Luminosity Measurement at the LHeC

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- Mission
- Suitable processes
- Challenges
- Possible options
- Conclusions

Future of DIS, April 22, 2010
• optimisation and tuning of $ep$-collisions
  \[ dL_{stat} = 1\%/sec, \text{overall scale} \sim 5\% \text{ is Ok} \quad \Rightarrow \quad 20 \text{ kHz} \]

• mid-term variations of instantaneous $L$
  \[ dL_{stat} = 1\% \text{ per run (10 min - few hours)} \quad \Rightarrow \quad 20 \text{ Hz} \]

• absolute integrated $L$ for physics normalization
  \[ dL_{tot} = 1 - 2\% \text{ per sample (week-month)} \quad \Rightarrow \quad 0.02 \text{ Hz} \]
\[ L_{\text{LHeC}}(ep) = 10^{31} - 10^{33} \text{ cm}^{-2}\text{s}^{-1} \]

- optimisation and tuning of \( ep \)-collisions
  \[ dL_{\text{stat}} = 1\%/\text{sec}, \text{ overall scale } \sim 5\% \text{ is Ok} \quad \Rightarrow \quad 20 \text{ kHz} > (0.02 - 2) \text{ mb} \]

- mid-term variations of instantaneous \( L \)
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- absolute integrated \( \mathcal{L} \) for physics normalization
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All cross sections in this talk are estimated for the case \( 70 \times 7000 \text{ GeV} \).
B-H process: $\sigma(E > 8) = 112\text{mb}$
(poles in both $e^*$ and $\gamma^*$ propagators)

B-H with "internal conversion"
$\sigma \simeq 1/200\sigma_{BH}$

QED Compton: $\sigma_{el}(\theta < 179^\circ) = 6\text{nb}$
(poles in $\gamma^*$ propagator, but large $e^*$ mass)

F2 (NC DIS): $\sigma(Q^2 > 10) = 300\text{nb}$
$\sigma(Q^2 > 100) = 25\text{nb}$
**Processess**

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**Dedicated (tunnel) detectors**

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Detector options

Two setups for Main Detector (low $Q^2$ vs high $Q^2$)
Two setups for Main Detector (low $Q^2$ vs high $Q^2$)

1° − 179° acceptance (9 units in $\eta$)

at $L = 10^{31}\text{cm}^{-2}\text{s}^{-1}$
Detector options

Two setups for Main Detector (low $Q^2$ vs high $Q^2$)

1° − 179° acceptance (9 units in $\eta$) at $L = 10^{31}\text{cm}^{-2}\text{s}^{-1}$

10° − 170° acceptance (5 units in $\eta$) at $L = 10^{33}\text{cm}^{-2}\text{s}^{-1}$

(courtesy P. Kostka)

High $Q^2$

Low $Q^2$
Examles from HERA

Event yield / nb$^{-1}$

Run number

High $Q^2$ NC DIS

Precision: $1 - 2\% (F_2), 2\% (QEDC)$
Examles from HERA

High $Q^2$ NC DIS

Precision: $1 - 2\%$ ($F_2$), $2\%$ (QEDC)

LHeC MC study: (using H1 analysis strategy)

Generator: DJANGOH ($0.05 < y < 0.6$)

high $Q^2$ setup: $\sigma_{vis} \simeq 10$ nb

low $Q^2$ setup: $\sigma_{vis} \simeq 150$ nb

Rate (stat.err): $1.5 - 10$ Hz ($\delta \mathcal{L} \simeq 1\%$/hour)

COMPTON MC (elastic part)

$\sigma_{vis} \simeq 0.025$ nb

$\sigma_{vis} \simeq 3$ nb

$0.025 - 0.03$ Hz ($\delta \mathcal{L} \simeq 0.5\%$/month)
Challenges in Linac-Ring and Ring-Ring options

- crossing angle at IP
- large SR flux

⇒ Challenge: difficult
to catch zero-angle $\gamma$'s

RR scheme
Challenges in Linac-Ring and Ring-Ring options

- Head-on collisions.
  Similar to HERA, $\gamma$’s travel along the p-beam

- Lumi monitor located after proton dipole at $z = 100$ m
  ⇒ Challenge: large aperture required for proton magnets at $z = 60 - 80$ m

- crossing angle at IP
- large SR flux

⇒ Challenge: difficult to catch zero-angle $\gamma$’s
**LR option**

Medium BP – $A_\gamma = 35 - 45\%$

Large BP – $A_\gamma = 70 - 80\%$

$\delta L = 2.5 - 6.0\%$

Beampipe at $z=80\text{m}$

Photon Detector at $z=100\text{m}$
IP optics for RR option?

Crossing angle = 2 mr
Magnetic separation = 2 mr
⇒ 60 mm beam separation at 22m

Crossing angle = 1.5 mr
Magnetic separation = 0.75 mr
⇒ 40 mm beam separation at 22m

SR power profile at 22m

F. Willeke, May 2008
B. Holzer / B. Nagorny, Sept 2008
BH flux in SR absorber at 22m

- BH spot at the hottest place
BH-photon detector integrated into SR absorber

- Cooling system with 10 – 15 cm long water bath acting as Čerenkov radiator for BH γ’s
- Radiation hard, (almost) insensitive to SR
- Optimisation of crossing angle might be useful:
  - Version A: acceptance \( \sim (84 \pm 2\)%
  - Version B: acceptance \( \sim (10 \pm 1\)%
- Exact BH counter design and R/O
  still to be worked out
- Accurate acceptance control
  requires precise beam tilt
  monitoring (10-15% of the x-angle)

\[ \delta L = 3 - 10\% \]
Options for Electron Taggers

IR Layout

- ET-6m requires some dipole field ⇒ not possible for low luminosity setup
- An option: split separator dipole and position ET at $z = 13 - 14$ m?
Options for Electron Taggers

IR Layout

- ET-6m requires some dipole field \( \Rightarrow \) not possible for low luminosity setup

- An option: split separator dipole and position ET at \( z = 13 - 14 \text{m} \)

\( \Rightarrow \) No acceptance for oppositely charged leptons (Internal Conversion process is not detectable) 😞

\( \sim 50 \text{ GeV} \)

\( \sim 8 \text{ GeV} \)

\( \sim 30 \text{ GeV} \)

SR ?
et-Tagger Acceptances at different positions

\[
\langle y \rangle = 0.85
\]

\[
\langle y \rangle = 0.7
\]

\[
\langle y \rangle = 0.6
\]

\[
\langle y \rangle = 0.3
\]
ET-62m Acceptance variations

Acceptance control requirements

- ET position wrt $e$-beam: $< \pm 0.5 \text{mm}$
- $e$-orbit offset at IP $< \pm 20 \text{ mkm}$
Further remarks about Electron Taggers

- $e^{-}$-taggers are also useful to enhance physics programme (tagged $\gamma p$). Note however, that triggering might be problematic due to inefficient $\gamma$-veto

- ET-6m has small acceptance, but can access largest $W_{\gamma p}$
  ET-14m, ET-22m may suffer from SR,
  ET-62m is most promising (good acceptance, small SR, available space)

- Energy calibration might be a problem (leakage, abs.scale)

- Reliable geometrical acceptance determination (to $3 - 5\%$ precision) requires good knowledge/control of beam optics at IP (tilt, offset of e-trajectory)

Can one rely on Water Counter and $e$-taggers for online lumi measurement? 
⇒ Look at HERA experience
Rates at HERA (H1 Lumi system)

Figure 6

Figure 7

Figure 10

Figure 23

Figure 21

Figure 22
Dominant systematics

<table>
<thead>
<tr>
<th>Method</th>
<th>Stat. error</th>
<th>Syst. error</th>
<th>x-section</th>
<th>Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>BH (γ) 0.1%/sec 3 − 10%</td>
<td>= 0.5%</td>
<td>Monitoring, tuning, Absolute $L$ (?)</td>
<td>short term variations</td>
<td></td>
</tr>
<tr>
<td>BH (e) 1 − 3%/sec 5 − 6%</td>
<td>= 0.5%</td>
<td>Monitoring, tuning, Relative $L$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>QEDC 1 − 2%/week 1.5 − 2%</td>
<td>= 1%</td>
<td>Absolute $\mathcal{L}$, Global normalisation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>F2 0.5 − 1.5%/h 2.5%</td>
<td>= 2%</td>
<td>Relative $\mathcal{L}$, mid. term variations</td>
<td></td>
<td></td>
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</table>
Luminosity measurement at the LHeC is a non-trivial task. HERA experience: surprises are possible ⇒ prepare several scenarios

Precise integrated $\mathcal{L}$ for physics is possible with main Detector (QEDC, F2) $\delta \mathcal{L} = 2\%$ is within reach

Fast instantaneous $L$ monitoring is challenging, but few options do exist
  ▶ Photon Detector for LR option requires large p-beampipe at $z = 80m$
  ▶ In case of RR option B-H photons can be detected using water Čerenkov counter integrated with SR absorber (this also requires relatively large crossing angle)
  ▶ Electron tagger at 62 m is very promising for both LR and RR schemes

Good control of the $e$-beam optics at the IP is essential to monitor acceptances of the tunnel detectors at 5% level