QCD fits & Factorisation tests in diffraction at HERA

*A next-to-leading-order QCD analysis
of diffractive processes
measured by the ZEUS experiment*

DIS 2009

Diffraction and Vector Mesons parallel session

April 2009, Madrid

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On behalf of the ZEUS collaboration

Fitting & testing procedure

- **A systematic investigation**
 - NLO QCD fit to the inclusive DIS data
 - comparison and fit to dijets in DIS
 - comparison to dijets in PHP
- **Massive quarks treatment**
 - VFNS vs. FFNS
 - arguments for GM-VFNS
- **Fixing gluons**

Inclusive diffractive DIS

Kinematics of diffractive deep inelastic scattering

$$\beta = \frac{Q^2}{2(p - p')_q} \approx \text{parton in IP fract. momentum}$$

t -integrated cross section

$$\frac{d\sigma}{d\beta dQ^2 dx_{\mathbb{P}}} = \frac{2\pi\alpha^2}{\beta Q^4} \left(1 + (1 - y)^2\right) \sigma_r^{D(3)}(\beta, Q^2, x_{\mathbb{P}})$$

expressed in terms of diffractive structure functions

$$\sigma_r^{D(3)}(\beta, Q^2, x_{\mathbb{P}}) = \underline{F_2^{D(3)}(\beta, Q^2, x_{\mathbb{P}})} - \frac{y^2}{1 + (1 - y)^2} \underline{F_L^{D(3)}(\beta, Q^2, x_{\mathbb{P}})}$$

A model for diffractive $F_{2/L}$

Regge factorisation assumption

$$F_{2/L}^{D(4)}(\beta, Q^2, x_{\mathbb{P}}, t) = f_{\mathbb{P}}(x_{\mathbb{P}}, t) F_{2/L}^{\mathbb{P}}(\beta, Q^2) + f_{\mathbb{R}}(x_{\mathbb{P}}, t) F_{2/L}^{\mathbb{R}}(\beta, Q^2)$$

This assumption works for the inclusive DIS with

- Regge-type flux $f(x_{\mathbb{P}}, t) = \frac{A e^{Bt}}{x_{\mathbb{P}}^{2\alpha(t)-1}}$ with $\alpha(t) = \alpha(0) + \alpha' t$
- free $F_{2/L}^{\mathbb{P}}(\beta, Q^2)$
- $F_{2/L}^{\mathbb{R}}(\beta, Q^2) \propto F_{2/L}^{\pi}(\beta, Q^2)$ (GRV)

see Marta Ruspa talk

Can QCD + DGLAP describe $F_{2/L}^{\mathbb{P}}(\beta, Q^2)$?

Factorisation & heavy quarks

- **$F_{2/L}$ or any other cross section σ for N massless flavours**

- collinear divergencies caused by massless quarks factorised and absorbed into non-perturbative PDFs

$$\sigma(Q^2, \dots) = \sum_k f_k^{(N)}(Q^2) \otimes \sigma_k(\dots)$$

- nb. in diffraction

$$f_k^{(N)}(Q^2) \rightarrow f_k^{D(N)}(Q^2, x_{IP}, t)$$

Diffractive PDFs

- **+ 1 heavy flavour (massive quark) in FFNS**

$$\sigma(Q^2, \dots) = \sum_k f_k^{(N)}(Q^2) \otimes \sigma_k^{\text{FF}}(m^2/Q^2, \dots)$$

- still N partons, heavy flavour in final state only
- no extra collinear divergencies
- new types of terms
 - m^2/Q^2 — important at low Q^2
 - $\log(m^2/Q^2)$ — large at high Q^2

Fixed Flavour Number Scheme

Heavy quarks treatment in VFNS

- $m^2/Q^2 \rightarrow 0$ **massless or infinite Q^2 limit**

- large logs must be resummed
- $\rightarrow$ N+1 massless flavours

$$\sigma(Q^2, \dots) = \sum_k f_k^{(N+1)}(Q^2) \otimes \sigma_k(\dots)$$

- **ZM(zero mass)-VFNS**

- use (N+1) massless formula at $Q^2 > m^2$

- **GM(general mass)-VFNS**

- $\log(m^2/Q^2)$ resummed $\rightarrow$ heavy quark PDF
- proper behaviour at $Q^2 \sim m^2$

$$\sigma(Q^2, \dots) = \sum_k f_k^{(N+1)}(Q^2) \otimes \sigma_k^{\text{VF}}(m^2/Q^2, \dots)$$

- non-unique — Thorne-Roberts scheme used (as in ZEUS QCD fits)

recover massless limit at N+1

Variable Flavour Number Scheme

FN scheme choice

- **GM-VFNS is most general → best choice**
- **Inclusive DIS**
 - FFNS and VFNS formulae available
 - both schemes give good description of the data
- **Dijets production**
 - available formulae (computer codes) use massless quarks
 - “closer” to VFNS than FFNS
 - VFNS provides heavy quark PDFs
 - OK at high μ
 - still threshold effects missing at μ close to m_h

Diffraction PDFs parametrization

Regge factorisation assumption

$$f_k^{D(3)}(z, Q^2, x_P) = f_P(x_P) f_k^P(z, Q^2) + f_R(x_P) f_k^R(z, Q^2)$$

Flux parametrization

$$f(x_P, t) = \frac{A e^{Bt}}{x_P^{2\alpha(t)-1}}$$

with $\alpha(t) = \alpha(0) + \alpha' t$

$$f_{P/R}(x_P) = \int_{t_{\min}}^{t_{\max}} dt f_{P/R}(x_P, t)$$

4 parameters per flux:

$$A, b, \alpha(0), \alpha'$$

Reggeon PDFs
taken from pion (GRV)

Half of the parameters (b and α')
fixed by Regge fits
to e-p (ZEUS)
and p-p (Donnachie–Landshoff)

Pomeron PDFs parametrization

Pomeron PDFs parametrized at some initial Q_0^2

for all flavours $q = \bar{q}$

$$\Rightarrow \text{quark singlet (total sea)} \quad f_S^{IP} = \sum_q f_{q+}^{IP} = 2 \sum_q f_q^{IP}$$

symmetric light quarks assumed: $d = u = s$

$$zf_k^{IP}(z, Q_0^2) = A_k z^{B_k} (1-z)^{C_k} \quad k = g, S \quad \text{6 parameters}$$

× regularizing factor $\exp\left(-\frac{0.001}{1-z}\right)$ to allow for any C_k

Free flux parameters: $\alpha_P(0), \alpha_R(0), A_R$ 3 parameters

9 parameters in total

Models for gluons

Gluons expected to be poorly constrained by the inclusive data.

Consider two cases of the gluon parametrization

$$zf_g^{IP}(z, Q_0^2) = A_g z^{B_g} (1-z)^{C_g}$$

“Standard”: Fit S with B_g , C_g fitted

“Constant”: Fit C with $B_g = C_g = 0$ (as in H1-2006B)

Both models provide equally good data description
but
very different gluons

LRG data well described – low Q^2

LRG data well described – high Q^2

$$x_{IP} \sigma_r^{D(3)}(\beta, Q^2, x_{IP})$$

LPS data well described

$$x_{IP} \sigma_r^{D(3)}(\beta, Q^2, x_{IP})$$

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DPDFs from the inclusive fits

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yellow band shows
fit experimental
uncertainty

— flexible gluons
- - - stiff gluons

Huge gluons
uncertainty

Dijets in diffractive DIS & PHP

- **Dijet production is directly sensitive to gluons**
 - photon-gluon fusion at LO
- **DiJets in DIS (large Q^2)** *(J.C. Collins 1998)*
factorisation holds in pQCD
 - compare to predictions based on inclusive DIS fits
 - use in incl+dijets fit
- **DiJets in PHP ($Q^2 \rightarrow 0$)**
factorisation assumed for the resolved photon contribution

$$\sigma(E_{\perp}^2, \dots) = \sum_{j,k} f_j^{IP}(E_{\perp}^2) \otimes \sigma_{jk}(\dots) \otimes f_k^{\gamma}(E_{\perp}^2)$$

- strong suppression observed in pp collisions (CDF/Tevatron)
- compare to predictions based on incl+dijets fit

Dijets in DIS sensitive to gluons

ZEUS

Fit S fails at $z > 0.4$

Fit C works surprisingly well

NLO QCD predictions from DISENT (*Catani, Seymour*) vs. ZEUS data
EPJ C52 (2007) 813

NLOJET++ (Nagy) results agree within 5%

Inclusive + DIS dijets fit

ZEUS

Fit S incl+dijets

good data description

DPDFs from the inclusive+dijets fit

Predictions for photoproduction of dijets vs. x_γ

ZEUS

ZEUS data EPJ C55 (2008) 177

Very good data description
No evidence for suppression

NLO QCD predictions obtained *assuming factorisation*
Computer code by Frixione & Ridolfi, γ PDFs: GRV-HO

Predictions for photoproduction of dijets vs. E_T

Good data description
No evidence for suppression

NLO QCD predictions obtained *assuming factorisation*
Computer code by **Frixione & Ridolfi**

Summary

- **A systematic NLO analysis of the ZEUS diffractive data performed**
- **Successful GM-VFNS (Thorne-Roberts) fits to**
 - inclusive DIS only
 - inclusive DIS + DIS-dijets
- **NLO predictions for dijet production, using new DPDFs agree very well with the data**
- **No evidence for suppression in photoproduction**

EXTRAS

Q_0^2 , Q_{min}^2 and χ^2 for inclusive fits

Best χ^2 at $Q_0^2 = 1.8 \text{ GeV}^2$

Data samples used in the fits:

$Q_{min}^2 > 5 \text{ GeV}^2$: 229 (LRG) + 36 (LPS) = 265 points

$Q_{min}^2 > 10 \text{ GeV}^2$: 179 (LRG) + 25 (LPS) = 204 points

LPS: only $x_{IP} > 0.02$ — to remove overlap with the LRG sample

Resulting χ^2/NDF

	$Q_{min}^2 > 5 \text{ GeV}^2$	$Q_{min}^2 > 10 \text{ GeV}^2$
fit C	1.18	1.03
fit S	1.19	1.05

$Q^2_{\min}$ — χ^2 dependence

The choice
 $Q^2_{\min} = 5 \text{ GeV}^2$
acceptable.

Q^2_{min} — *DPDFs dependence*

light quarks

gluons

ZEUS

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Very small difference between $Q^2_{\min} = 5$ and 10 GeV^2