Saturation at the LHeC

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LHeC

70 GeV electrons in the LHC tunnel

7 TeV protons

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

A fantastic opportunity to explore very low $x$ dynamics at moderate $Q^2$
What can be done with $F_2$?

Three fits to HERA data, extrapolated to LHeC.

First glance looks very promising....

Systematics 1-3%

1 fb$^{-1}$ of data $\sim$ 1 year
Universal dipole cross-section:

- $F_2$ (and charm, beauty)
- $F_L$
- Diffractive DIS (high mass?)
- DVCS
- Exclusive vector mesons (meson wavefunction?)
Regge inspired dipole: FS04 no sat

Only dipoles with $r < r_0$ scatter with a $\sim x^{-0.3}$ cross-section. Larger dipoles scatter with a weaker $\sim x^{-0.07}$ cross-section.

No saturation: $r_0$ is constant.

Saturation dipole I: FS04 sat

Only dipoles with $r < r_s$ scatter with a $\sim x^{-0.3}$ cross-section. Larger dipoles scatter with a weaker $\sim x^{-0.06}$ cross-section.

Saturation: $r_s$ decreases with decreasing $x$.


Saturation dipole II: CGC

Dipoles with $r < r_s$ scatter with a $\sim$ BFKL cross-section. Larger dipoles scatter with a constant cross-section.

Saturation: $r_s$ decreases with decreasing $x$

HERA data

- Some tentative evidence for saturation but it relies on $F_2$ data at $Q^2$ below $2 \text{ GeV}^2$. See also Kowalski, Motyka, Watt.

- All other data can be fitted using the Regge model or either of the saturation models.
DVCS

\[ \sigma(W, Q^2) \]

\[ W = 82 \text{ GeV} \]
\[ B = 6.02 \text{ GeV}^2 \]

\[ Q^2 = 9.6 \text{ GeV}^2 \]
\[ B = 4.0 \text{ GeV}^2 \]

J/Psi

\[ \sigma(W, Q^2) \]

\[ Q^2 = 0 \]
\[ Q^2 = 0.4 \]
\[ Q^2 = 3.1 (\text{ZEUS}); 3.2 (\text{H1}) \]
\[ Q^2 = 0.4 \]
\[ Q^2 = 6.8 (\text{ZEUS}); 7.0 (\text{H1}) \]

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Also \( F^c_2 \)

Note 1: low beta region is theoretically uncertain
Note 2: theory does not include secondary exchanges relevant for xpom > 0.01
F_2 at LHeC

Can we see DGLAP fail at Q^2 > few GeV^2?

Can DGLAP be made to fit data which include saturation?

Curves: CTEQ 6.1 (extrapolated)

Points: Fake LHeC data using CGC & FS04 (1 fb^{-1})
But we should re-fit DGLAP before drawing conclusions:

\begin{align*}
  x\bar{q}(x, Q_0) &= A_q x^{B_q} (1 - x)^{C_q} \\
  xg(x, Q_0) &= A_g (1 - \exp[-B_g \log^2((x_0/x)\lambda)]) (1 - x)^{C_g}
\end{align*}

= Fit 6 parameters: \( A_q, B_q, A_g, B_g, x_0, \lambda \) and \( C_g \)

= Use H1pdf2k for valence quarks and \( C_q \)

= NLO evolution (\( \overline{MS} \))

= Fixed flavour number scheme \( M_c = 1.4 \) GeV and \( M_b = 4.5 \) GeV

= \( \alpha_s(M_Z) = 0.1185 \) and \( Q_0^2 = 1.9 \) GeV²
Fitting the FS04 LHeC “data” + ZEUS data using DGLAP

Fit is to data with $Q^2 \leq 20$ GeV$^2$ ($\chi^2 = 92$ for 92 data points)

$\Rightarrow$ Consistent with what we saw extrapolating CTEQ

$\Rightarrow$ Only the 4 points at highest $Q^2$ and lowest $x$ cause problems

$Q^2$ evolution of FS04 and CGC is an extrapolation of the fit to HERA data.
Fitting the CGC LHeC “data” + ZEUS data using DGLAP

Fit is to data with $Q^2 \leq 3 \text{ GeV}^2$ ($\chi^2 = 10.5$ for 14 data points)

⇒ Consistent with what we saw extrapolating CTEQ

⇒ Cannot fit evolved data
$F_L$ at LHeC

Varying proton beam energy from 7 TeV down to 450 GeV (or 1 TeV)

**FS04**

- $Q^2 = 2\ \text{GeV}^2$
- $Q^2 = 5\ \text{GeV}^2$
- $Q^2 = 13.5\ \text{GeV}^2$
- $Q^2 = 30\ \text{GeV}^2$

**CGC**

- $Q^2 = 2\ \text{GeV}^2$
- $Q^2 = 5\ \text{GeV}^2$
- $Q^2 = 13.5\ \text{GeV}^2$
- $Q^2 = 30\ \text{GeV}^2$

FS04 fitted to $Q^2 \leq 20\ \text{GeV}^2$: $F_2$ and $F_L$

CGC fitted to $Q^2 \leq 3\ \text{GeV}^2$: $F_2$ and $F_L$
Curves are the “predictions” after extrapolating CTEQ
Saturation effects may well be present in HERA data but there is no evidence within the perturbative domain.

Saturation models which fit the HERA data lead to predictions for LHeC which cannot be “faked” by DGLAP evolution.

It would be very important to measure the longitudinal structure function.

Other observables would also provide a handle: heavy quark structure functions, DVCS, exclusive vector mesons, diffractive deep inelastic scattering.