Electron-ion collisions and other options for HERA

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Development of the Luminosity for HERA-I

In 2000, design values have been surpassed for:

• specific luminosity
• peak luminosity
• integrated luminosity per year
The HERA Luminosity Upgrade

- Increase of luminosity from $1.5 \times 10^{31}$ to $7 \times 10^{31}$
- Beam separation by super-conducting magnets in the detectors
- Focusing to $\frac{1}{4}$ of the old beam cross-section

New limitations:
- beam-beam tune shift
- hourglass effect for protons
- dynamic aperture of e-beam
- background due to radiation
Lumi scan Nov. 2, 2001

- Data
- Gauss fit
- Gauss for proton emittances 16mm, electron emittances 21nm and 35% coupling
- Gauss for proton emittances 16mm, electron emittances 21nm and 17% coupling
HERA and its Pre-Accelerator Chain

<table>
<thead>
<tr>
<th>Energy (GeV)</th>
<th>Protons</th>
<th>Electrons</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>Source</td>
<td>Source</td>
</tr>
<tr>
<td>750</td>
<td>RFQ</td>
<td>Linac II</td>
</tr>
<tr>
<td>50</td>
<td>Linac III</td>
<td>Pia</td>
</tr>
<tr>
<td>8</td>
<td>DESY III</td>
<td>DESY II</td>
</tr>
<tr>
<td>40</td>
<td>PETRA</td>
<td>PETRA</td>
</tr>
<tr>
<td>920</td>
<td>HERA-p</td>
<td>HERA-e</td>
</tr>
</tbody>
</table>

DESY
PETRA
HERA
H1
778 m
HERMES
6336 m long

Polarized Electrons
Protons

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### Nominal and Ultimate Parameters

<table>
<thead>
<tr>
<th>Energy–p/e</th>
<th>p</th>
<th>e</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emit. hor/vert</td>
<td>920 GeV</td>
<td>27.5 GeV</td>
</tr>
<tr>
<td>β* at IP hor/vert</td>
<td>5/5π mm mrad</td>
<td>20/3.4 nm</td>
</tr>
<tr>
<td>Aperture hor/vert</td>
<td>2.45/0.18 m</td>
<td>0.63/0.26 m</td>
</tr>
<tr>
<td>p per bunch and e-cur.</td>
<td>12/12 σ</td>
<td>20/20 σ</td>
</tr>
<tr>
<td>Tune shift hor/vert</td>
<td>1.03·10^{11}</td>
<td>58 mA</td>
</tr>
<tr>
<td>Bunch Length</td>
<td>191 mm</td>
<td>10.3 mm</td>
</tr>
<tr>
<td>Luminosity</td>
<td>0.74 · 10^{32} cm^{-2}s^{-1}</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>p</th>
<th>e</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.5/3.5π mm mrad</td>
<td>20/2.7 nm</td>
</tr>
<tr>
<td>1.7/0.125 m</td>
<td>0.42/0.17 m</td>
</tr>
<tr>
<td>10/10 σ</td>
<td>12/12 σ</td>
</tr>
<tr>
<td>0.0017/0.0005</td>
<td>0.047/0.069</td>
</tr>
<tr>
<td>1.3 · 10^{32} cm^{-2}s^{-1}</td>
<td></td>
</tr>
</tbody>
</table>

- The performance goal of HERA is not unrealistic and should not be too hard to achieve.
- A shortfall of beam intensity in the short term can be compensated.
Increasing the Proton Current

PETRA: N=60, 50 MHz

N=30, 50 MHz

10 MHz & 5 MHz

10 MHz & 5 MHz
HERA III

Polarized protons in HERA

- Polarized protons (30MEuro)
- Polarized deuterons
- Electron precooling and cooling
- Ion acceleration (53MEuro)

\[ L_A = L_p \cdot \frac{1}{A} = 7 \cdot 10^{31} \cdot \frac{1}{A} \]

- Pulse stretcher for TESLA
- Collisions with TESLA (120ME.)

\[ L_{ep} = 1.6 \cdot 10^{31} \]

• Polarimeters
• Flattening Snakes
• Spin rotators
• At least 4 Siberian Snakes
Ions in HERA

Challenges:

- Longer bunch trains needed
- Stronger space charge and IBS
- Strong frequency swing
- Crossing of transition energy needed
- Long ramp cycles

\[ \frac{\Delta f}{f} = 200\% \quad \gamma > \gamma_t = 6.5 \]

\[ T_{\text{ramp}} = 20 \text{ min} \]

\[ \gamma > \gamma_t = 28 \]

HERA

DESY III

Linac III

Ion Source

30 – 45\mu s

8 GeV

40 GeV

PETRA

920 GeV
Polarized Deuterons

- Resonances are 25 times weaker and 25 times rarer for D than for p
- Transverse polarization could be achieved without Siberian Snakes
- Transverse RF dipoles could be used to rotate and stabilize longitudinal polarization
Problem: IBS in HERA

\[
\frac{1}{\tau_{\text{IBS}}} \propto I_{\text{bunch}} \cdot \left( \frac{Z}{A} \right)^2 \cdot \frac{1}{\gamma^3} \cdot Z
\]

<table>
<thead>
<tr>
<th></th>
<th>Deuteron</th>
<th>$^{16}\text{O}^{8+}$</th>
<th>$^{208}\text{Pb}^{82+}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\epsilon_N$</td>
<td>2.5(\mu)m</td>
<td>2.5(\mu)m</td>
<td>2.0(\mu)m</td>
</tr>
<tr>
<td>$N_{ppb}$</td>
<td>5.0 \cdot 10^{10}</td>
<td>6.0 \cdot 10^{9}</td>
<td>4.8 \cdot 10^{8}</td>
</tr>
<tr>
<td>$L$</td>
<td>3.5 \cdot 10^{31}</td>
<td>4.4 \cdot 10^{30}</td>
<td>3.4 \cdot 10^{29}</td>
</tr>
<tr>
<td>$\sum_{xyz} \tau_{\text{IBS}}$</td>
<td>140min</td>
<td>20min</td>
<td>2.5min</td>
</tr>
</tbody>
</table>
Summary on e – Ion collisions

• Deuteron acceleration:
  Technical solutions seem possible

• Heavy ions: $L \approx \frac{L_p}{A}$ does not seem possible

• e – cooling counter balances IBS and leads to the required emittances and therefore
  $L \approx \frac{L_p}{A}$
e – cooling for HERA and PETRA

- e – ion: balances IBS
- e – protons: doubles luminosity
- e – polarized protons: reduces emittance to a polarizable size

Cooling in PETRA: \( (\gamma \approx 19) \)
- \( \varepsilon_{px} : 5 \rightarrow 3.3\mu m \)
- \( \varepsilon_{py} : 5 \rightarrow 0.8\mu m \)

Cooling in HERA:
- preserve against IBS
- \( \varepsilon_{px} : 3.8\mu m \)
- \( \varepsilon_{py} : 0.9\mu m \)
Cooling for e– ion collisions

$^{197}A^{79+} : E = 330 GeV / u, \varepsilon_x = 1 \mu m, \varepsilon_y = 0.25 \mu m$

**Graph:**
- **With cooling**
- **Without cooling**

**Equations:**
- $\tau_{IBS} = \tau_{cool} = 30 \text{ min}$
- $\tau_{IBS} = \tau_{cool} = 18 \text{ min}$
- $L_A = L_p \frac{1}{A}$
- $L_p = 0.76 \cdot 10^{32} \text{ cm}^{-2} \text{ s}^{-1}$
Electron Cooling in PETRA

\[
\begin{align*}
B_z & = 0.3 \, \text{T} \\
N_{ppb}^e & = 3 \times 10^{10} \\
E & = 9.8 \, \text{MeV} \\
\frac{\Delta p}{p} & = 30 \times 10^{-4} \\
\sigma_z & = 0.017 \\
B_z & = 0.06 \, \text{T} \\
\frac{\Delta p}{p} & = 3 \times 10^{-4} \\
\sigma_z & = 0.5
\end{align*}
\]
Electron Cooling in HERA

Cooling section

- Width limit: dynamic aperture from sextupoles required due to strong focusing (tunnel has 5.2m)

- 37 wigglers section: $D = 0, \ D' = 0, \ B = 1\text{T}$

- Tuning section: tune control, decoupling, RF cavities
THERA: The TESLA on HERA Collider

- Cooling: $\varepsilon_{x/y} = 1/\frac{1}{4} \cdot 10^{-6} \text{ m}$

- Traveling focus $\beta^*_{x/y} = 10/2.5 \cdot \text{ cm}$

- Variable $e$-energies 250-800 GeV

Luminosity: $L \approx 2 \cdot 10^{31} \text{ cm}^{-2} \text{ s}^{-1}$
TESLA with Röntgen FEL

- HERA
- Super-conducting Electron Linac
- Detector and Experimental Area
- Wiggler for the Positron Source
- Cryogenic Halls
- Super-conducting Positron Linac
- Tunnel
- Damping Ring
- Röntgen FEL