electron Accelerators

<table>
<thead>
<tr>
<th></th>
<th>Ring</th>
<th>Linac</th>
</tr>
</thead>
<tbody>
<tr>
<td>beam energy</td>
<td>60 GeV</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>
<tr>
<td>RF and cryogenics</td>
<td></td>
<td></td>
</tr>
<tr>
<td>number of cavities</td>
<td>112</td>
<td>944</td>
</tr>
<tr>
<td>gradient [MV/m]</td>
<td>11.9</td>
<td>20</td>
</tr>
<tr>
<td>RF power [MW]</td>
<td>49</td>
<td>39</td>
</tr>
<tr>
<td>cavity voltage [MV]</td>
<td>5</td>
<td>21.2</td>
</tr>
<tr>
<td>cavity $R/Q$ [Ω]</td>
<td>114</td>
<td>285</td>
</tr>
<tr>
<td>cavity $Q_0$</td>
<td>–</td>
<td>$2.5 \times 10^{10}$</td>
</tr>
<tr>
<td>cooling power [kW]</td>
<td>5.4 @ 4.2 K</td>
<td>30 @ 2 K</td>
</tr>
</tbody>
</table>

5-cell 721 MHz cavities in individual 2 K bath

The cryogenics of the L-R version consists of a formidable engineering challenge, however, it is feasible and, CERN disposes of the respective know-how.
### Proton beam parameters:

- $E_p$ perhaps 6.5 TeV
- $N_p$ almost achieved
- $\varepsilon_p$ already lower in 2011

### Linac has real $\gamma$ beam option

### Table 1: Parameters of the RR and RL configurations.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Ring</th>
<th>Linac</th>
</tr>
</thead>
<tbody>
<tr>
<td>electron beam</td>
<td></td>
<td></td>
</tr>
<tr>
<td>beam energy $E_e$</td>
<td>60 GeV</td>
<td></td>
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<tr>
<td>$e^-$ ($e^+$) per bunch $N_e$ [10$^9$]</td>
<td>20 (20)</td>
<td>1 (0.1)</td>
</tr>
<tr>
<td>$e^-$ ($e^+$) polarisation [%]</td>
<td>40 (40)</td>
<td>90 (0)</td>
</tr>
<tr>
<td>bunch length [mm]</td>
<td>10</td>
<td>0.6</td>
</tr>
<tr>
<td>trans. emittance at IP $\gamma\varepsilon^e_{x,y}$ [mm]</td>
<td>0.58, 0.29</td>
<td>0.05</td>
</tr>
<tr>
<td>IP $\beta$ function $\beta^{*}_{x,y}$ [m]</td>
<td>0.4, 0.2</td>
<td>0.12</td>
</tr>
<tr>
<td>beam current [mA]</td>
<td>131</td>
<td>6.6</td>
</tr>
<tr>
<td>energy recovery intensity gain</td>
<td>–</td>
<td>17</td>
</tr>
<tr>
<td>total wall plug power</td>
<td>100 MW</td>
<td></td>
</tr>
<tr>
<td>syn rad power [kW]</td>
<td>51</td>
<td>49</td>
</tr>
<tr>
<td>critical energy [keV]</td>
<td>163</td>
<td>718</td>
</tr>
</tbody>
</table>

| proton beam                              |       |       |
| beam energy $E_p$                        | 7 TeV |       |
| protons per bunch $N_p$                  | $1.7 \cdot 10^{11}$ |       |
| transverse emittance $\gamma\varepsilon^p_{x,y}$ | 3.75 $\mu$m |       |

| collider                                 |       |       |
| bunch spacing                            | 25 ns |       |
| rms beam spot size $\sigma_{x,y}$ [$\mu$m] | 30, 16 | 7 |
| crossing angle $\theta$ [mrad]           | 1     | 0     |
| $L_{eN} = A L_{eA}$ [$10^{32}\text{cm}^{-2}\text{s}^{-1}$] | 0.3 | 1 |
Draft LHC Schedule for the coming decade

Figure 11.1: CERN medium term plan (MTP), draft as of July 2011
as shown by S. Myers at EPS 2011 Grenoble
Forward/backward asymmetry in energy deposited and thus in geometry and technology

Present dimensions: \( L \times D = 14 \times 9 \text{m}^2 \) [CMS 21 \( \times \) 15\( \text{m}^2 \), ATLAS 45 \( \times \) 25\( \text{m}^2 \)]

Taggers at -62m (e), 100m (\( \gamma \), LR), -22.4m (\( \gamma \), RR), +100m (n), +420m (p)
Detector Magnets

Dipole (for head on LR) and solenoid in common cryostat, perhaps with electromagnetic LAr

3.5T field at ~1m radius to house a Silicon tracker

Based on ATLAS+CMS experience

Table 13.1: Main parameters of the baseline LHec Solenoid providing 3.5T in a free bore of 1.8m.
Silicon Tracker and EM Calorimeter

Transverse momentum $\Delta p_t / p_t^2 \rightarrow 6 \times 10^{-4} \text{ GeV}^{-1}$
transverse impact parameter $\rightarrow 10 \mu \text{m}$

Figure 13.18: Tracker and barrel Electromagnetic-Calorimeter $r\phi$ view of the baseline detector (Linac-Ring case).
Liquid Argon Electromagnetic Calorimeter

Inside Coil H1, ATLAS experience.

Barrel: Pb, $20 \times 0$, $11\,m^3$

fwd/bwd inserts:
FEC: Si -W, $30 \times 0$, $0.3\,m^3$
BEC: Si -Pb, $25 \times 0$, $0.3\,m^3$

Figure 13.30: $x$-$y$ and $r$-$z$ view of the LHeC Barrel EM calorimeter (green).

GEANT4 Simulation

Figure 13.35: View of the parallel geometry accordion calorimeter (left) and simulation of a single electron shower with initial energy of 20 GeV (right).

Figure 13.36: LAr accordion calorimeter energy resolution for electrons between 10 and 400 GeV.
Hadronic Tile Calorimeter

Outside Coil: flux return
Modular. ATLAS experience.

<table>
<thead>
<tr>
<th></th>
<th>FEC1</th>
<th>FEC2</th>
<th>EMC</th>
<th>BEC2</th>
<th>BEC1</th>
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<tr>
<td>Min. Inner radius $R$ [cm]</td>
<td>3.1</td>
<td>21</td>
<td>48</td>
<td>21</td>
<td>3.1</td>
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<tr>
<td>Min. polar angle $\theta$ [°]</td>
<td>0.48</td>
<td>3.2</td>
<td>6.6/168.9</td>
<td>174.2</td>
<td>179.1</td>
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<tr>
<td>Max. pseudorapidity $\eta$</td>
<td>5.5</td>
<td>3.6</td>
<td>2.8/-2.3</td>
<td>-3.</td>
<td>-4.8</td>
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<tr>
<td>Outer radius [cm]</td>
<td>20</td>
<td>46</td>
<td>88</td>
<td>46</td>
<td>20</td>
</tr>
<tr>
<td>$z$-length [cm]</td>
<td>40</td>
<td>40</td>
<td>660</td>
<td>40</td>
<td>40</td>
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<tr>
<td>Volume [m$^3$]</td>
<td>0.3</td>
<td></td>
<td>11.3</td>
<td></td>
<td>0.3</td>
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<table>
<thead>
<tr>
<th></th>
<th>FHC4</th>
<th>HAC</th>
<th>BHC4</th>
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<tbody>
<tr>
<td>Inner radius [cm]</td>
<td>120</td>
<td>120</td>
<td>120</td>
</tr>
<tr>
<td>Outer radius [cm]</td>
<td>260</td>
<td>260</td>
<td>260</td>
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<tr>
<td>$z$-length [cm]</td>
<td>217</td>
<td>580</td>
<td>157</td>
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<tr>
<td>Volume [m$^3$]</td>
<td>121.2</td>
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</table>

<table>
<thead>
<tr>
<th></th>
<th>FHC1</th>
<th>FHC2</th>
<th>FHC3</th>
<th>BHC3</th>
<th>BHC2</th>
<th>BHC1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Min. inner radius $R$ [cm]</td>
<td>11</td>
<td>21</td>
<td>48</td>
<td>48</td>
<td>21</td>
<td>11</td>
</tr>
<tr>
<td>Min. polar angle $\theta$ [°]</td>
<td>0.43</td>
<td>2.9</td>
<td>6.6</td>
<td>169.</td>
<td>175.2</td>
<td>179.3</td>
</tr>
<tr>
<td>Max/min pseudorapidity $\eta$</td>
<td>5.6</td>
<td>3.7</td>
<td>2.9</td>
<td>-2.4</td>
<td>-3.2</td>
<td>-5.</td>
</tr>
<tr>
<td>Outer radius [cm]</td>
<td>20</td>
<td>46</td>
<td>88</td>
<td>88</td>
<td>46</td>
<td>20</td>
</tr>
<tr>
<td>$z$-length [cm]</td>
<td>177</td>
<td>177</td>
<td>177</td>
<td>117</td>
<td>117</td>
<td>117</td>
</tr>
<tr>
<td>Volume [m$^3$]</td>
<td>4.2</td>
<td></td>
<td></td>
<td>2.8</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 13.6: Summary of calorimeter dimensions.
The electromagnetic barrel calorimeter is currently represented by the barrel part EMC (LAr-Pb module); the setup reaches $X_0 \approx 25$ radiation length) and the movable inserts forward FEC1, FEC2 (Si-W modules ($X_0 \approx 30$) and the backward BEC1, BEC2 (Si-Pb modules; $X_0 \approx 25$).
The hadronic barrel parts are represented by FHC4, HAC, BHC4 (forward, central and backward - Scintillator-Fe Tile modules; $\lambda_f \approx 8$ interaction length) and the movable inserts FHC1, FHC2, FHC3 (Si-W modules; $\lambda_f \approx 10$), BHC1, BHC2, BHC3 (Si-Cu modules, $\lambda_f \approx 8$) see Fig. 13.9.

$\sigma = \frac{(28.12 \pm 0.84\%)\%}{\sqrt{E}}$ for (6.8 $\pm$ 0.31)\% without Al

$\sigma = \frac{(31.92 \pm 1.84\%)\%}{\sqrt{E}}$ for (8.57 $\pm$ 0.64)\% with Al

Combined GEANT4 Calorimeter Simulation
III. Relations to LHC and EIC
Technicolor ??

“We argue that the existence of fundamental scalar fields constitutes a serious flaw of the Weinberg-Salam theory…

L. Susskind, Dynamics of Spontaneous Symmetry Breaking in the Weinberg Salam Theory. Phys D20 (1979) 2619-2625

Dimopoulos, Susskind: Mass Without Scalars NP. B155 (1979) 237

CMS similar results

LHCb: $B_s \rightarrow \mu \mu < 4.5 \times 10^{-9}$ SM$(3.2 \pm 0.2) \times 10^{-9}$
Higgs with LHeC

Higgs is light (or absent), CC: $WW \rightarrow H \rightarrow bb$
CP even: SM, CP odd: nonSM, mixture?

Process determines much of detector acceptance and $b$ tag (also single top) and $L/E_e$ requirement.
PDFs – Strange Quark Distribution

$s+\bar{s}$ distribution at $Q^2 = 1.9$ GeV$^2$

$Q^2 = 1.9$ GeV$^2$, $x=0.023$

Trend confirmed in NNPDF collider only fit (Ubiali)

Change of strange affects sea - UHE $\nu$
The knowledge on QCD and electroweak physics with the LHC will much evolve! 

(19/12/11)

Publications http://atlasresults.web.cern.ch/atlasresults/

The knowledge on QCD and electroweak physics with the LHC will much evolve!
Determination of $\Delta G$ and polarised PDFs requires high luminosity ep collider of modest but variable energy with electron and proton polarisation.

**Mapping of spin and spatial structure of partons in nucleons.**
Novel programme in eA: between fixed target experiments and LHeC

cf Summary by E. Aschenauer
Heavy Ion Physics

Initial state of QGP

Hadronization in Media

Nuclear Parton Distributions

Black body limit

Saturation in $ep$ AND in $eA$?

Diffraction in $eA$ scattering

Deuterons: tag $p$ in $en$ to beat Fermi motion and exploit Diffraction-shadowing relation …

LHeC $eA$ is natural continuation of (part of) the heavy ion physics of the LHC ($AA$ and $pA$, forward)

EIC programme:
see recent workshop arXiv:1108.1713 [nucl-th]
MEIC at Jlab

Crabs, e Cooling, ERL: $14 \times 10^{33}$ with reduced Acc

Dashed: staged higher energy option $250 \times 20$ GeV$^2$

MEIC: 1340m circumference

Detector and Physics Studies (C.Keppel et al.)

<table>
<thead>
<tr>
<th></th>
<th>Proton</th>
<th>Electron</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beam energy</td>
<td>GeV</td>
<td>60</td>
</tr>
<tr>
<td>Collision frequency</td>
<td>MHz</td>
<td>750</td>
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<tr>
<td>Particles per bunch</td>
<td>$10^{10}$</td>
<td>0.416</td>
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<tr>
<td>Beam Current</td>
<td>A</td>
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<tr>
<td>Polarization</td>
<td>%</td>
<td>&gt; 70</td>
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<tr>
<td>Energy spread</td>
<td>$10^{-4}$</td>
<td>~ 3</td>
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<tr>
<td>RMS bunch length</td>
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<td>10</td>
</tr>
<tr>
<td>Horizontal emittance, normalized</td>
<td>$\mu m$ rad</td>
<td>0.35</td>
</tr>
<tr>
<td>Vertical emittance, normalized</td>
<td>$\mu m$ rad</td>
<td>0.07</td>
</tr>
<tr>
<td>Horizontal $\beta^*$</td>
<td>cm</td>
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<tr>
<td>Vertical $\beta^*$</td>
<td>cm</td>
<td>2</td>
</tr>
<tr>
<td>Vertical beam-beam tune shift</td>
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<td>0.014</td>
</tr>
<tr>
<td>Laslett tune shift</td>
<td></td>
<td>0.06</td>
</tr>
<tr>
<td>Distance from IP to 1st FF quad</td>
<td>m</td>
<td>7</td>
</tr>
<tr>
<td>Luminosity per IP, $10^{33}$</td>
<td>cm$^2$s$^{-1}$</td>
<td>5.6</td>
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</table>
eRHIC at BNL

Crabs, e Cooling, ERL

Detector and Physics Studies
(K. Dehmelt et al.)

Staging considered

<table>
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<tr>
<th>Protons</th>
<th>E, GeV</th>
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<th>75</th>
<th>100</th>
<th>130</th>
<th>250</th>
<th>325</th>
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<tbody>
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<td>Electrons</td>
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<td>0.077</td>
<td>0.26</td>
<td>0.62</td>
<td>1.4</td>
<td>9.7</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>0.077</td>
<td>0.26</td>
<td>0.62</td>
<td>1.4</td>
<td>9.7</td>
<td>15</td>
</tr>
<tr>
<td></td>
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<td>0.077</td>
<td>0.26</td>
<td>0.62</td>
<td>1.4</td>
<td>9.7</td>
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<td>0.35</td>
<td>2.4</td>
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</tbody>
</table>
IV. Next Steps on LHeC

Physics: Top, SUSY, Higgs, Relations to LHC – QCD+Eweak

Detector: Simulations, Forward Region, Beam Pipe, IR, Installation

Accelerator: f, ERL, Q1, Civil Engineering, LR-RR

Adjust the organisational structure to new phase of LHeC

Workshop June 14/15.6. at Chavannes near Coppet+CERN

https://indico.cern.ch/conferenceDisplay.py/183282
The 4th Workshop on the Large Hadron electron Collider will provide an overview on the completed conceptual design report, and is directed to steps for the further development of the LHeC, its physics programme & detector design.

More information on LHeC [websites](https://indico.cern.ch/conferenceDisplay.py/183282).

Contact address:
ECFA-CERN LHeC Workshop Secretariat
Mailbox Lo1800
CERN
1211-Geneva 23
or [e-mail](https://indico.cern.ch/conferenceDisplay.py/183282)

Join the workshop (there is no fee) and join the LHeC (there is much work) if you are interested.

Dates: from 14 June 2012 09:00 to 15 June 2012 18:00
Timezone: Europe/Zurich
Location: Chavannes-de-Bogis, Switzerland
HL-LHC will explore highest mass range which requires to control very high BJ x, where LHeC pins down partons such that resummation and factorisation effects can be tested.

**RPV SUSY in 3rd generation?**

\[
W_R = \frac{1}{2} \lambda^{ij,k} L_i L_j E_k + \lambda^{ij,k} Q_j \bar{D}_k + \frac{1}{2} \lambda^{ij,k} \bar{U}_i \bar{D}_j \bar{D}_k
\]

*L*: LH (s)leptons,  
*Q*: LH (s)quarks,  
*D*: RH down-type (s)quarks

\(i,j,k\) generation indices (27 couplings)
**ERL Choice of frequency** (Erk Jensen - Chamonix12)

- The frequency has to be a harmonic of 20.04 MHz!
- LHeC baseline: 721.42 MHz, alternative 1322.6 MHz.

**Advantages of lower frequency:**
- Less cryo-power
- High-power couplers easier
- Less cells per cavity – less trapped modes
- Less beam loading and transverse wake – better beam stability
- Less HOM power
- Synergy with SPL, e-RHIC and ESS.

**Advantages of higher frequency:**
- Larger $R/Q \rightarrow$ with same $Q_{ext}$ less RF power (but $Q_{ext}$ must be reduced!)
- Synergy with ILC/X-FEL
Collaboration on ERL

IHEP ERL, Beijing

2 x 7 cell 1.3 GHz + DC Gun
10 mA, 35 MeV, 2 ps

BERLinPro

3 x 7 cell cavities, 1.3 GHz
100 mA, 50 MeV, 1 mm mrad (norm), 2 ps

Peking ERL-FEL

1 x 9 cell, 1.3 GHz
60 pC, 30 MeV, 2 ms bunch train

ALICE, Daresbury

2 x 9 cell, 1.3 GHz
100 pC, 10 MeV, 100 μs bunch train

2loop-CERL, KEK

9 cell, 1.3 GHz cavities, 4 modules
77 pC, 245 MeV, 1-3 ps

Brookhaven ERL

1 x 5 cell, 704 MHz
0.7-5 nC, 20 MeV, CW

Budker Institute
High-gradient SC IR quadrupoles based on Nb₃Sn for colliding proton beam with common low-field.
## Magnet Development at CERN

### on Magnet R+D for LHeC + HE-LHC

<table>
<thead>
<tr>
<th>LHeC</th>
<th>Comments</th>
</tr>
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<tbody>
<tr>
<td><strong>Low field resistive magnets</strong></td>
<td>field quality and reproducibility X</td>
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<tr>
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<td>operating cost x</td>
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<tr>
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<td>integration in the LHC tunnel x</td>
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<td><strong>IR magnets</strong></td>
<td>large aperture X X</td>
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<td>large gradient X</td>
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<td>heat removal x X</td>
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<td>co-activities and tunnel works</td>
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<table>
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<tr>
<th>HE-LHC</th>
<th>Options reviewed at HE-LHC workshop in Malta, 2010</th>
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<td><strong>Very high field magnets</strong></td>
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<tr>
<td></td>
<td>5 T dipole insert x X</td>
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<td>high gradient quadrupoles x</td>
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<td>magnet protection x X X X</td>
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<td>heat loads and removal x X</td>
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<td>low-loss cables X</td>
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<td><strong>Transfer lines</strong></td>
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<td><strong>Material availability and cost</strong></td>
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<tr>
<td><strong>Installation in 2030</strong></td>
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</table>
Concluding Remarks

The physics of deep inelastic scattering has been an essential part of HEP.

Major breakthroughs in (particle) physics are difficult to plan, despite the “overconfidence of theorists” [Ledermann ICHEP 1980] in the past.

The LHeC has passed a major milestone with a refereed CDR, supported and monitored by CERN, ECFA and NuPECC, soon to be published.

The time schedule of the LHC is such that there is not more time than a decade+ for realising the LHeC. This requires to continue to be realistic.

Collaborations are soon to be built for further design, of the machine and the detector. The experimental prospect challenges theory and requires to continue our intimate interaction with our thy colleagues.

While the LHeC is crucial for the DIS exploration of the energy frontier, the medium energy, polarised eN collider(s) and a vigorous fixed target programme as at FNAL, CERN and Jlab are essentials of DIS to be maintained as a rich part of our culture, which we jointly develop.
Backup
gg luminosity at LHC ($\sqrt{s} = 7$ TeV)
linac e\(^+\) source options

- recycle e\(^+\) together with energy, multiple use, damping ring in SPS tunnel w \(\tau_\perp \sim 2\) ms
- Compton ring, Compton ERL, coherent pair production, or undulator for high-energy beam
- 3-ring transformer & cooling scheme

(D. Schulte)
(Y. Papaphilippou)

(H. Braun, E. Bulyak, T. Omori, V. Yakimenko)
Tentative Time Schedule

We base our estimates for the project time line on the experience of other projects, such as (LEP, LHC and LINAC4 at CERN and the European XFEL at DESY and the PSI XFEL)

from draft CDR
Neutrino Scattering

- $\sigma_{\nu n}^{\text{tot}}$ cross section (τ energy loss) dominated by DIS structure functions (n)pdfs at small-x and large (small) $Q^2$.
- Key ingredient for estimating fluxes.

$$\left\langle \frac{dE}{dX} \right\rangle = a(E') + b(E'E)$$
HERA in one box
the first ep collider

$E_p E_e = 920 \times 27.6 \text{GeV}^2$
$\sqrt{s} = 2 \times E_p E_e = 320 \text{GeV}$

$L = 1 \ldots 4 \times 10^{31} \text{cm}^{-2} \text{s}^{-1}$
$\Rightarrow \Sigma L = 0.5 \text{fb}^{-1}$


$Q^2 = [0.1 -- 3 \times 10^4] \text{GeV}^2$
-4-momentum transfer

$x = \frac{Q^2}{(sy)} \approx 10^{-4} \ldots 0.7$
Bjorken $x$

$\gamma \approx 0.005 \ldots 0.9$
inelasticity

Test of **the isospin symmetry** (u-d) with eD - no deuterons
Investigation of the q-g dynamics in **nuclei** - no time for eA
Verification of **saturation** prediction at low $x$ -- too low $s$
Measurement of the **strange** quark distribution -- too low L
Discovery of **Higgs** in WW fusion in CC -- too low cross section
Study of **top** quark distribution in the proton -- too low $s$
Precise measurement of $F_L$ -- too short running time left
Resolving d/u question at **large Bjorken $x$** -- too low L
Determination of **gluon distribution at hi/lo $x$** -- too small range
High precision measurement of $\alpha_s$ -- overall not precise enough
Discovering **instantons, odderon**s -- don’t know why not
Finding **RPV SUSY** and/or leptoquarks -- may reside higher up ...

The H1 and ZEUS apparatus were basically well suited
The machine had too low luminosity and running time

HEP needs a TeV energy scale machine with 100 times higher luminosity than HERA to develop DIS physics further and to complement the physics at the LHC. The **Large Hadron Collider** $p$ and $A$ beams offer a unique opportunity to build a second ep and first eA collider at the energy frontier [discussed at DIS since Madison 2005]
In-medium Hadronisation

The study of particle production in eA (fragmentation functions and hadrochemistry) allows the study of the space-time picture of hadronisation (the final phase of QGP).

Low energy ($\nu$): need of hadronization inside.
Parton propagation: pt broadening
Hadron formation: attenuation

High energy ($\nu$): partonic evolution altered in the nuclear medium.

LHeC:
+ study the transition from small to high energies in much extended range wrt. fixed target data
+ testing the energy loss mechanism crucial for understanding of the medium produced in HIC
+ detailed study of heavy quark hadronisation ...

W.Brooks, Divonne09