Inclusive Diffraction in DIS – H1 Results

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Diffraction 2006, Milos
Overview

- Diffractive DIS at H1
  - Kinematics and Observables
- Comparison of Experimental Techniques
  - Rapidity Gap and Leading Proton Techniques Agree
- Factorisation, NLO QCD Fits and Diffractive PDFs
  - $M_Y$, $t$ and $x_{IP}$ Dependences Factorise from $Q^2$ and $\beta$ Dependences
  - QCD and the High $z$ Gluon
- Ratio of Diffractive : Inclusive Cross Sections
  - Gluon : Quark Ratio is the Same
- Diffractive Charged Currents
  - Predicted from Fit to NC Data
- New Preliminary Data
  - H1 and the $M_X$ Method
Diffractive DIS Kinematics

Fractional momentum of Parton wrt Pomeron
\[ \beta = \frac{Q^2}{Q^2 + M_X^2} \]

\[ x = x_{IP} \beta \]

Fractional Momentum of Pomeron wrt Proton
\[ x_{IP} = \frac{Q^2 + M_X^2}{Q^2 + W^2} \]

Photon virtuality
\[ Q^2 = sxy \]

Large Gap in Rapidity

Momentum Transfer at Proton Vertex
\[ t = (p - Y)^2 \]
Experimentally selecting $ep \rightarrow eXp$

Forward Proton Spectrometer

Measure Leading Proton (FPS)
No proton dissociation
Measure the $t$ dependence
Low detector acceptance

Large Rapidity Gap in H1

$z = 64, z = 80m$

Require Large Rapidity Gap (LRG) spanning at least $3.3 < \eta < \sim 7.5$

Kinematics measured from $X$ system, integrate $|t| < 1.0$ GeV$^2$, $M_Y < 1.6$ GeV

High detector acceptance $\rightarrow$ precision
Data Sets and Observables

- FPS data sample – 1999–2000 data, 28 pb\(^{-1}\) hep-ex/0606003
- Measure \( t \) Dependence \[ \frac{d\sigma}{dt} \sim \exp B|t| \]
- And Differential Cross Section

\[
\frac{d^4\sigma^{ep\rightarrow eXp}}{dx dQ^2 dx_{IP} dt} = \frac{4\pi\alpha^2}{xQ^4} Y + \sigma^D(4)(x, Q^2, x_{IP}, t)
\]

Where

\[
Y_+ = 1 + (1 - y)^2 \quad \text{and} \quad \sigma^D(4) = F_2^D(4) - \frac{y^2}{Y+F_L}F_L^D(4)
\]

- LRG Data – 1997 – 2000 e+ data hep-ex/0606004
  - \( 3 < Q^2 < 13.5 \) GeV\(^2\) \quad 2.0 \text{ pb}^{-1}\)
  - \( 13.5 < Q^2 < 105 \) GeV\(^2\) \quad 10.6 \text{ pb}^{-1}\)
  - \( Q^2 > 133 \) GeV\(^2\) \quad 61.6 \text{ pb}^{-1}\)

- Measure Reduced Cross Section Integrated over \( t \)

\[ \sigma^D(3) = \int_{-1}^{t_{\text{min}}} \sigma^D(4) dt \]
QCD hard scattering collinear factorisation (Collins) at fixed $x_{IP}$ and $t$

$$d\sigma_{parton_i}(ep \rightarrow eXY) = f_i^D(x, Q^2, x_{IP}, t)) \otimes d\sigma^{ei}(x, Q^2)$$

Applied after integration over $M_Y$ and $t$ ranges

‘Proton vertex’ factorisation of $\beta$ and $Q^2$ from $x_{IP}$, $t$, and $M_Y$ dependences

$$f_i^D(x, Q^2, x_{IP}, t) = f_{IP/p}(x_{IP}, t) \cdot f_i^{IP}(\beta = \frac{x}{x_{IP}}, Q^2)$$
Data Overview

LRG: $M_Y < 1.6$ GeV

3.5 $Q^2$ 1600 GeV$^2$

FPS: $Y = p$

$Q^2 = 2.7$ GeV$^2$

$Q^3 = 1600$ GeV$^2$

$\beta = 0.01$, $\beta = 0.04$, $\beta = 0.1$, $\beta = 0.2$, $\beta = 0.4$, $\beta = 0.65$, $\beta = 0.9$

$Q^2 [\text{GeV}^2]$

$3.5$

$5$

$6.5$

$8.5$

$12$

$15$

$20$

$25$

$35$

$45$

$60$

$90$

$200$

$400$

$800$

$1600$

$X_{IP}$
Comparison of H1 LRG, H1 FPS, ZEUS LPS Data

- **ZEUS (LPS)** and **H1 (FPS)** Leading Proton Data agree very well (they agree to 8% cf. 10% normalisation uncertainties)
- **ZEUS LPS** and **H1 FPS** scaled by global factor of 1.23 to compare with LRG $M_y < 1.6$ GeV
- Very good agreement between Leading Proton and LRG methods after accounting for proton diss’n
- Both experimental techniques measure the same cross section
Detailed Comparison LRG v FPS

- LRG measurement also done with FPS bins

- Form ratio of measurements as a function of $x_{IP}$, $\beta$ and $Q^2$

\[
\frac{\sigma(M_Y < 1.6 \text{ GeV})}{\sigma(Y = p)} = 1.23 \pm 0.03 \text{ (stat.)} \pm 0.16 \text{ (syst.)}
\]

$M_Y$ dependence factorises from $x_{IP}$, $\beta$ and $Q^2$ within 10% (non-normalisation) errors.
B(x_{IP}) from fit to $\frac{d\sigma}{dt} \sim \exp B|t|$

- Fitting low $x_{IP}$ data to

$$B = B_{IP} + 2\alpha'_{IP} \ln(1/x_{IP})$$

yields:

$$\alpha'_{IP} = 0.06^{+0.19}_{-0.06} \text{ GeV}^{-2} \quad B_{IP} = 5.5^{2.0}_{-0.7} \text{ GeV}^{-2}$$

- $B(x_{IP})$ data constrain $IP, IR$ flux factors in proton vertex factorisation model
$t$ Slope Dependence on $\beta$ or $Q^2$?

$B$ measured double differentially in ($\beta$ or $Q^2$) at fixed $x_{IP}$

- $t$ dependence does not change with $\beta$ or $Q^2$ at fixed $x_{IP}$
Effective Pomeron Intercept Independent of $\beta$ and $Q^2$

From fit to LRG data: \[ \alpha_{IP}(0) = 1.118 \pm 0.008 \text{ (exp.)} \pm 0.029 \text{ (theory)} \]

- No dependence of $\alpha_{IP}(0)$ on $Q^2$ or $\beta$
- The $x_{IP}$ dependence also factorises from $Q^2$ and $\beta$
- $x_{IP}, t$ and $M_Y$ dependences factorise from the $Q^2$ and $\beta$ dependences within errors

$\rightarrow$ Data support Proton Vertex Factorisation
Study $\beta$ and $Q^2$ dependences at fixed $x_{IP}$

Analogous to making an inclusive $F_2$ measurement at each value of $x_{IP}$
Directly measure the quark content

Large scaling violations out to $\beta \sim 0.6$ are suggestive of a large gluon content…
$Q^2$ Dependence in More Detail

Fit data at fixed $x$, $x_{IP}$ to

$$\sigma^D_r = A + B \ln Q^2$$

such that

$$B = \frac{d\sigma^D_r}{d \ln Q^2}$$

Divide results by $f_{IP/p}(x_{IP})$ to compare different $x_{IP}$ values

Different $x_{IP}$ measurements agree

Derivatives large and positive at low $\beta$ ... suggests large gluon
H1 2006 DPDF Fit, Overview

- **IP component**: Fit $\alpha_{IP}(0)$ ($x_{IP}$ dependence). Simultaneously, fit 5 parameters of DPDFs ($\beta$ and $Q^2$ dependences) using NLO QCD.

- **IR component**: fit one free parameter for normalisation, $n_{IR}$

All flux params taken from previous H1 data. PDFs taken from Owens-π.
Kinematic Range and DPDF Parameterisation

- Fit is stable with variations of, e.g. $\beta_{\text{max}}$ – the maximum value of $\beta$ allowed in the fit.

- Systematic variation of gluon density with minimum $Q^2$ of data included in fit for $Q^2_{\text{min}} < 8.5$ GeV$^2$. Stable for larger $Q^2_{\text{min}}$.

- Fit all data with $Q^2 > 8.5$ GeV$^2$ (and $M_X > 2$ GeV, $\beta > 0.8$).

- Parameterise quark singlet $z\Sigma(z,Q_0^2)$ and gluon $zg(z,Q_0^2)$ densities, where $z$ is parton momentum fraction (= $\beta$ for QPM).

Parameterisation used is: $z\Sigma(z,Q_0^2) = A_q z^{B_q} (1-z)^{C_q}$ and $zg(z,Q_0^2) = A_g (1-z)^{C_g}$ (gluon insensitive to $B_g$).

- Results reproducible with Chebyshev polynomials.
$Q_0^2 = 1.75 \text{ GeV}^2$

$\chi^2 \sim 158 / 183 \text{ d.o.f.}$

- Experimental uncertainty obtained by propagating errors on data through $\chi^2$ minimisation procedure

- Theoretical uncertainty estimated by varying fixed parameters of fit and $Q_0^2$

- Singlet constrained to $\sim 5\%$, gluon to $\sim 15\%$ at low $z$, growing considerably at high $z$

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~70% gluons

Integrated over $z$
A Closer Look at the High $z$ Region

We have only singlet quarks, so DGLAP evolution equation for $F_2^D$ ....

$$\frac{dF_2^D}{d \ln Q^2} \sim \frac{\alpha_s}{2\pi} P_{qg} g + P_{qq} \sum$$

At high $\beta$, relative error on derivative grows, $q$ $qg$ contribution to evolution becomes important ... sensitivity to gluon is lost
DPDFs (linear $z$ scale)

- Lack of sensitivity to high $z$ gluon confirmed by dropping (high $z$) $C_g$ parameter, so gluon is a simple constant at the starting scale!

- **Fit B**
  \[
  \chi^2 \sim 164 / 184 \text{ d.o.f.}
  \]
  \[
  Q_0^2 = 2.5 \text{ GeV}^2
  \]

- Quarks very stable
- Gluon similar at low $z$
- Substantial change to gluon at high $z$
$Q^2$ dependence of diffractive/inclusive ratio

Make ratio at fixed $x_{IP}$ and $x$ and fit to

$$\frac{\sigma_r^D}{\sigma_r} = A + B \ln Q^2$$

such that

$$B = \frac{d\left(\frac{\sigma_r^D}{\sigma_r}\right)}{d \ln Q^2}$$

Ratio remarkably flat (derivative $\sim 0$) except at high $\beta$
If \( \frac{d(\sigma^D_r / \sigma_r)}{d \ln Q^2} \sim 0 \) then \( \frac{1}{\sigma^D_r} \frac{d \sigma^D_r}{d \ln Q^2} \approx \frac{1}{\sigma_r} \frac{d \sigma_r}{d \ln Q^2} \rightarrow \frac{g^D}{q^D} \sim \frac{g}{q} \)

Low \( x \), gluon:quark ratio \( \sim 70\%/30\% \), common to diffractive and inclusive.
Ratio
diffractive/inclusive: x dependence

- Plot $\sigma_r^D/\sigma_r$ vs $x$ ($\sim 1/W^2$) at fixed $\beta Q^2$ (hence fixed $M_X$)

- Remarkably flat vs $x$ over most of kinematic range (bins with large $F_L$ or IR contribution not shown)

- Diffractive and inclusive cross sections cannot be described with the same $\alpha_{IP}(0)$, even if it is $Q^2$ dependent
Diffractive Charged Current

- Sensitive to flavour decomposition of singlet (which is completely unconstrained by NC data)

- Good agreement with H1 2006 DPDF fit (which assumes $u = d = s = \bar{u} = \bar{d} = \bar{s}$ though statistics very limited so far
New Data using Rapidity Gap Method

- Published data
- Prel. 99-00 data, 34 pb\(^{-1}\)
  \(10 < Q^2 < 105\) GeV\(^2\)
- Prel. 2004 data, 34 pb\(^{-1}\)
  \(17.5 < Q^2 < 105\) GeV\(^2\)
- Large increase in statistics at medium \(Q^2\)
- Consistent with published data
H1 LRG and ZEUS Mx

The $M_x$ method does not agree with the other two experimental methods

• Long-standing discrepancy between $M_x$ and both LRG and Leading Proton methods
• Differences apparent at the cross-section level (see also comparisons for Hera-LHC workshop by Newman and Schilling)
Comparisons of H1 LRG, H1 $M_X$ and ZEUS $M_X$

- H1 $M_X$ measurement limited in acceptance to low $M_X$ (no forward plug calorimeter)

- In this region of small subtraction the two experimental methods agree rather well

Suggests the difference comes from making the subtraction
Summary

- H1 diffractive measurements using FPS and LRG methods published
  - hep-ex/0606003 and hep-ex/0606004 (both accepted by EPJC)
  - Data from two methods agree in detail! Also agreement with ZEUS-LPS
- Proton vertex factorization holds: $M_y$, $t$ and $x_{IP}$ dependences factorise from $\beta$ and $Q^2$
- DPDFs from NLO QCD fits to $\beta$ $Q^2$ dependences (H1 2006 DPDF Fits A+B)
  - Quark singlet very well constrained ($\sim 5\%$)
  - Gluon constrained to $\sim 15\%$, but poorly known at high $z$ (see talk by M. Mozer)
- Ratio of diffractive/inclusive DIS measured
  - $\sim$flat with $Q^2$ (fixed $x$, $x_{IP}$), also with $x$ (fixed $Q^2$, $M_X$)
- Diffractive Charged Currents predicted by fit to NC data, thought statistics are low
- New preliminary H1 data with large improvement in statistics at medium $Q^2$
  - $M_X$ method agrees with other experimental techniques when subtraction is small
BACK-UP SLIDES FOLLOW
Inclusive Diffraction in DIS - H1 results

Diffraction 2006
