LHeC
Considerations for a Lepton Hadron Collider Option for the LHC
F. Willeke, BNL
The 4th Electron Ion Collider Workshop
Hampton University, 19-23 May, 2008

Ring–Ring Option
Linac Ring Option
LHeC a physics opportunity with a Threefold physical goal:
New Physics - QCD and EW Physics – High Parton Density
Several Options under consideration:

- **p-Ring-e-Ring:**
  “conservative”, limited in c.m. energy, luminosity limited by RF power, beam-beam limited

- **p-Ring-e-Linac:**
  No energy limit (in principle), luminosity severely limited by RF power, beam-beam limit

- **ERL Option:**
  very exotic, energy limited, RF power limitation and beam-beam limit reduced
Luminosity: Ring-Ring

\[ L = \frac{N_p \gamma}{4\pi e \epsilon_{pn}} \cdot \frac{I_e}{\sqrt{\beta_{px} \beta_{py}}} = 8.310^{32} \cdot \frac{I_e}{50 mA} \cdot \frac{m}{\sqrt{\beta_{px} \beta_{pn}}} \text{ cm}^{-2} \text{s}^{-1} \]

\[ \epsilon_{pn} = 3.8 \mu m \]
\[ N_p = 1.7 \cdot 10^{11} \]
\[ \sigma_{p(x,y)} = \sigma_{e(x,y)} \]
\[ \beta_{px} = 1.8 m \]
\[ \beta_{py} = 0.5 m \]

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

$10^{33}$ can be reached in RR

\[ E_e = 40-80 \text{ GeV} \& P = 5-60 \text{ MW} \]

HERA was 1-4 $10^{31}$ cm$^{-2}$ s$^{-1}$

huge gain with SLHC p beam

F.Willeke in hep-ex/0603016:
Design of interaction region
for $10^{33}$ : 50 MW, 70 GeV

Factor of 5 possible to gain with
intensity and beam emittance
(cf H.Braun this workshop).
May relax power requirement.

cf also A.Verdier 1990, E.Keil 1986
Luminosity: Linac-Ring

\[ L = \frac{N_p \gamma}{4 \pi e \varepsilon_{pn} \beta^*} \cdot \frac{P}{E_e} = 1 \cdot 10^{32} \cdot \frac{P / MW}{E_e / GeV} \cdot cm^{-2} s^{-1} \]

\[ \varepsilon_{pn} = 1.9 \mu m \]
\[ N_p = 3.4 \cdot 10^{11} \]
\[ \beta^* = 0.10 m \]

**DIS08, H.Braun**

2 \(10^{32}\) may be reached with LR:

\(E_e = 40-140\) GeV & \(P=20-60\) MW

LR: average lumi close to peak!

-> 10 times HERA II luminosity.

LINAC is not physics limited in energy, but cost + power limited

140 GeV at 23 MV/m: 6 km + gaps

Note: positron source challenge:

SLC \(10^{15}\) /sec
ILC \(10^{14}\) /sec
LHeC at \(10^{32}\) needs \(10^{15}\) /sec
Recircularing Linac Scheme proposed by Hans Braun

**Recirculated superconducting c.w. Linac for LHeC**

**Tentative parameter set for $10^{33}\text{cm}^{-2}\text{s}^{-1}$**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$E$</td>
<td>70 GeV</td>
</tr>
<tr>
<td>$E_{\text{Injector}}$</td>
<td>1 GeV</td>
</tr>
<tr>
<td>$I_{\text{Beam}}$</td>
<td>1.2 mA</td>
</tr>
<tr>
<td>$N_B$</td>
<td>$1.87 \times 10^6$</td>
</tr>
<tr>
<td>Bunch spacing*</td>
<td>25 ns</td>
</tr>
<tr>
<td>$P_{\text{Beam}}$</td>
<td>84 MW</td>
</tr>
<tr>
<td>$P_{\text{SR}}$</td>
<td>5.6 MW</td>
</tr>
<tr>
<td>$N_{\text{Recirculation}}$</td>
<td>6</td>
</tr>
<tr>
<td>$V_{\text{Linac}}$</td>
<td>2 x 6.14 GeV</td>
</tr>
<tr>
<td>$L_{\text{Linac}}$</td>
<td>2 x 750 m</td>
</tr>
<tr>
<td>$L_{\text{ARC}}$</td>
<td>500 m</td>
</tr>
<tr>
<td>$L_{\text{Tunnel}}$</td>
<td>$\approx$ 5 km</td>
</tr>
<tr>
<td>$G$</td>
<td>12 MV/m</td>
</tr>
<tr>
<td>$P_{\text{AC RF plant}}$</td>
<td>236 MW</td>
</tr>
<tr>
<td>$P_{\text{AC cryogenic plant}}$</td>
<td>29 MW</td>
</tr>
<tr>
<td>$P_{\text{Beam}}/P_{\text{AC}}$</td>
<td>32%</td>
</tr>
</tbody>
</table>

*Here an uniform filling of LHC with proton bunches is assumed. Still needs to be adapted to real filling pattern.*

Max Klein LHeC DIS08 London 11.4.08
Ring – Ring Option

Design Study J.Dainton, M.Klein, P.Newman, E.Perez, F.Willeke

A high luminosity approach based on matured accelerator technology and on experience in operating HERA.

Design Goal: \( L = 10^{33}\text{cm}^{-2}\text{sec}^{-1} \) with 1.4 GeV centre of mass energy
Design Assumptions *)

based on LHC Proton beam parameters

Energy
Particles per Bunch
Emittance
Bunch spacing
Bunch Length

\( E_p = 7 \text{ TeV} \)
\( N_p = 1.68 \times 10^{11} \)
\( \varepsilon_{Np} = 3.75 \text{ rad} \mu \text{m} \)
\( \tau_b = 25 \text{ ns} \)
\( \sigma_p = 7.55 \text{ cm} \)

\( E_e = 70 \text{ GeV} \)

Circumference = 26658.883 m

*) There are more optimistic parameters under discussion for the LHC Upgrade
Luminosity

\[ L = \frac{N_p \cdot N_e \cdot f_{rev} \cdot n_b}{2 \cdot \pi \cdot \sqrt{\varepsilon_{xp} \beta_{xp} + \varepsilon_{xe} \beta_{xe}} \cdot \sqrt{\varepsilon_{yp} \beta_{yp} + \varepsilon_{ye} \beta_{ye}}} \]

Matched beam cross sections at IP \( \sigma_{xp} = \sigma_{xe}, \sigma_{yp} = \sigma_{ye} \)

Lepton Beam-beam tune shift limit to be avoided

\[ L = \frac{I_e \cdot N_p \cdot \gamma_p}{2\pi \cdot e \cdot \varepsilon_{Np} \cdot \sqrt{\beta_{xp} \cdot \beta_{yp}}} \]

With the proton beam brightness given by LHC, \( N_p \gamma_p / \varepsilon_{Np} = 3.2 \cdot 10^{20} \text{m}^{-1} \)

\[ \frac{I_e}{\sqrt{\beta_{xp} \beta_{yp}}} = 0.063 \frac{A}{m} \]
Lepton Beam Current

Assumptions: Limited by RF Power only depends on Bending radius
\[ \rho = 0.8 \cdot (C_{LHC} - 8 \cdot L_{straight}) / 2\pi = 2886 \text{ m} \]
\[ eU_{loss} = C_g E_e^4 / (e \rho) = 734 \text{ MeV} \]

If 50 MW beam power considered as a limit  \( 5000 \text{ h/y} \times 50\text{MW} \times 5 = 1250 \text{ GWh/y} \)

\[ I_e = 68 \text{ mA} \quad (\text{with } \Delta t=25\text{ns} \Rightarrow N_e = 1.3 \times 10^{10}) \]
e-Ring Lattice Parameters

bend radius & circumference fixed by LHC effective FODO structure chosen (no alternative) the only choice to be made id the FODO cell length or the number of cell length of the arc

- This determines the lepton beam emittance and the dynamic aperture

Constraints under the assumption of matched beam sizes at the IP:

Small emittance $\Rightarrow$ large $\beta*$ $\Rightarrow$ strong beam-beam effect $\Rightarrow$ no stability

large emittance $\Rightarrow$ small $\beta*$ $\Rightarrow$ strong hourglass effect $\Rightarrow$ less lumi

Long cells $\Rightarrow$ large emittance $\Rightarrow$ reduced dynamic aperture $\Rightarrow$ no stability

Short cell $\Rightarrow$ small emittance, high cost
Choosing Lepton Ring Lattice Parameters

- 22km arc
- D.A. limit
- Dynamic Aperture (rms beam size)
- 72 degrees per FODO cell
- Emittance
  - $\Delta f/f = 3 \times 10^{-7}$
  - $\Delta f/f = 0$
- Hourglass limit
- Beam-beam limit

Number of FODO cells
# Main Parameters of LeHC

<table>
<thead>
<tr>
<th>Property</th>
<th>Unit</th>
<th>Leptons</th>
<th>Protons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beam Energies</td>
<td>GeV</td>
<td>70</td>
<td>7000</td>
</tr>
<tr>
<td>Total Beam Current</td>
<td>mA</td>
<td>74</td>
<td>544</td>
</tr>
<tr>
<td>Number of Particles / bunch</td>
<td>$10^{10}$</td>
<td>1.04</td>
<td>17.0</td>
</tr>
<tr>
<td>Horizontal Beam Emittance</td>
<td>nm</td>
<td>7.6</td>
<td>0.501</td>
</tr>
<tr>
<td>Vertical Beam Emittance</td>
<td>nm</td>
<td>3.8</td>
<td>0.501</td>
</tr>
<tr>
<td>Horizontal $\beta$-functions at IP</td>
<td>cm</td>
<td>12.7</td>
<td>180</td>
</tr>
<tr>
<td>Vertical $\beta$-function at the IP</td>
<td>cm</td>
<td>7.1</td>
<td>50</td>
</tr>
<tr>
<td>Energy loss per turn</td>
<td>GeV</td>
<td>0.707</td>
<td>$6 \times 10^{-6}$</td>
</tr>
<tr>
<td>Radiated Energy</td>
<td>MW</td>
<td>50</td>
<td>0.003</td>
</tr>
<tr>
<td>Bunch frequency / bunch spacing</td>
<td>MHz / ns</td>
<td>40 / 25</td>
<td></td>
</tr>
<tr>
<td>Center of Mass Energy</td>
<td>GeV</td>
<td>1400</td>
<td></td>
</tr>
<tr>
<td>Luminosity</td>
<td>$10^{33}$ cm$^{-2}$ s$^{-1}$</td>
<td>1.1</td>
<td></td>
</tr>
</tbody>
</table>
e Lattice

8 Octants with 500m Straight section each
376 FODO cells, Cell length 60.3 m
Dipole length 2 x 12.52 m  B= 810 Gauss
Quadrupole length 1.5 m (G = 8 T/m)

$\Delta \phi_{\text{fodo}} = 72$ degree
$\varepsilon_{xe} = 8 \text{ nm}$
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Circumference C</td>
<td>m</td>
<td>26658.86</td>
</tr>
<tr>
<td>Beam Energy $E_\text{b}$</td>
<td>GeV</td>
<td>70</td>
</tr>
<tr>
<td>Arc Focusing</td>
<td></td>
<td>FODO</td>
</tr>
<tr>
<td>Cell length $L_c$</td>
<td>m</td>
<td>60.3</td>
</tr>
<tr>
<td>Bending radius $\rho$</td>
<td>m</td>
<td>2997</td>
</tr>
<tr>
<td>Horizontal betatron Phase Adv./cell $\Delta \phi_x$</td>
<td>degree</td>
<td>72</td>
</tr>
<tr>
<td>Vertical betatron Phase Adv./cell $\Delta \phi_y$</td>
<td>degree</td>
<td>72</td>
</tr>
<tr>
<td>Number of FODO cells in the Arcs $N_{\text{cell}}$</td>
<td></td>
<td>376</td>
</tr>
<tr>
<td>Arc Chromaticity (hor/vert.) $\xi_{x,y}$</td>
<td></td>
<td>94/120</td>
</tr>
<tr>
<td>Beam Current $I_\text{b}$</td>
<td>mA</td>
<td>70.7</td>
</tr>
<tr>
<td>Bunch spacing $t_b$</td>
<td>ns</td>
<td>25</td>
</tr>
<tr>
<td>Number of bunches $n_b$</td>
<td></td>
<td>2800</td>
</tr>
<tr>
<td>Number of particles per bunch $N_\text{u}$</td>
<td>$10^{10}$</td>
<td>1.4</td>
</tr>
<tr>
<td>Momentum compaction factor $\alpha$</td>
<td></td>
<td>1.34</td>
</tr>
<tr>
<td>Horizontal beam emittance $\varepsilon_{x}$</td>
<td>mm</td>
<td>7.6</td>
</tr>
<tr>
<td>Vertical beam emittance $\varepsilon_{y}$</td>
<td>mm</td>
<td>3.8</td>
</tr>
<tr>
<td>RMS energy spread $\sigma_e$</td>
<td></td>
<td>2.4</td>
</tr>
<tr>
<td>RMS bunch length</td>
<td>mm</td>
<td>7.1</td>
</tr>
<tr>
<td>Particle Radiation energy loss per turn $eU_{\text{loss}}$</td>
<td>MeV/turn</td>
<td>706.8</td>
</tr>
<tr>
<td>Beam Power loss $P_{\text{loss}}$</td>
<td>MW</td>
<td>50</td>
</tr>
<tr>
<td>Circumferential Voltage $U$</td>
<td>MV</td>
<td>1521</td>
</tr>
<tr>
<td>Synchronous Phase $\phi_{\text{sync}}$</td>
<td>degree</td>
<td>27</td>
</tr>
<tr>
<td>RF frequency $f_{r/f}$</td>
<td>MHz</td>
<td>1000</td>
</tr>
<tr>
<td>Bucket height $h_b$</td>
<td>$\sigma_e$</td>
<td>8.4</td>
</tr>
<tr>
<td>RF frequency shift</td>
<td>Hz</td>
<td>250</td>
</tr>
<tr>
<td>Synchrotron frequency $f_s$</td>
<td>$f_{\text{rev}}$</td>
<td>0.191</td>
</tr>
</tbody>
</table>
Tunnel Cross Section
Which IR?

LHC Ring

IP1 ATLAS
IP2 ALICE
IP3 Momentum Cleaning
IP4 RF
IP5 CMS
IP6 Abort
IP7 Betatron Cleaning
IP8 LHCb

possible ep Interaction Region
Bypass around Atlas and CMS

No additional radiation
Little, easy to correct influence on Circ.
But
Existing Bypass Tunnels probably not available
## Additional Tunnels needed

<table>
<thead>
<tr>
<th>Type</th>
<th>Point 1 ATLAS</th>
<th>Point 5 CMS</th>
<th>Point 2 and/or 8 RF</th>
<th>Point 3 Collimators</th>
<th>Point 7 Collimators</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bypass Experiment</td>
<td>Bypass Experiment</td>
<td>Bypass ; allow for space for e - ring RF</td>
<td>Bypass Collimation</td>
<td>Bypass Collimation</td>
<td></td>
</tr>
<tr>
<td>Approximate Tunnel length</td>
<td>500 m</td>
<td>500 m</td>
<td>500 m</td>
<td>500 m</td>
<td>500 m</td>
</tr>
<tr>
<td>Diameter</td>
<td>4.40 m</td>
<td>3.80 m</td>
<td>5.50 m</td>
<td>4.20 m</td>
<td>3.80 m</td>
</tr>
<tr>
<td>Distance to p- Ring axis</td>
<td>10 - 13 m</td>
<td>10 - 13 m</td>
<td>500 m</td>
<td>500 m</td>
<td>500 m</td>
</tr>
</tbody>
</table>

From H. Burckhard, DIS 08
IR Layout
<table>
<thead>
<tr>
<th>Property</th>
<th>Unit</th>
<th>Leptons</th>
<th>Protons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horizontal Beta function at IP</td>
<td>cm</td>
<td>12.7</td>
<td>180</td>
</tr>
<tr>
<td>Vertical beta function at IP</td>
<td>cm</td>
<td>7.07</td>
<td>50</td>
</tr>
<tr>
<td>Horizontal IR Chromaticity</td>
<td></td>
<td>-7.5</td>
<td>-7.9</td>
</tr>
<tr>
<td>Vertical IR chromaticity</td>
<td></td>
<td>-29.7</td>
<td>-7.7</td>
</tr>
<tr>
<td>Maximum horizontal Beta</td>
<td>m</td>
<td>131.7</td>
<td>2279</td>
</tr>
<tr>
<td>Maximum vertical Beta</td>
<td>m</td>
<td>704.4</td>
<td>2161</td>
</tr>
<tr>
<td>Minimum of available Aperture</td>
<td>$\sigma_x$</td>
<td>16</td>
<td>13.5</td>
</tr>
<tr>
<td>Low beta quadrupole gradient</td>
<td>T/m</td>
<td>93.3</td>
<td>115</td>
</tr>
<tr>
<td>Separation dipole field</td>
<td>T</td>
<td>0.033</td>
<td>-</td>
</tr>
<tr>
<td>Synchrotron Radiation Power</td>
<td>kW</td>
<td>9.1</td>
<td>-</td>
</tr>
<tr>
<td>Low beta quadrupole length</td>
<td>m</td>
<td>0.96/2.43/1.14</td>
<td>16.5/18.6/11</td>
</tr>
<tr>
<td>Low beta quadrupole apertures</td>
<td>mm</td>
<td>30/40/50</td>
<td>12/15/15</td>
</tr>
<tr>
<td>Distance of first quadrupole from IP</td>
<td>m</td>
<td>1.2</td>
<td>22</td>
</tr>
<tr>
<td>Detector Acceptance Polar Angle</td>
<td>degree</td>
<td>9.4</td>
<td></td>
</tr>
<tr>
<td>Crossing Angle</td>
<td>mrad</td>
<td>2</td>
<td></td>
</tr>
</tbody>
</table>
IR Parameters

\[ \sigma_{xp} = \sigma_{xe}, \quad \sigma_{yp} = \sigma_{ye} \]
\[ \varepsilon_{xp} = 0.5 \text{ nm} \quad \varepsilon_{xe} = 7.6 \text{ nm} \]

Need to match “flat” e beam with “round” p beam

\[ \beta_{xp}/\beta_{yp} \approx 4 \]

IR optics with low-beta tripletts for both e and p beams

\[ \beta_{xp} = 1.8 \text{ m} \]
\[ \beta_{yp} = 0.5 \text{ m} \]
\[ \beta_{xe} = 12.7 \text{ cm} \]
\[ \beta_{ye} = 7.1 \text{ cm} \]
IR Layout

IR free space: 1.25m x 2
Acceptance angle 10 degree
Crossing angle 2mr
Beam Separation

Crossing angle 2mr

Magnetic separation 2mr

⇒ 60 mm separation @20m
Crab Crossing

Crab Crossing

Crossing angle will enhance effective beam size $\sigma^2 = \varepsilon \beta + \theta^2 \sigma_s^2$

$\theta_c / 2$

IP

$\Delta \phi_\beta = 90$ degree

Transverse RF resonators

Crab Cavities

"Crabbed Trajectories"

$\theta_c = (0.5-3) \text{mr}$
Crab Cavity Calculations

Required Crossing Angle \( k_s := 42 \)

ep Separation \( x_{p_k_s} - x_{e_k_s} = 65.571 \text{ mm} \quad s_{k_s} = 22.232 \text{ m} \)

\( \Delta x_{\text{sep}} := x_{p_k_s} - x_{e_k_s} \quad \theta_r := \theta_c \quad \theta_r = -2 \text{ mrad} \)

required crab cavity orbit kick for \( 1 \sigma \Delta \sigma/\sigma \) particles

\( x_r := \frac{\theta_r}{2} \cdot \sigma_s \quad \beta_{p_{x_0}} = 1.8 \text{ m} \quad \beta_{p_{x_{82}}} = 708.766 \text{ m} \)

\( \theta_{cc} := \frac{-x_r}{\sqrt{\beta_{p_{x_0}} \cdot \beta_{p_{x_{82}}}}} \quad \theta_{cc} = 2.1 \mu \text{rad} \)

crac cavity frequency \( f_{cc} := 0.5 \text{ GHz} \)

\( \lambda_{cc} := \frac{c}{f_{cc}} \quad \lambda_{cc} = 599.585 \text{ mm} \quad \sigma_s = 75 \text{ mm} \)

crabcavity phase of one sigma particle \( \phi_{cc\,1s} := \frac{2 \cdot \pi \cdot \sigma_s}{\lambda_{cc}} \quad \phi_{cc\,1s} \cdot \frac{180}{\pi} = 45.031 \)

Required cavity voltage: \( U_{cc} := \frac{\theta_{cc} \cdot E_p}{e \cdot \sin(\phi_{cc\,1s})} \quad U_{cc} = 20.775 \text{ MV} \)

achievable gradient: \( G_{cc} := 3.4 \text{ MV} \cdot \text{m}^{-1} \)

Length of the cc structure: \( L_{cc} := \frac{U_{cc}}{G_{cc}} \quad L_{cc} = 6.11 \text{ m} \)
Synchrotron Radiation

\( \rho_{ir} = 10000 \text{ m} \)

Instantaneous Power for one electron

\( P_g(E_e, \rho_{ir}) = 1.615 \times 10^{-7} \text{ watt} \)

Total Power

\( 2P_{syn}(E_e, \rho_{ir}, \Theta_{ir}, I_e) = -9.111 \text{ kW} \)

Power per unit Length

\( P_s(E_e, \rho_{ir}, I_e) = 0.238 \text{ kW.m}^{-1} \)

Critical Energy

\( \mu_c(E_e, \rho_{ir}) = 76.137 \text{ keV} \)

Photonflux

\( \Phi_{ph}(E_e, \rho_{ir}, I) = 2.957 \times 10^{19} \frac{1}{\text{m.s.A}} \)

\( \rho_{ir} = -1.001 \times 10^4 \text{ m} \quad L_{ir} = 19.132 \text{ m} \)
SR Power Density on Absorber
**ep Collision Parameters and Luminosity**

\[ E_p = 7 \times 10^3 \text{ GeV} \quad E_e = 70 \text{ GeV} \]

\[ I_p = 0.856 \text{ A} \quad I_e = 0.071 \text{ A} \]

\[ N_p = 1.7 \times 10^{11} \quad N_e = 1.404 \times 10^{10} \]

\[ \beta^* \]

\[ \beta_{xp} = 180 \text{ cm} \quad \beta_{xe} = 12.73 \text{ cm} \quad \max(\beta_{py}) = 2.637 \times 10^3 \text{ m} \quad \max(\beta_{ey}) = 704.454 \text{ m} \]

\[ \beta_{yp} = 50 \text{ cm} \quad \beta_{ye} = 7.072 \text{ cm} \quad \max(\beta_{px}) = 2.668 \times 10^3 \text{ m} \quad \max(\beta_{ex}) = 131.728 \text{ m} \]

**Beam size**

\[ \sigma_{xp} = 31.066 \mu\text{m} \quad \sigma_{xe} = 31.066 \mu\text{m} \]

\[ \sigma_{yp} = 16.373 \mu\text{m} \quad \sigma_{ye} = 16.373 \mu\text{m} \]

\[ \sigma_s = 75 \text{ mm} \quad \sigma_{be} = 7.085 \text{ mm} \]

**IR Chromaticity**

\[ \xi_{pxIR} = -7.969 \quad \xi_{exIR} = -7.517 \]

\[ \xi_{pyIR} = -7.74 \quad \xi_{eyIR} = -29.757 \]

**Beam-Beam Tuneshift**

\[ \Delta \nu_{xp} = 8.318 \times 10^{-4} \quad \Delta \nu_{xe} = 0.043 \quad \Delta \nu_{xpar} = 0.029 \times 10^{-3} \]

\[ \Delta \nu_{yp} = 3.177 \times 10^{-4} \quad \Delta \nu_{ye} = 0.051 \quad \Delta \nu_{ypar} = -0.444 \times 10^{-3} \]

**Crossing Angle**

\[ \theta_c = -2 \text{ mrad} \]

**Hourglass factor**

\[ R(\sigma_s) = 0.947 \]

**Peak Luminosity**

\[ L_{\text{peak}} = 1.103 \times 10^{33} \text{ sec}^{-1} \cdot \text{cm}^{-2} \]
Beam-Beam Effect

Central crossing beam-beam parameters well within the HERA range

\[
\Delta \nu_{xe} := \frac{r_e \cdot N_p \cdot \beta_{xe}}{2 \cdot \pi \cdot \gamma_e \cdot \sigma_{xp} \cdot (\sigma_{xp} + \sigma_{yp})} \quad \Delta \nu_{xe} = 0.048
\]

\[
\Delta \nu_{ye} := \frac{r_e \cdot N_p \cdot \beta_{ye}}{2 \cdot \pi \cdot \gamma_e \cdot \sigma_{yp} \cdot (\sigma_{xp} + \sigma_{yp})} \quad \Delta \nu_{ye} = 0.051
\]

\[
\Delta \nu_{xp} := \frac{r_p \cdot N_e \cdot \beta_{xp}}{2 \cdot \pi \cdot \gamma_p \cdot \sigma_{xe} \cdot (\sigma_{xe} + \sigma_{ye})} \quad \Delta \nu_{xp} = 5.122 \times 10^{-4}
\]

\[
\Delta \nu_{yp} := \frac{r_p \cdot N_e \cdot \beta_{yp}}{2 \cdot \pi \cdot \gamma_p \cdot \sigma_{ye} \cdot (\sigma_{xe} + \sigma_{ye})} \quad \Delta \nu_{yp} = 2.7 \times 10^{-4}
\]
Parasitic Crossings

\[ \Delta v_x^{\text{par}} = \frac{N_p r_0 \beta_x^{\text{par}}}{2 \pi \gamma_0 \Delta x^2} \]
\[ \Delta v_y^{\text{par}} = \frac{-N_p r_0 \beta_y^{\text{par}}}{2 \pi \gamma_0 \Delta x^2} \]

<table>
<thead>
<tr>
<th>Bunch spacing</th>
<th>Crossing angle</th>
<th>Separation</th>
<th>Separation</th>
<th>Horiz. parasitic beam-beam tune shift</th>
<th>Vertical parasitic beam-beam tune shift</th>
</tr>
</thead>
<tbody>
<tr>
<td>[ns]</td>
<td>[mrad]</td>
<td>[mm]</td>
<td>[mrad]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>25</td>
<td>2.0</td>
<td>7.7</td>
<td>8.3</td>
<td>0.0011</td>
<td>-0.0015</td>
</tr>
<tr>
<td>50</td>
<td>2.0</td>
<td>15</td>
<td>23</td>
<td>0.0001</td>
<td>-0.0002</td>
</tr>
<tr>
<td>75</td>
<td>2.0</td>
<td>27</td>
<td>50</td>
<td>0.00003</td>
<td>-0.0004</td>
</tr>
</tbody>
</table>
Luminosity vs Bunch Spacing

$L$ independent of bunch spacing as long as $I_e$ total can be maintained

At very large bunch spacings limitations by
- Proton beam-beam effect
- Single bunch instabilities of e-beam
  (up to 75ns bunch spacing far from becoming a problem)
Quadrupole Magnets
Modified ELFE as LHeC injector

ELFE@CERN

\[ f_{\text{rf}} = 352 \, \text{MHz, gradient 8 MV/m} \]
\[ V_{\text{rf}} = 3.5 \, \text{GV}, \ 72 \, \text{rf-modules} \]
7 passes (last at 21.5 GeV)
\[ L = 3924 \, \text{m of which Linac 1081 m} \]
\[ q = 56.9 \, \text{m} \]

LHeC injector

\[ f_{\text{rf}} \sim 1 \, \text{GHz, gradient 31.5 MV/m} \]
Linac \( L = 150 \, \text{m} \) \( 7 \times \) shorter
\[ V_{\text{rf}} = 4 \, \text{GV}, \ 5 \, \text{passes} ; \text{last 16 GeV} \]
\[ q = (16/21.5)^4 \times 56.9 \, \text{m} = 17.5 \, \text{m} \]
or \( 3.3 \times \) shorter
significantly downscaled \( L \approx 600 \, \text{m} \)
and simplified (5 passes) version of ELFE@CERN

more cost effective (?) than single LINAC
+ extra phys. potential

From H. Burckhard, DIS08
LHeC Activities

The first ECFA-CERN workshop on the LHeC is announced:  http://www.lhec.org.uk

The workshop takes place at Divonne, not far from CERN, Monday-Wednesday 1.-3.9.2008.

The working group convenors are nominated and can be found on the web page.

The LHeC work will focus on the work of these groups in the preparation for the workshop and beyond.

Meeting on exchange of information on the LHeC project status and on the NuPECC long range planning. NuPECC expressed an interest in the LHeC. NuPECC has formed a study group on the future of lepton-hadron colliders, which will investigate the potential of the EIC (eRHIC/ELIC) and the LHeC as part of NuPECC's long range planning.

At the DIS08 meeting new physics studies and updates on the two machine options were presented by Helmut Burkardt (Ring-Ring) and by Hans Braun(Linac-Ring).
Conclusions

• Comparison of different options ring-ring, ring linac and ERL show specific advantages of each of the options. The final physics case, and the cost/luminosity and energy trade off will decide which option is the most favorable one.

• A first look at a ring-ring based lepton proton collider in the LHC tunnel with a luminosity of $10^{33} \text{cm}^{-2}\text{s}^{-1}$ appears to be technical possible.

• Simultaneous operation of pp and ep should be possible (however with reduced pp luminosity).

• More work is needed to determine the most optimum parameters, the optimum technical choices and the cost of such a facility, a workshop had been held, several working groups (CERN, CI, DESY) have started to work out scenarios in more detail.

• Further activities on the layout of the accelerator should be coordinated with and integrated into the discussions on LHC upgrades.