The Large Hadron electron Collider (LHeC) at the LHC


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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-* energy $\sim 60-140$ GeV

*luminosity* $\sim 10^{33}$ cm$^{-2}$s$^{-1}$
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

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; γ-hadron option

SPL, operating with leptons, as injector for the ring, possibly with recirculation
# 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: $\sim$700 MHz

4 passes

2 passes

Anders Eide
example linac optics for 4-pass ERL option

Anders Eide
# Luminosity constraints

## LHC 7-TeV $p$ beam parameters

<table>
<thead>
<tr>
<th></th>
<th>$N_{b,p}$</th>
<th>$T_{\text{sep}}$</th>
<th>$\epsilon_p \gamma_p$</th>
<th>$\beta^*_{p,\text{min}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>LHC phase-I upgrade</td>
<td>$1.7 \times 10^{11}$</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>$5 \times 10^{11}$</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 $\gg$ linac emittance
- ring has larger IP beam divergence
- + hourglass effect ($\rightarrow$ larger $\beta^*$ for ring)

ring SR power = linac beam power & cryo power

= electrical power set to 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>Parameter</th>
<th>LHeC-RR</th>
<th>LHeC-RL high lumi</th>
<th>LHeC-RL 100 GeV</th>
<th>LHeC-RL 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>140</td>
<td>(2×)250</td>
<td>20</td>
</tr>
<tr>
<td>luminosity ([10^{32} \text{ cm}^{-2} \text{s}^{-1}])</td>
<td>29</td>
<td>29† (2.9‡)</td>
<td>2.2</td>
<td>1.5</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>0.2 (1.0)</td>
<td>2</td>
<td>0.6</td>
</tr>
<tr>
<td>e⁻ bunch length [(\mu\text{m})]</td>
<td>~10,000</td>
<td>300</td>
<td>300</td>
<td>300</td>
<td>300</td>
<td>24</td>
</tr>
<tr>
<td>bunch interval [ns]</td>
<td>50</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 [(\mu\text{m})]</td>
<td><strong>4000, 2500</strong></td>
<td>50</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>0.5</td>
<td>0.04</td>
<td>0.03</td>
</tr>
<tr>
<td>rms IP beam size [(\mu\text{m})]</td>
<td>44, 27</td>
<td>7</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>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>14286</td>
<td>2625</td>
<td>3250</td>
</tr>
<tr>
<td>pulse current [mA]</td>
<td>N/A</td>
<td>N/A</td>
<td>10</td>
<td>10</td>
<td>9</td>
<td>25</td>
</tr>
<tr>
<td>beam pulse length [ms]</td>
<td>N/A</td>
<td>N/A</td>
<td>5</td>
<td>5</td>
<td>1</td>
<td>0.65</td>
</tr>
<tr>
<td>cryo power [MW]</td>
<td>0.5</td>
<td>20</td>
<td>4</td>
<td>6</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>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 \(10^{33}\text{ cm}^{-2}\text{s}^{-1}\).
IR layout & crab crossing (for RR)

crossing angle to support early separation: 1-2 mrad

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

SC half quadrupoles synchrotron radiation
positrons

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

linac
true challenge: 10x more e\(^+\) than ILC!
large \# bunches \(\rightarrow\) 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
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

**linac**

e- : from polarized dc gun with ~90% polarization,

10-100 μm normalized emittance

e+: up to ~60% from undulator or Compton-based source
conclusions

LHeC could provide high-energy high-luminosity e±p & e±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

ing 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