The LHeC Conceptual Design

A status report on behalf of the LHeC Study Group

Physics
Machine
Organisation

Max Klein

ICHEP Paris: Future Machines and Projects 24.7.2010

http://cern.ch/lhec
Electron-proton colliders open new horizons on all three of the fundamental questions: the spectroscopy of fundamental fermions, the spectroscopy of gauge bosons, and the problem of hadron structure. In addressing these issues, the ep collider is approaching the same physics as is studied in $e^+e^-$ and $\bar{p}p$ colliders, but in a complementary way, with emphasis on the t-channel. Each technique has its own strengths and weaknesses, which I leave you to contemplate.

Chris Quigg

FERMILAB-Conf-81/52-THY

LEP*LHC (1984, 1990) - Lausanne, Aachen
E.Keil LHC project report 93 (1997)
Thera (2001),
QCD explorer (2003)
J.Dainton et al, 2006 JINST 1 10001

LHeC at DIS conferences since Madison 2005

2007 CERN SPC and [r]ECFA
2008 Divonne I, ICFA,ECFA
2009 Divonne II, NuPECC, ECFA
2010 Divonne III, ECFA - CDR
Lepton-Proton Scattering Experiments

Tevatron/LEP/HERA (Fermiscale) \rightarrow \text{LHC/LC/LHeC (Terascale)}

100 fold increase in luminosity, in $Q^2$ and $1/x$ w.r.t. HERA
**Luminosity**

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

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

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

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

**Ring-Ring**

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

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

HERA 0.5fb\(^{-1}\) with 100 times less L

**LINAC Ring**

Pulsed, 60 GeV: \(\sim10^{32}\)

High luminosity:

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

\(\beta^* = 0.1m\)

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

\(L = 10^{33} \text{cm}^{-2} \text{s}^{-1} \rightarrow O(100) \text{ fb}^{-1}\)
Based on weak = electromagnetic cross sections, p, d, e±,Pe and high precision and full acceptance

Structure functions \([F_2,F_3,xF_3^g,xF_3^Z; F_2^{cc},F_2^{bb},F_2^{ss}]\) in p/d and A
Quark distributions from direct measurements and QCD fits
Strong coupling constant \(\alpha_s\) to per mille accuracy
Gluon distribution in full x range to unprecedented precision
Standard Model Higgs
Single top and anti-top quark production at high rate (5pb)
Electroweak couplings (light and heavy quarks and mixing angle)
Heavy quark fragmentation functions
Charm and beauty below and way beyond threshold at per cent accuracy
Heavy quarks in real photon-proton collisions [LR option]
Jets and QCD in photoproduction and DIS
Gluon structure of the photon
....
Strong Coupling Constant

\( \alpha_s \) 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

Simulation of \( \alpha_s \) measurement at LHeC

**DATA**

<table>
<thead>
<tr>
<th></th>
<th>exp. error on ( \alpha_s )</th>
</tr>
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<tbody>
<tr>
<td>NC e(^+) only</td>
<td>0.48%</td>
</tr>
<tr>
<td>NC</td>
<td>0.41%</td>
</tr>
<tr>
<td><strong>NC &amp; CC</strong></td>
<td><strong>0.23%</strong> :=(1)</td>
</tr>
</tbody>
</table>

\( ^{[1]} \gamma_h > 5^\circ \)

\( ^{[2]} \gamma \) + BCDMS

\( ^{[1]} \) + BCDMS

\( ^{[2]} \) stat. *= 2

0.36\% :=(2)

0.22%

0.22%

0.35%

Single top and anti-top Production in Charged Currents

LHeC is a single top and single tbar quark 'factory'
CC t cross section O(5)pb

CC events for 10 fb⁻¹
New Physics at the LHeC

- Lepto-Quark Production and Decay (s and t-channel effects)
  \[ \text{Maximum } W < 1.4 \text{ TeV} \]
  \[ \text{for } E_e = 140 \text{ GeV, } E_p = 7 \text{ TeV} \]
- Squarks and Gluinos
- \(ZZ, WZ, WW\) elastic and inelastic collisions
- Technicolor
- Novel Higgs Production Mechanisms
- Composite electrons
- Lepton-Flavor Violation
- QCD at High Density in ep and eA collisions
- Odderon

Broad physics goals (to be discussed at the Workshop)

- Proton structure and QCD physics in the domain of \(x\) and \(Q^2\) of LHC experiments
- Small-\(x\) physics in eP and eA collisions
- Probing the \(e^\pm\)-quark system at ~\(\text{TeV}\) energy
  - eg leptoquarks, excited e*'s, mirror e, SUSY with no R-parity......
- Searching for new EW currents
  - eg RH W's, effective eeqq contact interactions...

G. Altarelli

J. Bartels: Theory on low \(x\)

LHeC Physics Overview

Stan Brodsky, SLAC
In MSSM Higgs production is $b$ dominated

First measurements of $b$ at HERA can be turned to precision measurement of $b$-df.

LHeC: higher fraction of $b$, larger range, smaller beam spot, better Si detectors
Low x Physics: non-linear parton evolution (ep/eA)

Based on $p/A [e^\pm, P_e]$ and high precision and full acceptance in forward and backward region

- Unitarity and QCD
- Expectations from LHC
- Nuclear Parton Distributions
- New physics at low x
- Diffraction
- Vector Mesons
- Deeply Virtual Compton Scattering
- Jets and Parton Dynamics
- Forward jets and parton emission
- Initial QGP [AA-eA]
- UHE Neutrino Scattering and LHeC
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)
Saturation of Gluon Density

\[ xG(x) = \frac{dN_g}{dy} \]

\[ xG(x) \sim x^{-\lambda} \]

BFKL

\[ F_L \text{ at the LHeC - Simulated data from FS04 saturation model} \]

MUST show up as LHeC measures in unitarity limited region. Can be uniquely identified (inclusive \( F_2/F_L \), diffraction, J/ψ).

With eA reach effectively \( x \) of \( 10^{-8} \) (UHEv)
# NuPECC – Roadmap 5/2010: New Large-Scale Facilities

<table>
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<tr>
<th>Facility</th>
<th>2010</th>
<th>2015</th>
<th>2020</th>
<th>2025</th>
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<td>FAIR</td>
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<td>Construction</td>
<td>Commissioning</td>
<td>Exploitation</td>
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<td>PAVE/INC</td>
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<td>R&amp;D</td>
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<td>Exploitation</td>
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<td>Exploitation</td>
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<td>Injector Upgrade</td>
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<tr>
<td>SPES</td>
<td>Constr./Commission.</td>
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<td>EURISOL</td>
<td>Design Study</td>
<td>R&amp;D</td>
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<td>LHeC</td>
<td>Design Study</td>
<td>R&amp;D</td>
<td>Engineering Study</td>
<td>Construction/Commissioning</td>
</tr>
</tbody>
</table>

G. Rosner, NuPECC Chair, Madrid 5/10
Newly built magnets installed on top of the LHC, bypassing LHC experiments in the twenties.

10 GeV injector into bypass of P1
2 \cdot 10^{10}e (LEP: 4 \cdot 10^{11})
~10 min filling time
synchronous ep + pp

\[ 10^{33} \text{cm}^{-2}s^{-1}, \int L = 100 fb^{-1}, E_e = 60 GeV \]
Bypasses

Away from galeries

Double tunnel (?): use to install rf [typically 0.5-1km]

Aim to keep $U_e = U_p$

Tunnel connection (CGNS, DESY)

Possibly in line with P1,5 redesigns
Accelerator: Ring - Ring

Based on HERA, LEP and LHC Experience

<table>
<thead>
<tr>
<th>Workpackages for CDR</th>
<th>BINP Novosibirsk</th>
<th>BNL</th>
<th>CERN</th>
<th>Cockcroft</th>
<th>Cornell</th>
<th>DESY</th>
<th>EPFL Lausanne</th>
<th>KEK</th>
<th>Liverpool U</th>
<th>SLAC</th>
<th>TAC Turkey</th>
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<td>Beam-beam effects</td>
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<td>Deuteron and Ion Beams</td>
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</tbody>
</table>
Arc cell design: \( L_{\text{FODO}}(e) = L_{\text{FODO}}(p)/2 \)

- LHC Cryo jumpers accounted for in asymmetric FODO.
- Further interferences mapped and being studied.
- Experiments bypassed in new tunnels which houses rf.

Meets spatial LHC constraints
Synchrotron radiation < 50MW
Two types of quadrupoles
Reasonable sextupole parameters
Dipoles: 4x lighter/slimmer than LEP
Prototypes: Novosibirsk and CERN
Interaction Region

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

Focus of current activity

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

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

Note: CLIC x LHC $\sim 10^{30}$ due to different time structure (0.5 vs 50ns)

Baseline: Energy Recovery Linac
60 GeV Power=100MW  $10^{33}$cm$^{-2}$s$^{-1}$

Tentative sketch
Linac-Ring Configurations

**Pulsed-60**

Least effort: $\sim 10^{32}$

**Pulsed-140**

High Energy, $0.5 \times 10^{32}$

Luminosity $\sim 10^{33}$

**or linear**

7.8 km
Accelerator: LINAC - Ring

Based on ILC, SLC and LHC Experience

Workpackages for CDR

Baseline Parameters [Designs, Real photon option, ERL]
Sources [Positrons, Polarisation]
Rf Design
Injection and Dump
Beam-beam effects
Lattice/Optics and Impedance
Vacuum and Beam Pipe
Integration and Layout
Interaction Region
Powering Issues
Magnets
Cryogenics

BINP Novosibirsk
BNL
CERN
Cockcroft
Cornell
DESY
EPFL Lausanne
KEK
Liverpool U
SLAC
TAC Turkey
## LINAC-Ring Parameters

Table 4: Lepton beam parameters and luminosity.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>p-60</th>
<th>erl</th>
<th>p-140</th>
</tr>
</thead>
<tbody>
<tr>
<td>e⁻ energy at IP [GeV]</td>
<td>60</td>
<td>60</td>
<td>140</td>
</tr>
<tr>
<td>luminosity [10^{32} cm^{-2}s^{-1}]</td>
<td>1.1</td>
<td>10.1</td>
<td>0.4</td>
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<tr>
<td>polarization [%]</td>
<td>90</td>
<td>90</td>
<td>90</td>
</tr>
<tr>
<td>bunch population [10^9]</td>
<td>4.5</td>
<td>2.0</td>
<td>1.6</td>
</tr>
<tr>
<td>e⁻ bunch length [μm]</td>
<td>300</td>
<td>300</td>
<td>300</td>
</tr>
<tr>
<td>bunch interval [ns]</td>
<td>50</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>transv. emit. $\gamma_{x,y}$ [μm]</td>
<td>50</td>
<td>50</td>
<td>100</td>
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<tr>
<td>rms IP beam size [μm]</td>
<td>7</td>
<td>7</td>
<td>7</td>
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<tr>
<td>hourglass reduction $H_{hg}$</td>
<td>0.91</td>
<td>0.91</td>
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<td>crossing angle $\theta_c$</td>
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<td>repetition rate [Hz]</td>
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<td>CW</td>
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<td>10</td>
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<td>beam pulse length [ms]</td>
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<td>ER efficiency $\eta$</td>
<td>0</td>
<td>94%</td>
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<tr>
<td>total wall plug power [MW]</td>
<td>100</td>
<td>100</td>
<td>100</td>
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</tbody>
</table>

For ERL version:

- 2 x 560, 1m long cavities
- 25 MW cryo power

---

Table 2: SC linac parameters. *RT: room temperature.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>p-60</th>
<th>erl</th>
<th>p-140</th>
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<tbody>
<tr>
<td>RF frequency [MHz]</td>
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<td>700</td>
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<tr>
<td>cavity length [m]</td>
<td>1</td>
<td>1</td>
<td>1</td>
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<tr>
<td>energy gain / cavity</td>
<td>31.5</td>
<td>18</td>
<td>31.5</td>
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<td>$R/Q$ [Ω]</td>
<td>403</td>
<td>403</td>
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<tr>
<td>$Q_0$ [$10^{18}$]</td>
<td>1</td>
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<td>power loss, stat [W/cav.]</td>
<td>5</td>
<td>5</td>
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<tr>
<td>power loss, RF [W/cav.]</td>
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<td>32</td>
<td>12.3</td>
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<tr>
<td>power loss, total [W/cav]</td>
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<td>37.2</td>
<td>17.3</td>
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<td>real-est. gradient [MeV/m]</td>
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<td>10.26</td>
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<td>length/GeV [m]</td>
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<td>97.5</td>
<td>55.7</td>
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<tr>
<td>#cavities/(1 GeV)</td>
<td>31.8</td>
<td>55.6</td>
<td>31.8</td>
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<td>power loss/GeV (2 K) [kW]</td>
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<td>2.06</td>
<td>0.55</td>
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<td>“W per W” (1.8 K to RT*)</td>
<td>600</td>
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<td>power loss/GeV (RT*) [MW]</td>
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<td>final energy [GeV]</td>
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<td>60</td>
<td>140</td>
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<tr>
<td># passes for acceleration</td>
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<td># passes for deceleration</td>
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<td>total linac length [km]</td>
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<td>1.95</td>
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<td>tot. cryo power (RT) [MW]</td>
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<td>24.75</td>
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<td>av. beam current [mA]</td>
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<td>beam power at IP [MW]</td>
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<td>396</td>
<td>39</td>
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<td>RF power [MW]</td>
<td>89</td>
<td>(22)</td>
<td>75.6</td>
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<td>cryo + RF power [MW]</td>
<td>99</td>
<td>(47)</td>
<td>98.4</td>
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Cf recent papers to IPAC10 at Kyoto (from LHeC web page)
## Design Parameters

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<tr>
<td>e- energy at IP[GeV]</td>
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<td>60</td>
<td>140</td>
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<tr>
<td>luminosity [$10^{32}$ cm$^{-2}$s$^{-1}$]</td>
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<td>10</td>
<td>0.44</td>
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<td>polarization [%]</td>
<td>40</td>
<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>
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<td>0.3</td>
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<td>bunch interval [ns]</td>
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<tr>
<td>transv. emit. $\gamma_{x,y}$ [mm]</td>
<td>0.58, 0.29</td>
<td>0.05</td>
<td>0.1</td>
</tr>
<tr>
<td>rms IP beam size $\sigma_{x,y}$ [µm]</td>
<td>30, 16</td>
<td>7</td>
<td>7</td>
</tr>
<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>
</tr>
<tr>
<td>full crossing angle [mrad]</td>
<td>0.93</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>geometric reduction $H_{hg}$</td>
<td>0.77</td>
<td>0.91</td>
<td>0.94</td>
</tr>
<tr>
<td>repetition rate [Hz]</td>
<td>N/A</td>
<td>N/A</td>
<td>10</td>
</tr>
<tr>
<td>beam pulse length [ms]</td>
<td>N/A</td>
<td>N/A</td>
<td>5</td>
</tr>
<tr>
<td>ER efficiency</td>
<td>N/A</td>
<td>94%</td>
<td>N/A</td>
</tr>
<tr>
<td>average current [mA]</td>
<td>131</td>
<td>6.6</td>
<td>5.4</td>
</tr>
<tr>
<td>tot. wall plug power[MW]</td>
<td>100</td>
<td>100</td>
<td>100</td>
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<table>
<thead>
<tr>
<th>proton beam</th>
<th>RR</th>
<th>LR</th>
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</thead>
<tbody>
<tr>
<td>bunch pop. [$10^{11}$]</td>
<td>1.7</td>
<td>1.7</td>
</tr>
<tr>
<td>tr.emit.$\gamma_{x,y}$ [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”

present record $N_p = 1.3 \times 10^{11}$

1.7 probably conservative

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

RR = Ring – Ring

LR = Linac – Ring

Tentative: 8.7.2010
Detector

Calibration:
H1/2

Resolution:
H $\rightarrow$ bbar

Acceptance:
Down to 1-179°

Forward: TeV Jets
Backwards: 100 GeV Electrons
FB Asymmetry of detector

Beampipe: as small as possible

Modularity for installation in ‘short’ times
Hadron Calorimeter - 5 Modules (beige)
inner R = 112. cm; outer R = 289. cm
Modules 1 - 5:
ΔZ1,5 = 217. / 250. / 250. / 250. / 217. cm

Elliptical Beam Pipe:
inner-∅x = 7.3cm
inner-∅y = 5.8cm
outer-∅x = 8.1cm
outer-∅y = 6.6cm
thickness: 0.8cm

Fwd Tracker - active Thickness 8. cm each
Si-Pix/Si-Strip/SiGas Tracker:
inner R = 4.86 cm; outer R = 61.3 cm
Planes 1 - 5:
Δz = 140. / 200. / 260. / 320. / 370. cm

Elliptical Pixel Tracker:
inner-∅x = 9.32cm
inner-∅y = 7.82cm
2.4cm active radius

Barrel Tracker - active Radius 2.5cm each
Si-Pix/Si-Strip/SiGas Tracker:
1. layer: inner R = 8.8 cm; outer R = 11.3 cm
2. layer: R = 21.3 cm; R = 23.8 cm
3. layer: R = 33.8 cm; R = 36.3 cm
4. layer: R = 46.3 cm; R = 48.8 cm
5. layer: R = 58.8 cm; R = 61.3 cm

4 Cone structured fwd/bwd Si-pix/Si-strip/Si-gas Tracker
R_min = 4.86 cm
2.5cm active thickness

Bwd Tracker - active Thickness 8. cm each
Si-Pix/Si-Strip/SiGas Tracker:
inner R = 4.86 cm; outer R = 61.3 cm
Planes 1 - 5:
Δz = -140. / -210. / -280. / -340. / -370. cm

Solenoid - 3.5T
inner-R = 300.0cm
inner-R = 330.0cm
half length = 600. cm

Fwd/Bwd Hadron Calo - (grey)
inner R = 21.0 cm; outer R = 110. cm
ΔZ = 177. cm

Fwd/Bwd Hadron Calo Insert - (beige)
inner R = 6.5 cm; outer R = 20. cm
ΔZ = 177. cm

Barrel Electromagn. Calo - (green)
inner R = 70. cm; outer R = 110. cm
ΔZ = 250. cm

Fwd/Bwd Electromagn. Calo 2 - (green)
inner R = 21. cm; outer R = 110. cm
ΔZ = 40. cm

Fwd/Bwd Electromagn. Calo 1 - (green)
inner R = 70. cm; outer R = 110. cm
ΔZ = 250. cm

Fwd/Bwd Electromagn Calo Insert 1&2 - (pink)
inner R= 6.5 cm; outer R = 20. cm
inner R= 21. cm; outer R = 40. cm
ΔZ = 40. cm

Kostka, Polini, Wallny
20th April 2010, DIS2010 Florence
# Organisation for the CDR

## Scientific Advisory Committee

<table>
<thead>
<tr>
<th>Name</th>
<th>Affiliation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Guido Altarelli</td>
<td>Rome</td>
</tr>
<tr>
<td>Sergio Bertolucci</td>
<td>CERN</td>
</tr>
<tr>
<td>Stan Brodsky</td>
<td>SLAC</td>
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<tr>
<td>Allen Caldwell -chair</td>
<td>MPI Munich</td>
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<tr>
<td>Swapan Chattopadhyay</td>
<td>Cockcroft</td>
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<tr>
<td>John Dainton</td>
<td>Liverpool</td>
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<tr>
<td>John Ellis</td>
<td>CERN</td>
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<tr>
<td>Jos Engelen</td>
<td>CERN</td>
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<tr>
<td>Joel Feltesse</td>
<td>Saclay</td>
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<tr>
<td>Lev Lipatov</td>
<td>St.Petersburg</td>
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<tr>
<td>Roland Garoby</td>
<td>CERN</td>
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<tr>
<td>Roland Horisberger (PSI)</td>
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<tr>
<td>Young-Kee Kim</td>
<td>Fermilab</td>
</tr>
<tr>
<td>Aharon Levy</td>
<td>Tel Aviv</td>
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<td>Karlheinz Meier</td>
<td>Heidelberg</td>
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<tr>
<td>Richard Milner</td>
<td>Bates</td>
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<tr>
<td>Joachim Mnich</td>
<td>DESY</td>
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<tr>
<td>Steven Myers</td>
<td>CERN</td>
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<tr>
<td>Tatsuya Nakada</td>
<td>Lausanne, ECFA</td>
</tr>
<tr>
<td>Guenther Rosner</td>
<td>Glasgow, NuPECC</td>
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<tr>
<td>Alexander Skrinsky</td>
<td>Novosibirsk</td>
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<tr>
<td>Anthony Thomas</td>
<td>Jlab</td>
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<tr>
<td>Steven Vigdor</td>
<td>BNL</td>
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<tr>
<td>Frank Wilczek</td>
<td>MIT</td>
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<tr>
<td>Ferdinand Willeke</td>
<td>BNL</td>
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</table>

## Steering Committee

<table>
<thead>
<tr>
<th>Name</th>
<th>Affiliation</th>
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<tbody>
<tr>
<td>Oliver Bruening</td>
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<td>John Dainton</td>
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<td>Albert DeRoeck</td>
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<tr>
<td>Stefano Forte</td>
<td>Milano</td>
</tr>
<tr>
<td>Max Klein - chair</td>
<td>Liverpool</td>
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<tr>
<td>Paul Laycock (secretary)</td>
<td>L'pool</td>
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<tr>
<td>Paul Newman</td>
<td>Birmingham</td>
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<tr>
<td>Emmanuelle Perez</td>
<td>CERN</td>
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<td>Wesley Smith</td>
<td>Wisconsin</td>
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<tr>
<td>Bernd Surrow</td>
<td>MIT</td>
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<tr>
<td>Katsuo Tokushuku</td>
<td>KEK</td>
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<tr>
<td>Urs Wiedemann</td>
<td>CERN</td>
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<td>Frank Zimmermann</td>
<td>CERN</td>
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## Working Group Convenors

<table>
<thead>
<tr>
<th>Name</th>
<th>Affiliation</th>
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<tbody>
<tr>
<td>Accelerator Design [RR and LR]</td>
<td>Oliver Bruening (CERN),</td>
</tr>
<tr>
<td></td>
<td>John Dainton (CI/Liverpool)</td>
</tr>
<tr>
<td>Interaction Region and Fwd/Bwd</td>
<td>Bernhard Holzer (DESY),</td>
</tr>
<tr>
<td></td>
<td>Uwe Schneekloth (DESY),</td>
</tr>
<tr>
<td></td>
<td>Pierre van Mechelen (Antwerpen)</td>
</tr>
<tr>
<td>Detector Design</td>
<td>Peter Kostka (DESY),</td>
</tr>
<tr>
<td></td>
<td>Rainer Wallny (UCLA),</td>
</tr>
<tr>
<td></td>
<td>Alessandro Polini (Bologna)</td>
</tr>
<tr>
<td>New Physics at Large Scales</td>
<td>George Azuelos (Montreal)</td>
</tr>
<tr>
<td></td>
<td>Emmanuelle Perez (CERN),</td>
</tr>
<tr>
<td></td>
<td>Georg Weiglein (Durham)</td>
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<tr>
<td>Precision QCD and Electroweak</td>
<td>Olaf Behnke (DESY),</td>
</tr>
<tr>
<td></td>
<td>Paolo Gambino (Torino),</td>
</tr>
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<td></td>
<td>Thomas Gehrmann (Zuerich)</td>
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<td>Claire Gwenlan (Oxford)</td>
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<tr>
<td>Physics at High Parton Densities</td>
<td>Nestor Armesto (Santiago),</td>
</tr>
<tr>
<td></td>
<td>Brian Cole (Columbia),</td>
</tr>
<tr>
<td></td>
<td>Paul Newman (Birmingham),</td>
</tr>
<tr>
<td></td>
<td>Anna Stasto (MSU)</td>
</tr>
</tbody>
</table>

[http://cern.ch/lhec](http://cern.ch/lhec)
Steps towards completion of CDR

CERN invites referees for

- QCD/electroweak
- BSM
- eA/low x
- Detector
- Interaction Region Design
- Ring-Ring Design
- Linac-Ring Design
- Energy Recovery
- Magnets
- Cost
- Installation and Infrastructure
- Project Position in HEP

Presentation to Science Policy Committee  June 10

Invitation of Referees July/August 2010

Draft of CDR by October 2010

CERN-ECFA-NuPECC Workshop (November)

Report to ECFA: 26.11.2010

Finalisation of design involving referees

Ready for print:  March 2011

Evaluation

possibly a TDR with dedicated groups at CERN
Towards a Tentative Schedule

CDR printed in spring 2011
  Study of installation and interference issues still to be done

Installation of (ring or linac) LHeC towards 2021
  Make maximum use of LHC shutdowns (~50 months).

2021-30: ~10 years of operation with LHC [p/A]
  colliding with $E_e \approx 60$ GeV [e$^-$/e$^+$]: ~100fb$^{-1}$ in ep

later: possible extension to high $E_e$ LHeC
  During HE-LHC upgrade shutdown and long term operation
  With 16 TeV p colliding with e.g. $E_e = 140$ GeV [e$^-$/e$^+$]
  $Q^2_{\text{max}} = 9$ TeV$^2$, $x_{\text{min}} = 10^{-7}$ in DIS region

The time schedule of the LHeC is linked to the LHC, ep has to be doable as an upgrade or 5th experiment to the LHC, so far that looks feasible
Thanks to

Machine and detector experts

CERN: Simona Bettoni, Frederick Bordry, Chiara Bracco, Oliver Bruning, Helmut Burkhardt, Rama Calaga, Edmond Ciapala, Miriam Fitterer, Massimo Giovannozzi, Brennan Goddard, Werner Herr, Bernhard Holzer, John M. Jowett, Trevor Linnecar, Karl Hubert Mess, Steve Myers, Yvon Muttoni, John Andrew Osborne, Louis Riolffi, Stephan Russenschuck, Daniel Schulte, Rogelio Tomas, Davide Tommasini, Joachim Tuckmantel, Alessandro Vivoli, Uli Wienands, Frank Zimmermann

BNL: Ilan Ben Zvi, Vladimir Litvinenko, Ferdinand Willeke

BINP: Eugene B. Levichev, Ivan Morozov, Yurii Pupkov, Pavel Vobly, Alexander Skrinsky

Bologna University: Alessandro Polini

University of Antwerp: Pierre Van Mechelen

Cockcroft Institute: Rob Appleby, Ian Bailey, Graeme Burt, Maxim Korostelev, Neil Marks, Luke Thompson

Cornell University: Georg Hofstaetter

DESY: Desmond P. Barber, Sergey Levonian, Alexander Kling, Peter Kostka, Uwe Schneekloth

Liverpool University: John B. Dainton, Tim Greenshaw, Max Klein

KEK: Tsunehiko Omori, Junji Urukawa

SLAC: Chris Adolphsen, Tor Raubenheimer, Michael Sullivan, Yipeng Sun

TAC: A. Kenan Ciftci, Saleh Sultansoy

ITEP, Moscow: Vladimir Andreev

UCLA: Rainer Wallny

EPFL: Leonid Rifkin

Forgotten someone? ... apologies!

and a similar number of particle physicists engaged in this study to CERN, ECFA, NuPECC and my UK
Backup slides
**HERA - an unfinished programme**

Low x: DGLAP seems to hold though ln1/x is large
Gluon Saturation not proven

High x: would have required much higher luminosity
[u/d ?, xg ?]

Neutron structure not explored

Nuclear structure not explored

New concepts introduced, investigation just started:
- parton amplitudes (GPD’s, proton hologram)
- diffractive partons
- unintegrated partons

Instantons not observed

Odderonas not found
...

Fermions still pointlike
Lepton-quark states (as in RPV SUSY) not observed

*) For an experimental review see:
M.Klein, R.Yoshida, "Collider Physics at HERA’’
arXiv 0805.3334, Prog.Part.Nucl.Phys.61,343(2008)
HERA II analysis still ongoing
LQ Quantum Numbers

Scalar LQ, $\lambda=0.1$, single production

Fermion number determination

In SM Higgs production is gluon dominated

LHeC: huge $x, Q^2$ range for $xg$ determination

WW to Higgs fusion has sizeable ep xsection

CTEQ, Belyaev et al. JHEP 0601:069, 2006

$H \rightarrow bb$

QCD3j
Electroweak Couplings

CDF: $q' \to e^+e^-$ (Drell-Yan), $A_{FB}$


LEP/SLC: $e^- \to q\gamma$, $a_q^2 + v_q^2$


For H1, CDF, LEP cf. Z. Zhang DIS10
Contact Interactions

\[ \mathcal{L} = \frac{4\pi}{2\Lambda^2} j^{(s)}_\mu j^{(s)}_{\mu} ; \]

\[ j^{(f=a,k)}_\mu = \eta_L \bar{f}_L \gamma_\mu f_L + \eta_R \bar{f}_R \gamma_\mu f_R + h.c. \]

⇒ all combinations of couplings \( \eta_{ij} = \eta_{ij}^{(s)}; q = u, d \)

CI study:
LHeC freezes the pdfs which allows new physics to be revealed.
HERA+BCDMS reshuffle the sea...
Dipole Magnets

<table>
<thead>
<tr>
<th>Feature</th>
<th>LEP</th>
<th>LHeC</th>
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</thead>
<tbody>
<tr>
<td>Cross Section/ cm²</td>
<td>50 x 50</td>
<td>20 x 10</td>
</tr>
<tr>
<td>Magnetic field/ T</td>
<td>0.02-0.11</td>
<td>0.01-0.10</td>
</tr>
<tr>
<td>Energy Range/GeV</td>
<td>20-100</td>
<td>10-80</td>
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<tr>
<td>Good Field Area/cm²</td>
<td>5.9 x 5.9</td>
<td>6 x 3.8</td>
</tr>
<tr>
<td>FODO length/m</td>
<td>76</td>
<td>107 [double]</td>
</tr>
<tr>
<td>Magnet length/m</td>
<td>11.5</td>
<td>5.5</td>
</tr>
<tr>
<td>segmentation</td>
<td>8x31x6</td>
<td>8x23x15</td>
</tr>
<tr>
<td>Number of magnets</td>
<td>1488+192 [DS]</td>
<td>3080+320</td>
</tr>
<tr>
<td>Weight / kg/m</td>
<td>800</td>
<td>200</td>
</tr>
</tbody>
</table>

Fe based magnet prototypes [BINP-CERN] → CDR challenges:
compact design for installation
good reproducibility at injection: 0.01T to $10^{-3}$ to $10^{-4}$
LHC proton interaction-region optics for $\beta_{x,y}^* = 0.1$ m, scaled from the nominal IR optics (left) [5], and a new IR optics with $\beta_{x,y}^* = 0.1$ m for protons [$l^* = 10$ m] (top right) and electrons [$l^* = 20$ m] (bottom right) [4].
The Detector - Low Q\(^2\) Setup

Fwd/Bwd asymmetry in energy deposited and thus in technology \([W/Si \text{ vs Pb/Sc..}]\)

Present dimensions: \(L \times D = 17 \times 10\text{m}^2\) [CMS 21 x 15\text{m}^2, ATLAS 25 x 45 \text{m}^2]
The Detector - High $Q^2$ Setup

Aim of current evaluations: avoid detector split in two phases: time and effort
motivation:
• rich physics program: eq physics at TeV energies
  □ precision QCD & electroweak physics
  □ complementing LHC physics results
  □ beyond the Standard Model
  □ high density matter: low x and eA

\[
\text{Tevatron/LEP/HERA (Fermiscale) } \rightarrow \text{ LHC/LC/LHeC (Terascale)}
\]

100 fold increase in luminosity, in $Q^2$ and $1/x$ w.r.t. HERA

status:
• Conceptual Design Report in print by spring 2011
e-Pb Collisions (RR)

- Assume present nominal Pb beam in LHC
  - Same beam size as protons, fewer bunches
    \[ k_b = 592 \text{ bunches of } N_b = 7 \times 10^7 \text{ } ^{208}\text{Pb}^{82+} \text{ nuclei} \]

- Assume lepton injectors can create matching train of \( e^- \)
  \[ k_b = 592 \text{ bunches of } N_b = 1.4 \times 10^{10} \text{ } e^- \]

- Lepton-nucleus or lepton-nucleon luminosity in ring-ring option at 70 GeV
  \[ L = 1.09 \times 10^{29} \text{ cm}^2\text{s}^{-1} \quad \Leftrightarrow \quad L_{ca} = 2.2 \times 10^{31} \text{ cm}^2\text{s}^{-1} \]
  gives 11 MW radiated power

- May be possible to exploit additional power by increasing electron single-bunch intensity by factor \( 592/2808 = 4.7. \)
title