Beam-Beam Experience in HERA

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H1 (318 GeV)
HERMES (7 GeV)
HERA-B (42 GeV)
HERA
ZEUS
PETRA

Graph showing data points for different experiments:
- SLAC + HERMES
- SMC (CERN)
- ZEUS + H1

The graph plots $Q^2 / GeV^2$ against $x$.
Superconducting HERA-p + HERA-e
## Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>up to 2000</th>
<th>after the upgrade</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>HERA-e</td>
<td>HERA-p</td>
</tr>
<tr>
<td>$E$(GeV)</td>
<td>27.5</td>
<td>920</td>
</tr>
<tr>
<td>$I$(mA)</td>
<td>50</td>
<td>100</td>
</tr>
<tr>
<td>$N_{ppb}(10^{10})$</td>
<td>3.5</td>
<td>7.3</td>
</tr>
<tr>
<td>$n_{tot}/n_{col}$</td>
<td>189/174</td>
<td>180/174</td>
</tr>
<tr>
<td>$\beta_x^<em>/\beta_y^</em>(m)$</td>
<td>0.90/0.60</td>
<td>7.0/0.5</td>
</tr>
<tr>
<td>$\epsilon_x$(nm)</td>
<td>41</td>
<td>5000</td>
</tr>
<tr>
<td>$\epsilon_y/\epsilon_x$</td>
<td>10%</td>
<td>1</td>
</tr>
<tr>
<td>$\sigma_x/\sigma_y$(\mu m)</td>
<td>192/50</td>
<td>189/50</td>
</tr>
<tr>
<td>$\sigma_z$(mm)</td>
<td>11.2</td>
<td>191</td>
</tr>
<tr>
<td>$2\Delta\nu_x$</td>
<td>0.024</td>
<td>0.0026</td>
</tr>
<tr>
<td>$2\Delta\nu_y$</td>
<td>0.061</td>
<td>0.0007</td>
</tr>
<tr>
<td>$\mathcal{L}$(cm$^{-2}$s$^{-1}$)</td>
<td>16.9$\cdot$10$^{30}$</td>
<td>75.7$\cdot$10$^{30}$</td>
</tr>
<tr>
<td>$\mathcal{L}_3$(cm$^{-2}$s$^{-1}$mA$^{-2}$)</td>
<td>0.66$\cdot$10$^{30}$</td>
<td>1.82$\cdot$10$^{30}$</td>
</tr>
</tbody>
</table>
Specific Luminosity ($1/cm^2/s/mA^2$)

Luminosity extrapolation

Luminosity ($1/cm^2/s$)

120 Bunches
$I_p < 70\ mA$
$I_e < 35\ mA$
$L_{peak} < 2.7 \times 10^{31} \ cm^{-2}s^{-1}$
HERA III

Polarized protons in HERA

- Polarimeters
- Flattening Snakes
- Spin rotators
- At least 4 Siberian Snakes

e-A in HERA

- Deuteron acceleration: with same Linac
- Ion Acceleration requires:
  - a new Linac
  - high energy e-cooling
- Luminosity:

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

- At the time of HERA's design (1980) there was no experience with high Energy e/p collision.
- Beam sizes have to be matched to let the proton lifetime be long.
- Beams have to meet head on to about 0.1 sigma to avoid bad electron lifetime.
- Proton and electron tunes have to be controlled to about 0.002.
- Tunes were chosen to avoid resonances Qx=0.293 Qy=0.297
- Crossing angles were avoided.
p lifetime drops with e current
Luminosity for different e currents

L_s is independent of e-current

time (min)
Higher p halo production for higher le

Accumulated halo

HERA-B rates

p bunch number

Newly produced halo

HERA-B rates

p bunch number

Tail scraping at HERA-B

HERA-B rates

t(s)
No reduction of $L_s$ by the second experiment
No reduction of $L_s$ by a larger $\beta$-funktionen

So far no reduction of $L_s$ by the bunch current

| $\beta_x^e$ | $\beta_y^e$ | $L_s^{ZEUS}$ (without H1) | $L_s^{ZEUS}$ (with H1) | $\Delta \Phi \in [0, 2\pi]$ | $\Delta Q_x^e$ | $\Delta Q_y^e$
|---|---|---|---|---|---|---
| 0.9m | 0.6m | $7.1 \cdot 10^{29}$ | $7.0 \cdot 10^{29}$ | $[7.00, 7.20] \cdot 10^{29}$ | 0.0106 | 0.0311
| 1.0m | 0.7m | $6.78 \cdot 10^{29}$ | $7.0 \cdot 10^{29}$ | $[6.67, 6.89] \cdot 10^{29}$ | 0.0118 | 0.0363
| 2.2m | 0.9m | $5.18 \cdot 10^{29}$ | $5.5 \cdot 10^{29}$ | $[4.97, 5.42] \cdot 10^{29}$ | 0.0259 | 0.0467
Measures against drop in $L_s$

1. Moving the electron tune away from the beam-beam enhanced resonance $2Q_y+6Q_x=\text{integer}$.

2. Change phase advance so that the dynamic beta beat of the two collider experiments H1 and Zeus subtracts.

3. Reduce proton emittance grows by switching of electron tune controller PLL during collisions.
Recent lumi scaling

\[ \mathcal{L} = \frac{N_{ppb}^p \cdot I^e}{4\pi \cdot e \cdot \epsilon_p} \frac{1}{\sqrt{\beta_{px} \cdot \beta_{py}}} \]

\[ \left( \frac{\sigma_e}{\epsilon_{px}} = \frac{\sigma_p}{\epsilon_{py}} \right) \]

\[ L_{\text{peak}} \approx 0.78 \cdot L_{\text{calc}} \]

- The luminosity depends on many quantities, many of which could influence the reduction factor.
- One likely possibility would be a dependence on the proton brightness, i.e. the number of proton / emittance

\[ L_{\text{peak}} \approx 0.78 \cdot L_{\text{calc}} \]
Current operation experience

- The horizontal tune has to be small for good polarization
- Tails of the e-beam on synchro beta resonance leads to proton background
- Core e-tune on synchro beta resonance leads to electron loss

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Longitudinal polarization at 3 IRs

Goal: longitudinal polarization at ZEUS \(\text{(new)}\), H1 \(\text{(new)}\), and HERMES using the new spin rotators

Challenges: The experimental solenoid requires longitudinal polarization at ZEUS & H1, otherwise there is no significant buildup.
First polarization at H1 and Zeus

3 Rotator Polarization Studies with Harmonic Bumps May 1, 2003

51% polarization with e/p collisions was possible with Specific luminosities close to the design:

Luminosity at H1, Lsp = 1.7 (su)  Luminosity at ZEUS, Lsp = 1.4 (su)
Second e-fills have more polarization

Explanation: The first fill and the refilling procedure have increased the proton emittances and decreased the beam beam force that acts on spins.
Runs with more lumi have less pol.

Explanation: Runs with more initial lumi (that is at the time of maximum lumi in this run) have a higher beam beam force than runs with lower initial lumi, given that the initial electron current is about the same from run to run.
Where are the Beam-Beam Limits?

Upgrade and Ip=140mA: emittance starts to grow
Simulation of large beam beam forces

- $L_s(e_y, \text{measured})$
- $L_{s, \text{measured}}$

Measured lumi
Expected lumi for measured emittance
Simulation
Dipole modes of Gaussian bunches

• Beam beam tune shift for one particle in the beam beam field of a Gaussian bunch:

\[ \xi_{ex} = \beta_{ex} \frac{r_e}{2\pi\gamma_e} \frac{N_{ppb}}{\sigma_{px}(\sigma_{px} + \sigma_{py})} \]

• Shift in the dipole modes oscillation frequency of a Gaussian bunch:

\[ \Delta Q_{ex} = \xi_{ex} \frac{\sigma_{px}(\sigma_{px} + \sigma_{py})}{\sum_{px}(\sum_{px} + \sum_{py})} \]

Assumption: the bunches remain Gaussian

This approximation is justified for a stiff beam hitting a much less stiff beam when the first beam creates a small beam beam kick.
Beam Beam experiments of Feb. 2003

Unexplained lumi change over each bunch train:

Higher p current

Lower specific luminosity
Beam Beam Tune shifts

\[ \Delta Q_{\text{ex}}(\text{comp., meas.}) \]

\[ \Delta Q_{\text{ey}}(\text{comp., meas.}) \]
Simulated coherent modes

\[ \beta_{ey}^* = 4.0 \text{m} \]
\[ \xi_{ex} = 0.041 \]
\[ \xi_{ey} = 0.272 \]
\[ dQ_{ex} = 0.027 \]
\[ dQ_{ey} = 0.082 \]
\[ \Delta \nu_{ex}^m = 0.009 \]
\[ \Delta \nu_{ey}^m = 0.013 \]

(From work with Jack Shi, KU)

why?
how?

\[ \Delta \nu_{ex}^{\text{sim}} = 0.003 \]
\[ \Delta \nu_{ey}^{\text{sim}} = 0.013 \]