Jet production in diffractive and non-diffractive scattering at HERA

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Outline:

Introduction
Experimental Signatures
Inclusive Diffraction and jet production
QCD analysis
Jet production in DIS, $\alpha_s$
what is Diffraction?  at least one beam particle stays intact

Large cross sections in hadronic interactions
(Regge pole phenomenology of the sixties)
colourless exchange, in QCD not fully understood yet

Advantage of HERA:
study with methods of pQCD
hard scale provided by Q2

Beam particle (proton) stays intact

Ordinary Deep inelastic scattering

Hard interaction of exchanged photon with parton of proton
proton destroyed
Kinematics and Observables in Diffraction

standard DIS variables

\[ Q^2 = s \times y \]

proton may dissociate in low mass system Y

proton momentum fraction of exchange

\[ x_{IP} = \frac{Q^2 + M_x^2}{Q^2 + W^2} \]

momentum fraction of exchange in hard interaction

\[ \beta = \frac{Q^2}{Q^2 + M_x^2} \]

\[ x = x_{IP} \beta \]
Kinematics and Observables in Diffraction

standard DIS variables

\[ Q^2 = s x y \]

assumed colourless exchange

proton may dissociate in low mass system \[ Y \]

proton momentum fraction of exchange

\[ x_{IP} = \frac{Q^2 + M_x^2}{Q^2 + W^2} \]

momentum fraction of exchange in hard interaction

\[ \beta = \frac{Q^2}{Q^2 + M_x^2} \]

\[ z_{IP} = \beta \]

for \[ M_{1,2}^2 = 0 \]
Factorisation in Diffractive DIS

QCD hard scattering collinear factorisation at fixed $x_{IP}$ and $t$

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

diffractive parton density

hard interaction Xsection

¿ diffractive pdfs applicable like proton pdfs? e.g. in some channels at LHC?
Factorisation in Diffractive DIS, extension

(Trentadue, Veneziano, Berera, Soper, Collins . . .)

QCD hard scattering collinear factorisation at fixed $x_{IP}$ and $t$

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

diffractive parton density

hard interaction $\sigma$

assumption of ‘proton vertex factorisation’

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

p vertex

structure of exchanged object $IP$
Experimental Signatures of Diffraction

1) require large rapidity gap (LRG)

2) detect proton in forward spectrometers

   free of proton dissociation

3) “M_x method”

   non-diffractive DIS

   consistent results of 3 methods

   diffraction

   p dissociation

   W = 200 - 245 GeV
   Q^2 = 40 - 50 GeV^2

   Events

   lnM_x^2
Inclusive diffractive cross sections

new LRG data of ZEUS
(large rapidity gap)

ZEUS renormalised to H1
(-13%, within uncertainties of the experiments)

H1 and ZEUS in good agreement
Diffractive pdfs

- NLO QCD (DGLAP) fits to inclusive cross sections
- quark pdfs well constrained
- sizeable gluon density at high z
- but gluon not well constrained
- more experimental input?

\[
F_2 = x \sum e^2 q(q(x) + \bar{q}(x))
\]

\[
z = \beta
\]

\[
M^2
\]

\[
W = \pi \alpha \sqrt{2} G_1 \sin^2 \theta_W
\]

\[
\alpha_3 s \alpha_s (M_Z) = 0.118
\]

\[
\theta = 310
\]

\[
Q^n = -(l - l')^2
\]

\[
\xi = x_{ Bj}(1 + M^2) / Q^2,
\]

\[
x_p = x_{ Bj} / \xi
\]

in LO

\[
z = \beta
\]

(momentum fraction of exchange into hard interaction)
Jet data

- QCD fit similar to fit B
- fit describes jet data and inclusive diffraction
- jet data constrain gluon (also seen by ZEUS)

factorisation works for jets but ...

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... but naive application of diffractive pdfs fails in $p\bar{p}$

explained by secondary interactions which fill the gap (e.g. Kaidalov, Khoze, Martin, Ryskin.)

$\rightarrow$ cross sections suppressed

photoproduction similar to $p\bar{p}$ reactions?

"direct"

"resolved" $\gamma$

at small $x_\gamma$

panic08
photoproduction

H1 2006 Fit B DPDF
- FR NLO \times (1 + \delta_{had})
- FR NLO Frixione et al.

observe suppression with respect to NLO based on diffractive pdfs independent of $x_\gamma$

ICHEP 08 Philadelphia Paul Laycock 21

Factorisation tests at HERA
H1 saw that the cross section was suppressed in ... saw consistency with no suppression but did confirm the absence of dependence of $x$!
observe suppression with respect to NLO based on diffractive pdfs independent of $x_{\gamma}$

Conclusion:

factorisation ansatz works in DIS for inclusive data, for jets in DIS, charm production (not shown), but only approximately for photoproduction
Jet production in High $Q^2$ DIS

hard parton interaction, nucleon destroyed

sensitivity to $\alpha_s$ by $p_t$ in $\gamma^*P$ system

$\alpha_s$ is determined by comparison of data with NLO pQCD calculations
ZEUS used kt cluster algorithm with different jet radii R

Excellent description by NLO (DISENT, Catani, Seymour)

fit for $Q^2 > 500 \text{ GeV}^2$

$$\alpha_s(M_Z) = 0.1207 \pm 0.0014 \text{ (stat.)} \pm 0.0022 \text{ (th.)}.$$
Ratio of inclusive jets to total NC DIS (to improve precision)

Normalised Inclusive Jet Cross Section

H1 Preliminary
150GeV^2 < Q^2 < 200GeV^2

H1
200GeV^2 < Q^2 < 270GeV^2

H1
270GeV^2 < Q^2 < 400GeV^2

H1
400GeV^2 < Q^2 < 700GeV^2

H1
700GeV^2 < Q^2 < 5000GeV^2

H1
5000GeV^2 < Q^2 < 15000GeV^2

NLO
DISENT and NLOJET++
(Z. Nagy, Z. Trocsanyi)

HERA I
65 pb

HERA I,II
395 pb^{-1}

good agreement with HERA I and with NLO pQCD

in addition 2-jets and 3-jet jets analysed
Determination of $\alpha_s$ as function of $Q$

H1 Preliminary
- $\alpha_s(\mu = Q)$ for $Q^2 < 100$ GeV$^2$ (HERA I)
- $\alpha_s(\mu = Q)$ for $Q^2 > 150$ GeV$^2$ (HERA I+II)
- Combined $\langle \alpha_s(\mu) \rangle$ (incl., 2-, 3-jet) from $Q^2 > 150$ GeV$^2$

NLO uncertainty

$\alpha_s(M_Z)$ fit for $Q^2 > 150$ GeV$^2$

low $Q^2$ data consistent with high $Q^2$ result

using inclusive jets, 2-jets, 3-jets:

$\alpha_s(M_Z) = 0.1182 \pm 0.0008\text{(exp.)}^{+0.0041}_{-0.0031}\text{(scale)} \pm 0.0018\text{(PDF)}$  

(preliminary)

small exp. error

large theoretical uncertainty
Recent determinations of the strong coupling from HERA jet analyses

precise $\alpha_s(M_Z)$ determinations from jets in DIS

limitation by theoretical uncertainties
Conclusions

Diffraction

factorisation holds, i.e. diffractive pdfs can be applied

in inclusive DIS

jet production in DIS

charm production (not shown)

only approximately in photoproduction

(not straight forward in $p\bar{p}$ )

Non-diffractive jet production

precise $\alpha_s$ determinations

limitation by theoretical uncertainties
Check Factorisation in Diffractive photoproduction of D*
- Data/theory comparison same for all $x_\gamma$
- “Suppression” factor of $\sim 0.5$
- Indications of $E_T$ dependence (ZEUS sees weaker global suppression at higher $E_T$)
- Sensitive to choice of dPDF