Measurement of Diffractive Scattering of Photons with Large Momentum Transfer at HERA

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Tomáš Hreus
Université Libre de Bruxelles

On behalf of the H1 Collaboration

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scattering process is described by the usual DIS kinematic variables:

\[ Q^2 = -q^2 = -(k' - k)^2 \]

\[ W^2 = (q + p)^2 \]

in addition the diffractive kinematics:

\[ x_{IP} = \frac{q \cdot (p - p_Y)}{q \cdot p} \quad t = (q - p_x)^2 \]

\[ y_{IP} = \frac{p \cdot (q - p_x)}{p \cdot q} \approx e^{-\Delta \eta} \]

- process is an extension of Deeply Virtual Compton Scattering at large \(|t|\) and small \(Q^2\)
- complements measurements of vector mesons at large \(|t|\) \(\rho, \phi, J/\psi\)
- hard scale $t$ is present at photon and proton vertices

- $\gamma p$ interaction: via the photon fluctuation into $q\bar{q}$ pair

- the $p_T$ of the scattered photon is balanced by the struck parton in the proton

\[ \Delta \eta \simeq \log(\hat{s}/p_T^2) \]

- no strong ordering in $k_T$, but strong ordering in $1/x$: process expected to be described by the BFKL approach

- in the LLA approx., the exchanged colour singlet is modelled by the effective exchange of a gluon ladder

- this BFKL approach is implemented into $MC$
Data Selection

- analysed is 1999/2000 (HERA I) data period (integrated luminosity of 46.2 pb⁻¹)

\[ e^+ p \rightarrow e^+ \gamma Y \]

\[ p_T^\gamma > 2 \text{ GeV} \]

limits \( Q^2, W \) to

\[ Q^2 < 0.01 \text{ GeV}^2 \]

\[ 175 < W < 247 \text{ GeV} \]

240 selected events

Kinematic Reconstruction

\[ |t| = (p_T^\gamma)^2 \]

\[ W \sim (1 - E_{e'}/E_e) s \]

\[ x_F \sim \frac{(E + P_z)}{2 E_p} \gamma \]

\[ y_F \sim \frac{\Sigma_y (E - P_z)}{2 (E_e - E_{e'})} \]
Signal Simulation

HERWIG 6.4 using LLA BFKL  \textit{Cox and Forshaw, J.Phys.G26 (2000) 702}

- 2 free parameters: strong coupling $\alpha_s$ and scale $c$ which defines the leading logarithms in the expansion of the BFKL amplitude

for vector meson production $c = m_{VM}/2$

in $\gamma p \rightarrow \gamma Y$ the scale is unknown – absence of normalisation prediction for $\sigma$

$\alpha_s^{BFKL} = 0.17$ (running with scale is ignored at LLA)

- in the asymptotic approximation of the calculations:

$$\sigma(W) \sim W^\delta \quad \delta = 4(3\alpha_s^{BFKL}/\pi)4 \ln 2$$

$$\frac{d\sigma}{dT} \sim |t|^{-n}$$

- $M_Y$ dependence given by the dynamics

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Background Estimate

Inclusive diffractive $\gamma p$  
$e p \rightarrow e X Y$
- PHOJET MC
- single em particle ($\pi^0$) mimicking the final state photon

Dileptons  
$e p \rightarrow e^+ e^- X$
- elastic+inelastic channels (GRAPE MC)
- topology:
  1 lepton in electron tagger (mimic the scattered electron)
  1 lepton in backward calo (mimic the final state photon)
  1 lepton lost in the beam pipe

$\omega^0$ production
- elastic/proton-dissociation high $|t|$ $\omega^0$ production
($\pi^+ \pi^- \pi^0$ and $\pi^0 \gamma$ decays) found to be negligible (DIFFVM MC)

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Control Plots

background is normalised to luminosity

signal MC normalised to number of events corrected for background

in order to describe data distribution for the acceptance correction:
t-slope reweighted by $t^{0.73}$

distributions are reasonably described by the sum of MC (after the $|t|$ reweight of HERWIG)
Systematic Errors

calculated using HERWIG signal MC

| Experimental                     | Variation | Model Parameters          | Variation     |
|----------------------------------|-----------|---------------------------|---------------|
| photon energy scale              | ±1%       | $x_F$ dependence          | $(1/x_F)^{\pm0.4}$ |
| photon polar angle               | ±2.5 mrad | $|t|$ dependence          | $(1/|t|)^{\pm0.2}$ |
| HFS energy scale                 | ±4%       | $M_Y$ dependence          | $(1/M_Y^2)^{\pm0.3}$ |
| e-tagger energy scale            | ±1.5%     | incl. diff. $\gamma p$ contribution | 100% |
| calo noise thresh.              | ±25%      |                           |               |
| luminosity uncertainty          | ±1.5%     |                           |               |

Largest contributions: $x_F$ slope / e-tagger energy (~10% for the $W$ cross-section)

Other contributions < 5%

Systematic errors are smaller / comparable to statistical errors

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$\gamma p$ Cross Section in $W$

LLA BFKL is normalised to integrated measured cross section

Fit: $\sigma \sim W^\delta$

$\delta = 2.73 \pm 1.02$ (stat) $^{+0.56}_{-0.78}$ (syst)

at $\langle |t| \rangle = 6.1$ GeV$^2$

- steep rise of $\sigma$ with $W$: hard subprocess in interaction

- $\delta$ compatible with $J/\psi$ in photopr. at $\langle |t| \rangle = 6.93$ GeV$^2$

$\delta_{J/\psi} = 1.29 \pm 0.23$ (stat) $\pm 0.16$ (syst)

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\[ \gamma p \] Cross Section in \( W \)

H1 Diffractive Scattering of \( \gamma \) at large \( |t| \)

\[ \sigma_{\gamma p \to \gamma X} \]

\[ 4 < |t| < 36 \text{ GeV}^2 \]
\[ y_{|p|} < 0.05 \]

\[ W^\delta \text{ fit: } \delta = 2.73 \alpha_s^{BFKL} = 0.26 \]

- H1 Data
- LLA BFKL \( \alpha_s^{BFKL} = 0.14 \)
- LLA BFKL \( \alpha_s^{BFKL} = 0.37 \)

\[ \delta = 4 \left( 3 \alpha_s^{Fit} / \pi \right) 4 \ln 2 \]

\[ \alpha_s^{Fit} = 0.26 \pm 0.10 \text{(stat)}^{+0.05}_{-0.07} \text{(syst)} \]

comparable with other measurements:

| \( \alpha_s^{BFKL} \) | \( \langle \alpha_s^{BFKL} \rangle \) |
|----------------------|------------------|
| H1:2003 \( J/\psi \) at high \( |t| \) | 0.18 |
| H1:2006 \( \rho \) at high \( |t| \) | 0.20 |
| ZEUS:2003 \( \phi \) at high \( |t| \) | 0.20 |
| ZEUS:2007 gaps between jets | 0.11 |

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γp Cross Section differential in |t|

H1 Diffractive Scattering of γ at large |t|

LLA BFKL is normalised to the integrated measured cross section

Fit: \( \frac{d\sigma}{dt} \sim |t|^{-n} \)

\[ n = 2.60 \pm 0.19{\text{ (stat)}}^{+0.03}_{-0.08}{\text{ (syst)}} \]

- harder |t| distribution than predicted by LLA BFKL

\[ J/\psi \text{ measurement at high |t|} \]

\[ n_{J/\psi} = 3.78 \pm 0.17{\text{ (stat)}} \pm 0.06{\text{ (syst)}} \]

in the range \( 2 < |t| < 30 \text{ GeV}^2 \)

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Comparison with $J/\psi$ at high $|t|$
Conclusion

- diffractive photon scattering $\gamma p \rightarrow \gamma Y$ at high $|t|$ has been measured for the first time

- important test of the BFKL dynamics

- measured $W$ power $\delta = 2.73 \pm 1.02^{+0.56}_{-0.78}\text{(stat)}^{+0.05}_{-0.07}\text{(syst)}$
  
  $\alpha_s^{\text{Fit}} = 0.26 \pm 0.10^{+0.05}_{-0.07}\text{(stat)}^{+0.08}_{-0.07}\text{(syst)}$
  
  is compatible with the LLA BFKL and with the $J/\psi$ production at high $|t|$ and is one of the strongest energy dependences measured in diffractive processes

- measured $|t|$ power $n = 2.60 \pm 0.19^{+0.03}_{-0.08}\text{(stat)}^{+0.03}_{-0.08}\text{(syst)}$
  
  is harder than that predicted by the LLA BFKL and that measured for diffractive production of $J/\psi$

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Backup
Cross Sections

ep cross sections are calculated as

$$\frac{d^2\sigma_{ep \rightarrow e\gamma\gamma}}{dW \, dt} = \frac{N_{data} - N_{bgr}}{\mathcal{L} A \Delta W \Delta t}$$

$\gamma p$ single-differential cross sections are then extracted using photon flux $\Gamma$

$$\frac{d^2\sigma_{ep \rightarrow e\gamma\gamma}}{dW \, dt} = \Gamma(W) \frac{d\sigma_{\gamma p \rightarrow \gamma\gamma}}{dt}(W)$$