A QCD analysis of ZEUS diffractive data

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On behalf of the ZEUS Collaboration

- Introduction and motivation
- Fitting framework and procedure
- Fit results
- Comparison of fits with other data
- Summary
Introduction—what is diffraction?

Deep inelastic scattering

\[ \sigma^{(D)}_{ep \rightarrow eX(p)} \sim f^{(D)}_{i/p} \otimes \sigma_{i\gamma \rightarrow jk} \]

Diffractive deep inelastic scattering

Parton densities in proton

Parton densities in “Pomeron” (i.e. when there is a fast proton in the final state)
Introduction—why study diffraction?

• To understand the nature of diffraction, QCD and its description of diffraction
  - Diffraction is a significant fraction of the inclusive cross section.
  - Can pQCD be used to describe diffraction?
  - Can we think of diffraction in terms of a factorisable structure function and a hard scattering process?
  - If so, what are the parton distributions (DPDFs) of the structure functions?

- Will it provide a “smoking-gun” for new physics?
**Introduction—what known and what to improve?**

- DIS data can be described by NLO DGLAP fits for DPDFs.
- Tevatron data cannot; MPIs or such need to be invoked.
- Want the best DPDFs we can achieve for LHC predictions.

**Have done**

- Several groups have extracted DPDFs (H1; Martin, Ryskin and Watt; Golec-Biernat and Luszczak).
- Use of jet data crucial for constraining gluon density.

**To improve**

- Theoretical assumptions.
- More precise data.
Fitting framework and procedure

Theoretical framework

• DPDFs $f_i^D(z, x_{IP}; Q^2)$ are densities or partons of type $i$.
  • fractional momentum $zx_{IP}$.
  • probed with resolution $Q^2$.
  • a fast proton with fractional momentum $(1 - x_{IP})$.
• Proton-vertex factorisation adopted for $x_{IP}$ dependence.

\[
f_i^D(z, x_{IP}; Q^2) = f_{IP}(x_{IP}) f_i(z, Q^2) + f_{IR}(x_{IP}) f_i^{IR}(z, Q^2).\]

Analysis method

• Input parameters fitted to data, minimising a $\chi^2$, using the “offset” method.
• NLO DGLAP QCD fit.
• Evolution done using QCDNUM and cross checked.
• $\alpha_s(M_Z) = 0.118$, $m_c = 1.35$ GeV, $m_b = 4.3$ GeV, $Q_0^2 = 1.8$ GeV$^2$.
• Heavy quarks: general-mass variable-flavour-number scheme of Thorne and Roberts.
• Inclusive data: $\mu_R = \mu_F = Q$. Jet data: $\mu_F = Q$, $\mu_R = E_{T}^{jet}$, use DISENT and NLOJET++.
Fits and data sets

Parametrisation of the DPDFs

\[ z f_{d,u,s}(z, Q_0^2) = A_q z^{B_q} (1 - z)^{C_q}, \]
\[ z f_{g}(z, Q_0^2) = A_g z^{B_g} (1 - z)^{C_g}. \]

| Fit name       | Data set                              | \( zg(z) \)                        |
|----------------|---------------------------------------|------------------------------------|
| ZEUS DPDF S    | LRG + LPS                             | \( A_g z^{B_g} (1 - z)^{C_g} \)    |
| ZEUS DPDF C    | LRG + LPS                             | \( A_g \)                           |
| ZEUS DPDF SJ   | LRG + LPS + DIS dijets                | \( A_g z^{B_g} (1 - z)^{C_g} \)    |

In total, 9 free parameters, \( A_{q,g}, B_{q,g}, C_{q,g} \), the Pomeron and Reggeon intercepts, \( \alpha_{IP}(0) \) and \( \alpha_{IR}(0) \), and normalisation of Reggeon term, \( A_{IR} \).

Data samples

- LRG : 40 < \( W \) < 240 GeV, 2 < \( Q^2 \) < 305 GeV\(^2\), 2 < \( M_X \) < 25 GeV, 0.0002 < \( x_{IP} \) < 0.02
- LPS : 40 < \( W \) < 240 GeV, 2 < \( Q^2 \) < 120 GeV\(^2\), 2 < \( M_X \) < 40 GeV, 0.002 < \( x_{IP} \) < 0.1
- Jet : 100 < \( W \) < 250 GeV, 5 < \( Q^2 \) < 100 GeV\(^2\), \( E_{Tjet1,2} > 5, 4 \) GeV, \( x_{IP} < 0.03 \)
- But :
  - Overlapping (\( x_{IP} < 0.02 \)) LPS data not used.
  - Only data with \( Q^2 > 5 \) GeV\(^2\) used.

LRG / LPS : ZEUS Coll., Nucl. Phys. B 816 (2009) 1, DESY-08-175;
Jet : ZEUS Coll., Euro. Phys. J. C 52 (2007) 813, DESY-07-126.
• All fits give a comparably good description of inclusive data.
• Clear deviance of fit and data for $Q^2 < 5$ GeV$^2$. 
Fit results

- LPS data likewise well described for $Q^2 > 5 \text{ GeV}^2$.
- Fit above data at low $\beta$, where no LRG data.
- Note only $x_{IP} > 0.02$ used; good cross check of fit.
- Values of $a_{IP}(0)$, $a_{IR}(0)$ and $A_{IR}$ consistent with Regge fit.

### Key message:
Approach works very well for $Q^2 > 5 \text{ GeV}^2$, however for fully inclusive DIS, DGLAP fits performed down to $Q^2 \sim 2.5 \text{ GeV}^2$. 

### Diagram:
- **ZEUS LPS 99-00**
- **ZEUS DPDF S**
- **ZEUS DPDF S (extrapolated)**

### Table:

| $Q^2 (\text{GeV}^2)$ | $x_{IP} D(3)$ |
|----------------------|---------------|
| 2.5                  | 0.002α, 0.007β, 0.020γ, 0.065δ, 0.217ε |
| 3.9                  | 0.004α, 0.011β, 0.031γ, 0.098δ, 0.302ε |
| 7.1                  | 0.007α, 0.019β, 0.055γ, 0.165δ, 0.441ε |
| 14                   | 0.013α, 0.037β, 0.104γ, 0.280δ, 0.609ε |
| 40                   | 0.038α, 0.100β, 0.248γ, 0.526δ, 0.816ε |
Resultant DPDFs

Example DPDF distributions

• Smallish uncertainties.
• Quarks similar for two fits.
• Gluons very different for two fits.
• Need jet data to constrain gluon density.
Comparison with DIS jet data

$Z_{IP} = (Q^2 + M_{jj}^2) / (Q^2 + M_X^2)$
Resultant DPDFs including jets

- Fit C shown as reference.
- Quark distributions similar.
- Gluon distribution similar to fit C.
- Similarly good description of inclusive data.
- Much better determination of gluon density.
- Which is about 60% of the momentum of the exchange.

![Diagram showing gluon fraction versus Q^2 for different values of Q^2.

ZEUS-ZJ = ZEUS proton 2005, ZEUS-D-SJ = ZEUS diffractive proton 2009, asymptotic = b = 16/31.]

W. Slominski
Comparison with H1 DPDF

Differences ZEUS // H1 fits:
- VFNS // FFNS.
- $Q^2 > 5 \text{ GeV}^2$ // $Q^2 > 8.5 \text{ GeV}^2$.
- $M_N = m_p$ // $M_N < 1.6 \text{ GeV}$; hence scaling 0.81.

Comparison:
- Agreement in shape for $\beta < 0.2$; ZEUS fit higher.
- At higher $\beta$ and where extrapolated, agreement worsens.
- Reflects degree of consistency between H1 and ZEUS data.
Comparison of fits with other data

To compare with independent data set and different process.

- Dijet photoproduction ($Q^2 \sim 0$) fits the bill.
- Consider the fraction of the photon’s energy invested in producing the dijets.
- Reasonable description of data by DPDFs used in NLO QCD calculation.
- Difference wrt H1 Fit up to 20%.
- These data do not suggest any suppression or factorisation breaking versus $x_{\gamma^{\text{obs}}}$ (or $E_T$).

- (Also compared to charm in DIS.)
Summary and discussion

• An NLO DGLAP QCD fit to inclusive and dijet diffractive DIS data performed.
• Data well described and quark densities (from inclusive data) and gluon densities (from jet data) well constrained.
• Can predict other processes: charm in DIS and dijet photoproduction.

• Only data with $Q^2 > 5 \text{GeV}^2$ could be fitted in the framework of DGLAP evolution and proton-vertex factorisation. Fully inclusive DIS starts at $Q^2 \sim 2.5 \text{GeV}^2$.
• No factorisation breaking for ZEUS photoproduction data. Improved DPDFs are not going to significantly improve agreement with Tevatron data. Is picture (@ H1 / ZEUS / Tevatron) consistent? Not necessarily inconsistent.
• Further improvements will come on detailed understanding of comparison of H1 and ZEUS data and its combination.
Back-up
Quality of fit

ZEUS

$\chi^2/\text{ndf}$

$Q^2_{\text{min}}$ (GeV$^2$)
DPDFs

ZEUS

$Q^2 = 6 \text{ GeV}^2$

$Q^2 = 20 \text{ GeV}^2$

$Q^2 = 60 \text{ GeV}^2$

$Q^2 = 200 \text{ GeV}^2$
Charm data

Charm contribution to the diffractive structure function
# Tables of parameters

| Parameter | Fixed to  | Measurement                                      | Ref.  |
|-----------|----------|-------------------------------------------------|-------|
| $\alpha_f^p$ | 0       | $-0.01 \pm 0.06\text{(stat.)}^{+0.04}_{-0.08}\text{(syst.)} \pm 0.04\text{(model)} \text{ GeV}^{-2}$ | [9]   |
| $\alpha_f^r$ | 0.9 GeV$^{-2}$ | 0.90 $\pm 0.10 \text{ GeV}^{-2}$ | [31]  |
| $B_f^p$    | 7.0 GeV$^{-2}$ | $7.1 \pm 0.7\text{(stat.)}^{+1.4}_{-0.7}\text{(syst.)} \text{ GeV}^{-2}$ | [9]   |
| $B_f^r$    | 2.0 GeV$^{-2}$ | 2.0 $\pm 2.0 \text{ GeV}^{-2}$ | [31]  |

| Parameter | Fit value  | Fit value  | Fit value  |
|-----------|------------|------------|------------|
|           | DPDF S     | DPDF C     | DPDF SJ    |
| $A_q$     | 0.135 $\pm$ 0.025 | 0.161 $\pm$ 0.030 | 0.151 $\pm$ 0.020 |
| $B_q$     | 1.34 $\pm$ 0.05    | 1.25 $\pm$ 0.03    | 1.23 $\pm$ 0.04    |
| $C_q$     | 0.340 $\pm$ 0.043  | 0.358 $\pm$ 0.043  | 0.332 $\pm$ 0.049  |
| $A_g$     | 0.131 $\pm$ 0.035  | 0.434 $\pm$ 0.074  | 0.301 $\pm$ 0.025  |
| $B_g$     | $-0.725 \pm 0.082$ | 0           | $-0.161 \pm 0.051$ |
| $C_g$     | $-0.422 \pm 0.066$ | 0           | $-0.232 \pm 0.058$ |
| $\alpha_f^p(0)$ | 1.12 $\pm$ 0.02 | 1.11 $\pm$ 0.02 | 1.11 $\pm$ 0.02 |
| $\alpha_f^r(0)$ | 0.732 $\pm$ 0.031 | 0.668 $\pm$ 0.040 | 0.699 $\pm$ 0.043 |
| $A_{fR}$  | 2.50 $\pm$ 0.52    | 3.41 $\pm$ 1.27    | 2.70 $\pm$ 0.66    |
| $\chi^2$/ndf | 315/265 = 1.19 | 312/265 = 1.18 | 336/293 = 1.15 |
DPDF theoretical uncertainties

The following sources of uncertainties were investigated:

- the starting scale $Q_0^2$. The value 1.8 GeV$^2$ was chosen as it minimises the $\chi^2$. Varying $Q_0^2$ for fit C between 1.6 and 2 GeV$^2$ yielded a $\chi^2$ between 1.18 and 1.20; the DPDFs did not change significantly;

- the fixed parameters in the fits (Table 1). Variations within the measurement errors resulted in a simple scaling of the fluxes integrated over $t$, absorbed into the normalisation parameters $A_q$, $A_g$ and $A_{IR}$, with negligible effect on the DPDFs;

- the renormalisation scale dependence. The scale $\mu_R$ for dijet data was taken as $0.5E_T^{\text{jet}}$ and $2E_T^{\text{jet}}$, whereas it was kept as $Q$ for the inclusive data. The effect on the parton densities was within 5% for light quarks, 15% for $c$ and $b$ and 30% for gluons, while the $\chi^2$ increased significantly;

- the masses of the charm and beauty quarks. The nominal values of $m_c = 1.35$ GeV and $m_b = 4.3$ GeV were varied in the ranges $1.35 < m_c < 1.75$ GeV and $4.3 < m_b < 5$ GeV. Neither the quark nor gluon distributions were sensitive to variations of $m_b$, whereas $m_c$ produced an effect comparable to the experimental uncertainty. The $\chi^2$ value changed only slightly, reaching the minimum at the nominal mass values.
Gluon fractions

At e.g. $Q^2 = 10$ GeV$^2$, 
- $g_{frac}(\text{ZEUS}) \sim 0.62 \pm 0.01$
- $g_{frac}(\text{H1}) \sim 0.70 \pm 0.04$
H1 dijet photoproduction data

![Graphs showing dijet photoproduction data and predictions vs. H1 data.](image-url)