The Large Hadron electron Collider (LHeC) at the LHC


S.Chattopadhyay, J. Dainton, Cockcroft Inst., Warrington; M. Klein, U.Liverpool, United Kingdom


T. Omori, J. Urakawa, KEK, Japan

F. Willeke, BNL, New York, U.S.A.
distance scales resolved in lepton-hadron scattering experiments since 1950s, and some of the new physics revealed

energies and luminosities of existing and proposed future lepton-proton scattering facilities

\( e^{-} \text{ energy } \sim 60-140 \text{ GeV} \)

\( \text{luminosity } \sim 10^{33} \text{ cm}^{-2}\text{s}^{-1} \)

>5x HERA c.m. energy

>>10x HERA luminosity
kinematic plane in Bjorken-x and resolving power $Q^2$, showing the coverage of fixed target experiments, **HERA** and **LHeC**

particle physicists request both $e^-p$ & $e^+p$ collisions; lepton polarization is also “very much desired”
option 1: “ring-ring” (RR) e-/e+ ring in LHC tunnel

SPL, operating with leptons, as injector for the ring, possibly with recirculation

option 2: “ring-linac” (RL)

up to 70 GeV: option for cw operation and recirculation with energy recovery; > 70 GeV: pulsed operation at higher gradient; $\gamma$-hadron option
**tentative SC linac parameters for RL**

<table>
<thead>
<tr>
<th>LHeC-RL scenario</th>
<th>lumi</th>
<th>baseline</th>
<th>energy</th>
</tr>
</thead>
<tbody>
<tr>
<td>final energy [GeV]</td>
<td>60</td>
<td>100</td>
<td>140</td>
</tr>
<tr>
<td>cell length [m]</td>
<td>24</td>
<td>24</td>
<td>24</td>
</tr>
<tr>
<td>cavity fill factor</td>
<td>0.7</td>
<td>0.7</td>
<td>0.7</td>
</tr>
<tr>
<td>tot. linac length [m]</td>
<td>3000</td>
<td>2712</td>
<td>3024</td>
</tr>
<tr>
<td>cav. gradient [MV/m]</td>
<td>13</td>
<td>25</td>
<td>32</td>
</tr>
<tr>
<td>operation mode</td>
<td>CW (ERL)</td>
<td>pulsed</td>
<td>pulsed</td>
</tr>
</tbody>
</table>

RF frequency: ~700 MHz

4 passes

2 passes

Anders Eide
example linac optics for 4-pass ERL option
**LHC 7-TeV p beam parameters**

<table>
<thead>
<tr>
<th></th>
<th>$N_{b,p}$</th>
<th>$T_{sep}$</th>
<th>$\varepsilon_p\gamma_p$</th>
<th>$\beta^*_{p,min}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>LHC phase-I upgrade</td>
<td>1.7x10^{11}</td>
<td>25 ns</td>
<td>3.75 $\mu$m</td>
<td>0.25 m</td>
</tr>
<tr>
<td>LHC phase-II upgrade (&quot;LPA&quot;)</td>
<td>5x10^{11}</td>
<td>50 ns</td>
<td>3.75 $\mu$m</td>
<td>0.10 m</td>
</tr>
</tbody>
</table>

$p$ and $e$ beams matched at collision point

- Ring emittance $>>$ Linac emittance
  - Ring has larger IP beam divergence
  - + Hourglass effect ($\rightarrow$ larger $\beta^*$ for ring)

Ring SR power = Linac beam power & cryo power
  = 100 MW
  Linac has much lower current
luminosity vs energy

luminosity $[10^{33} \text{ cm}^{-2} \text{ s}^{-1}]$

- lepton ring
- ERL (CW, $\eta=90\%$)
- pulsed linac

energy $[\text{GeV}]$
### Example Parameters

<table>
<thead>
<tr>
<th></th>
<th>LHeC-RR</th>
<th>LHeC-RL high lumi</th>
<th>LHeC-RL 100 GeV high energy</th>
<th>ILC</th>
<th>XFEL</th>
</tr>
</thead>
<tbody>
<tr>
<td>e⁻ energy at IP [GeV]</td>
<td>60</td>
<td>60</td>
<td>100</td>
<td>(2×)250</td>
<td>20</td>
</tr>
<tr>
<td>luminosity [10^{32} cm^{-2}s^{-1}]</td>
<td>29</td>
<td>29⁺ (2.9⁺)</td>
<td>2.2</td>
<td>200</td>
<td>N/A</td>
</tr>
<tr>
<td>bunch population [10^{10}]</td>
<td>5.6</td>
<td>0.19⁺ (0.02⁺)</td>
<td>0.3 (1.5)</td>
<td>300</td>
<td>24</td>
</tr>
<tr>
<td>e⁻ bunch length [μm]</td>
<td>~10,000</td>
<td>300</td>
<td>100</td>
<td>300</td>
<td>24</td>
</tr>
<tr>
<td>bunch interval [ns]</td>
<td>50</td>
<td>50 (250)</td>
<td>50 (250)</td>
<td>369</td>
<td>200</td>
</tr>
<tr>
<td>norm. hor.&amp; vert. emittance [μm]</td>
<td>4000, 2500</td>
<td>50</td>
<td>50</td>
<td>10, 0.04</td>
<td>1.4</td>
</tr>
<tr>
<td>average current [mA]</td>
<td>135</td>
<td>7⁺ (0.7⁺)</td>
<td>0.5</td>
<td>0.04</td>
<td>0.03</td>
</tr>
<tr>
<td>rms IP beam size [μm]</td>
<td>44, 27</td>
<td>7</td>
<td>7</td>
<td>0.64, 0.006</td>
<td>N/A</td>
</tr>
<tr>
<td>repetition rate [Hz]</td>
<td>CW</td>
<td>CW</td>
<td>10 [5% d.f.]</td>
<td>5</td>
<td>10</td>
</tr>
<tr>
<td>bunches/pulse</td>
<td>N/A</td>
<td>N/A</td>
<td>71430</td>
<td>2625</td>
<td>3250</td>
</tr>
<tr>
<td>pulse current [mA]</td>
<td>N/A</td>
<td>N/A</td>
<td>14286</td>
<td>2625</td>
<td>3250</td>
</tr>
<tr>
<td>beam pulse length [ms]</td>
<td>N/A</td>
<td>N/A</td>
<td>7</td>
<td>5</td>
<td>25</td>
</tr>
<tr>
<td>cryo power [MW]</td>
<td>0.5</td>
<td>20</td>
<td>4</td>
<td>34</td>
<td>3.6</td>
</tr>
<tr>
<td>total wall plug power [MW]</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>230</td>
<td>19</td>
</tr>
</tbody>
</table>

Example LHeC-RR and RL parameters. Numbers for LHeC-RL high-luminosity option marked by `⁺' assume energy recovery with $\eta_{ER}=90\%$; those with `‡' refer to $\eta_{ER}=0\%$. ILC and XFEL numbers are included for comparison. Note that optimization of the RR luminosity for different LHC beam assumptions leads to similar luminosity values of about $10^{33}$ cm\(^{-2}\) s\(^{-1}\).
IR layout & crab crossing (for RR)

crossing angle to support early separation: 1-2 mrad

proton crab cavities:
15-30 MV at 800 MHz)
positrons

ring

a rebuilt conventional e\(^+\) source would suffice

linac

true challenge: 10x more e\(^+\) than ILC!
large # bunches → damping ring difficult
candidate e\(^+\) sources under study (POSIPOL coll.):
  - ERL Compton source for CW operation
e.g. 100 mA ERL w. 10 optical cavities
  - undulator source using spent e- beam
  - linac-Compton source for pulsed operation
complementary options: collimate to shrink emittance,
extremely fast damping in laser cooling ring?,
recycle e+ together with recovering their energy?

T. Omori, J. Urakawa et al
**polarization**

**ring**

**LEP polarization vs. energy**

Sokolov-Ternov polarization time decreases from 5 hr at 46 GeV to ½ hr at 70 GeV but depolarizing rate increases even faster

“very very difficult, but polarization cannot be fully excluded w/o study”

R. Assmann, D. Barber

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**linac**

e- : from polarized dc gun with ~90% polarization, 10-100 µm normalized emittance
e+: up to ~60% from undulator or Compton-based source

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R. Assmann, Chamonix 1999, & Spin2000
conclusions

LHeC could provide high-energy high-luminosity $e^\pm p$ & $e^\pm A$ collisions

two major designs under study:

✓ ring-ring option with $10^{33}\text{cm}^{-2}\text{s}^{-1}$ up to 80 GeV

✓ linac-ring option with similar luminosity using energy recovery, possible extension to 140 GeV

ring injection may be provided by operating the SPL as an $e^-/e^+$ accelerator, possibly w. recirculation

some intriguing accelerator-physics issues:

$e^+$ production (L), energy recovery (L), crab cavities (R), polarization (R),...
more information

LHeC web site

www.lhec.org.uk

second ECFA-CERN workshop on the LHeC in September 2009