Charm production in diffractive DIS and PHP at ZEUS

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Outline

• Introduction
• Selection of diffractive events
• Reconstruction of D*
• Diffractive D* in photoproduction ($Q^2 \approx 0$) (new result)
• Comparison to inclusive D*
• Summary and Outlook
Deep Inelastic Scattering at HERA:
diffraction contributes substantially to the cross section
(~ 10% of visible low-x events)

Inclusive DIS:
Probe partonic structure
of the proton \( \to F_2 \)

Diffractive DIS:
Probe structure
of the exchanged
color singlet \( \to F_2^D \)

\( Q^2 \): 4-momentum exchange
\( W \): \( \gamma \) p centre of mass energy
\( x \): fraction of p momentum carried
by struck quark

\( x_{IP} \): fraction of p momentum carried
by the Pomeron (IP)

\[ x_{IP} = \frac{q \cdot (p - p')}{{q \cdot p}} \approx \frac{Q^2 + M_X^2}{Q^2 + W^2} \]

\( \beta \): fraction of IP momentum carried
by struck quark

\[ \beta = \frac{Q^2}{2q \cdot (p - p')} \approx \frac{Q^2}{Q^2 + M_X^2} = \frac{x}{x_{IP}} \]
Inclusive diffraction and factorisation theorem

Diffractive structure function:

\[
F_2^{D(3)}(\beta, Q^2, x_{IP}) = \frac{\beta Q^4}{4\pi\alpha_s^2(1 - y + y^2/2)} \cdot \frac{d\sigma_D^{ep\to e'Xp'}}{d\beta dQ^2 dx_{IP}}
\]

QCD Factorisation:

\[\sigma^D = \text{universal diffractive PDF} \otimes \text{hard ME}\]

Factorisation proven for DDIS by Collins.

Rapidity gap due to exchange of colorless object with vacuum quantum numbers.
Reminder: Diffractive $D^*$ in DIS

Kinematic range:
- $1.5 < Q^2 < 200$ GeV$^2$
- $0.02 < y < 0.7$
- $\beta < 0.8$

NLO calculation:
HVQDIS with:
- ACTW fit B (gluon dominated fit to H1 and ZEUS incl. diffr. DIS and ZEUS diffr. $\gamma P$ data)

$D^*$ cuts:
- $p_T(D^*) > 1.5$ GeV
- $|\eta(D^*)| < 1.5$

- good agreement of NLO calculations with data
- confirms QCD factorisation in DDIS
- data used to constrain gluons in ZEUS LPS fit
Diffractive PDFs:
- assume Regge factorisation
- parametrise flavour singlet and gluons at $Q^2 = 2$ or $3 \text{ GeV}^2$
- evolve with NLO DGLAP and fit

- Gluon dominated
- quark density well constrained
- larger gluon uncertainty at high $z$ (fractional momentum of parton)
Dijet cross section factor 3-10 lower than expected using different HERA PDFs

**Comparison to Tevatron**

**HERA:**
- DIS ($Q^2 > 5 GeV^2$) and direct photoproduction ($Q^2=0$):
  - photon directly involved in hard scattering

**TEVATRON and LHC:**
- interaction of two hadronic systems

**Resolved photoproduction:**
- photon fluctuates into hadronic system, which takes part in hadronic scattering
Comparison to Tevatron

Suppression due to secondary interactions by add. spectators

Test at HERA with resolved part of photoproduction
Kaidalov et al.: rescaling of resolved part by 0.34 (for dijets, less for charm due to enhancement of direct part)

Dijet and charm data:
Hard scale: $E_T$ of jet or charm mass
- tests of universality of PDF's (=QCD factorisation)
- test of DGLAP evolution

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Diffractive selection with rapidity gap method:
- $\eta_{\text{max}} < 3.0$
- $x_{\text{IP}} < 0.035$
- subset for cleaner diffr. events:
  - $x_{\text{IP}} < 0.01$

Strong reduction of non-diffractive background by cut on forward plug calorimeter (FPC).
**Diffractive D*(2010) in γP: D* selection**

D*(2010): reconstructed using decay chain:

\[ D^{*(2010)^+} \rightarrow D^0 \pi^+ \]

- **Identification of D* with mass difference method.**
- **Background estimated using wrong charge combinations.**

**Event selection:**

- Kinematic range:
  - \( Q^2 < 1 \text{ GeV}^2 \)
  - \( 130 < W < 300 \text{ GeV} \)

- **D* cuts:**
  - \( p_T(D^*) > 1.9 \text{ GeV} \)
  - \( |\eta(D^*)| < 1.6 \)

![Graph showing distributions and event counts](attachment:image.png)

- \( x_{IP} < 0.035: 458 \pm 30 \text{ events} \)
- \( x_{IP} < 0.01: 204 \pm 20 \text{ events} \)
90% of events produced in **direct process**
(due to color enhancement),
only **10% resolved** (including flavor excitation).
- good statistics to check factorisation in direct $\gamma P$
- too poor statistics to check factorisation for resolved $\gamma P$

**Monte Carlo (for corrections):**
RAPGAP 2.08/18 with H1 FIT2 LO

**NLO calculation:**
FMNR with the following diffractive PDFs:
- H1 fit 2006 A and B
- ZEUS-LPS + charm fit
Photon PDF: GRV-G-HO
Diffractive $D^*$: $\gamma P$

$x_{IP} < 0.035$ (new)

- good agreement of all NLO calculations with data
- large error in theory mainly due to scale variations

- supports QCD factorisation in direct $\gamma P$
**Diffractive D*: $\gamma p$

$x_{IP} < 0.01$ (new)

- $x_{IP} < 0.01$: cleaner events:
  - Reggeon contribution negligible,
  - non-diffr. background reduced

- Good agreement of all NLO calculations with data
- Large error in theory mainly due to scale variations

- Supports QCD factorisation in direct $\gamma p$
Calculation of ratio diffractive \( (x_{IP} < 0.035) \) /inclusive:

- Perform exactly the same analysis with/without diffractive cuts
- Use exactly the same program (FMNR) only with different PDFs

- systematic errors in analysis cancel out
- NLO uncertainties cancel out
- more precise test of PDFs

inclusive Monte Carlo (for corrections):
HERWIG 6.301

inclusive NLO calculation:
- FMNR with CTEQ5M
Diffractive $D^*$: $\gamma P$

comparison to inclusive $D^*$ (new!)

Ratio diffractive/inclusive $D^*$ ($R_D$) for $x_{IP} < 0.035$:

$$R_D(D^*) = 5.7 \pm 0.5_{\text{stat}} + 0.7 - 0.4_{\text{syst}} + 0.3_{\text{p.d.}} \%$$

Ratio from NLO calculations:
- H1 2006 Fit A: 6.0%
- H1 2006 Fit B: 5.7%
- LPS Fit: 5.8%

Very good agreement: strongly supports QCD factorisation for direct $\gamma P$
Diffractive D*: γP and DIS

Ratio $R_D$ for $x_{IP} < 0.035$
- visible cross section: 6% of D* are produced diffractively
- no $Q^2$ dependence observed

$$\text{ep} \rightarrow \text{eD'}X'\text{p}$$

$R_D(D^*)$ vs $Q^2 (\text{GeV}^2)$
Test of diffractive PDFs with ep charm (D*) data:
Data very well described by NLO
  ≈ about 6% of D* are produced diffractively for DIS and γP.

- **DIS:**
  - NLO QCD calculations with diffr. PDFs describe data
    - QCD factorisation confirmed

- **γP:**
  - NLO QCD calculations with diffr. PDFs describe D* data
    - strongly supports QCD factorisation for direct γP
    - too large uncertainties to draw conclusion for resolved γP (contribution only about 10%)

**Outlook:** need dijet analysis for conclusion on resolved γP
  - new ZEUS results presented by Y. Yamazaki
**Event selection: LPS, $M_x$ and LRG method**

**LPS**

Use of leading proton spectrometer (LPS):
- t-measurement
- access to high $x_{IP}$ range
- free of p-dissociation background
- small acceptance $\rightarrow$ low statistics

$$\frac{dN}{d\ln M_x^2} = D + c \cdot \exp(b \cdot \ln M_x^2)$$

(D, c, b from a fit to data)

- **Diffr.** flat vs $\ln M_x^2$ for diffractive events
- **Non-diffr.** exponentially falling for decreasing $M_x$ for non-diffractive events

**LRG**

Events with large rapidity gap (LRG):
p-dissociation background for $M_N < 1.6$ GeV, $|t| < 1$ GeV$^2$

$p$-dissociation background subtracted for mass of diss. p $M_N > 2.3$ GeV
Event selection with $M_x$ method

Forward Plug Calorimeter (FPC):

- CAL acceptance extended in pseudorapidity from $\eta=4$ to $\eta=5$
- higher $M_x$ (a factor 1.7) and lower $W$
- p-dissociation events: for $M_N>2.3$ GeV energy in FPC > 1GeV recognized and rejected

\[
\frac{dN}{dln M_x^2} = D + c \cdot \exp(b \cdot ln M_x^2)
\]

- flat vs ln $M_x^2$ for diffractive events
- exponentially falling for decreasing $M_x$ for non-diffractive events
Event selection with LPS

- t-measurement
- $x_{IP}$ measurement (access to high $x_{IP}$ range)
- free of p-dissociation background
- small acceptance $\rightarrow$ low statistics

$$x_{IP} = 1 - \frac{E'_p}{E_p}$$

$$x_L = \frac{p'_z}{p_z} \approx 1 - x_{IP}$$