Exclusive Diffraction at HERA

Outline:

• Vector mesons
• Deeply Virtual Compton Scattering

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on behalf of the H1 and ZEUS Collaborations
New Trends in HERA Physics 2011
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Hadron Elektron Ring Anlage at DESY
electron proton interactions
collected luminosity $0.5 \text{fb}^{-1}$/experiment
Diffraction in $ep$ collision at HERA

Non – diffractive $ep$

- Photon probes internal structure of the proton

Diffractive $ep$

- No quantum numbers exchanged

Rapidity Gap
Diffractive Production

\[ V = \rho, \rho', \rho'', \varpi, \phi, J/\psi, \Upsilon, \gamma \]

- \( M \) – invariant mass of the vector meson
- \( W \) – center-of-mass energy of the photon proton system
- \( Q^2 \) – virtuality of the photon
- \( t \) – the square of the momentum transfer between hadrons
- \( M_Y \) – mass of the proton dissociation system
Regge Phenomenology vs. pQCD

**Regge Phenomenology**

(soft diffraction)

\[ \alpha_{IP}(t) = \alpha_{IP}(0) + \alpha' \cdot t \]

\[
\frac{d\sigma}{dt} \propto e^{b(W) - t} \left( \frac{W}{W_0} \right)^{4(\alpha_{IP}(t) - 1)}
\]

\[
b(W) = b_0 + 4\alpha' \cdot \ln \left( \frac{W}{W_0} \right)
\]

From fit to hadronic data:

\[ \alpha_{IP}(t) = 1.08 + 0.25 \cdot t \]

(Donnachie, Landshoff)

\[ \sigma_{tot} \propto \left( \frac{W}{W_0} \right)^{2(\alpha_{IP}(0) - 1)} \]

**Perturbative QCD**

(hard diffraction)

simplest approach: colorless 2 gluon exchange

BFKL-type gluon ladder exchange

Various pQCD inspired models exist

little or no shrinkage
**独家矢量介子生产**

**VDM+Regge**

\[
\frac{d\sigma}{dt} = e^{b_1 \left( \frac{W}{W_0} \right)^{4(\alpha_\text{IP}(t)-1)}} \quad \Rightarrow \quad \sigma(W) \propto W^\delta \quad ; \quad \delta \approx 0.22
\]

\[
b(W) = b_0 + 4\alpha' \ln \frac{W}{W_0} \quad \Rightarrow \quad \text{Shrinkage} \quad ; \quad b \propto r^2
\]

**pQCD**

\[
r^2 = \left[ z(1-z)Q^2 + m_q^2 \right]^{-1} \quad \Rightarrow \quad r^2 \text{ small if } Q^2 \text{ large or } M_V \text{ large}
\]

\[
\sigma_{L} \propto \alpha_s^2(Q_{\text{eff}}^2) |x \cdot g(x,Q_{\text{eff}}^2)|^2 \quad \text{Ryskin} \quad ; \quad Q_{\text{eff}}^2 = \frac{1}{4}(Q^2 + M_V^2 + |t|)
\]

\[
\sigma(w) \propto W^\delta \quad ; \quad \delta \approx 0.8 \text{ fast rise with } W
\]

\[
b \approx 4 \text{ GeV}^2 \text{ and } \alpha' \approx 0 \quad \text{no or little shrinkage}
\]
Vector mesons at HERA
Mass scale

Photoproduction $Q^2 \approx 0$

The $W$-dependence of the “light” vector-meson ($\rho, \omega, \phi, \psi, \psi(2s)$) production is described by Regge phenomenology. The rise of the production cross section with $W$ gets steeper. This indicates the onset of hard diffractive scattering.

For higher mass vector mesons, the rise of the production cross section with $W$ gets steeper.

$\delta \approx 0.22$
Simultaneous extraction of the exclusive and proton-diffractive components from the data.

\[ \sqrt{s} = 318 \text{ GeV} \] — nominal energy run

Reduced energy run
\[ \Rightarrow \] allow to extend the phase-space towards lower W.
W dependence

Photoproduction

- cross section W dependence, $\sigma \sim W^\delta$
- two measured points $\delta = 1.2 \pm 0.8$
- consistent with theoretical prediction, $\delta \sim 1.7$

$\delta = 1.2 \pm 0.8$
W dependence as a function of $Q^2$

$\sigma \sim W^\delta$

- $\delta \sim 0.2$ for very low $Q^2$
- Cross section depends on $Q^2$ (steeper with increasing $Q^2$)

H1 Collab., JHEP05 (2010) 032, 10/09
ZEUS Collab, PMC Physics A 1, 6
DVCS - W dependence as a function of $Q^2$

$\sigma \sim W^\delta$

- $Q^2 = 8 \text{ GeV}^2$
- $Q^2 = 15.5 \text{ GeV}^2$
- $Q^2 = 25 \text{ GeV}^2$

- No $\delta$ dependence on $Q^2$ is observed
- Hard regime

ZEUS: JHEP05(2009)108
δ dependence as a function of scale $Q^2 + M^2$

Process becomes hard as scale $(Q^2 + M^2)$ becomes larger
The b-slope of ρ-production decreases with $Q^2$. 

$$\frac{d\sigma}{d|t|} \propto e^{-b|t|}$$ 

Transverse size of interaction region: $b = b_{v(\gamma)} + b_p$
b slope

Transverse size of interaction region:

\[ b = b_{v(\gamma)} + b_p \]

vector meson (gama) target (proton)

High \(|t|\) proton dissociation change dependence of \(t\)

\[ b = 4.3^{+1.7}_{-1.1} \pm 0.5 [GeV^{-2}] \]
$\sqrt{s} = 318 \text{ GeV} - \text{nominal energy run}$

- Slight dependence slope of $W$
- Differential proton dissociative cross section fitted with function behaving as an exponential at low $|t|$ and and follows a power law at larger $|t|$.

$\sqrt{s} = 225 \text{ GeV} - \text{reduced energy run}$
DVCS t dependence

\[ b = 5.45 \pm 0.19 \pm 0.34 \text{ GeV}^{-2} \]
for \( \langle Q^2 \rangle = 8 \text{ GeV}^2 \)

No evidence for W dependence of b

t dependence of DVCS at ZEUS

- ZEUS measures DVCS by using a direct measurement of the outgoing proton 4-momentum using the LPS spectrometer.
- No p dissociation background → Low detector acceptance → low statistics → Clean measurement
The slope $b$ decreasing with increasing scale, to asymptotic value 5 GeV$^{-2}$

Geometrical transverse size:

$$b = b_{v(\gamma)} + b_p$$

Vector meson $b_v = \frac{1}{Q^2 + M^2}$

Target $b_p \approx 5$ GeV$^{-2}$

$b_p$ can be interpreted as:

$\mathbf{r_{\text{gluons}}} \sim 0.5$ fm

Charge radius of the proton

$\mathbf{r_{\text{em}}} \sim 0.8$ fm
Pomeron trajectory

\[ \frac{d\sigma}{dt} \propto e^{b(W)\cdot t} \left( \frac{W}{W_0} \right)^{4(\alpha_{IP}(t)-1)} \]

Measure W-dependence separately for different t-bins Pomeron trajectory

\[ \alpha_{IP}(t) = \alpha_{IP}(0) + \alpha' \cdot t \]
Pomeron trajectory

$\alpha'_\text{IP}$ depends on $t$

However for high $|t|$, proton diffractive processes dominate.
exclusive dipion production

The two pion invariant mass is fitted as:

\[
\frac{dN}{dM_{\pi\pi}} = N \left[ |F_{\pi\pi}|^2 + B \left( \frac{M_\rho}{M_{\pi\pi}} \right)^n \right]
\]

\[F_\pi(M_{\pi\pi}) = \frac{[\text{BW}(\rho)+\beta\text{BW}(\rho')+\gamma\text{BW}(\rho'')]}{1+\beta+\gamma}\]

- \(\beta,\gamma\) are relative amplitudes
- \(\text{BW}\) Breit Wigner amplitude

- \(\rho\) (770) and \(\rho''\) (1700) are clearly visible, \(\rho'\) (1450) - a mere shoulder
- the masses and the widths of the \(\rho\) (770) and \(\rho''\) (1700) as well as the width of \(\rho'\) (1450) agree with PDG
Q² dependence of relative amplitude

Fit: the masses and the widths of the three resonances were fixed to the values found in overall fit.

- reasonable description of data in three Q² regions
- the absolute value of β increases with Q²
- γ remains Q² independent within the uncertainties
Ratio as a function of $Q^2$

Ratio is defined as:

$$R_V = \frac{\sigma(V \rightarrow \pi\pi)}{\sigma(\rho(770))}$$

- The value of $R\rho'(1450)$ increases with $Q^2$
- The value of $R\rho'' (1700)$ is approximately constant or slightly increases
- This behavior is predicted by several models
- The suppression of the 2S state ($\rho'(1450)$) is connected to a node effect which results in cancellations of contributions from different impact parameter regions at lower $Q^2$, while at higher $Q^2$ the effect of cancellation vanishes
- The D state ($\rho'' (1700)$) suppression is connected to the spinorial structure of the q\bar{q} state into which the photon fluctuates.
Summary

- A large variety of Vector Mesons as well as Deeply Virtual Compton Scattering has been studied in wide kinematics range.
- The measurements allow the study the transition from the soft to the hard regime as a function of scale.
- Two pion mass distribution, $0.4 < M_{\pi\pi} < 2.5$ GeV is well described by the pion electromagnetic form factor, which includes three resonances $\rho$, $\rho'$, $\rho''$. 
W dependence as a function of $Q^2$

INS-L Ivanov, Nikolev, Sawin with kt-unintegrated model

Goloskov, Kroll Generalised Parton Distributions

Kowalski, Motyka, Watt with Golec-Biernat Wuesthoff Saturation

H1 Collab., JHEP05 (2010) 032, 10/09
Data Selection

- data collected by the ZEUS Detector 1998-2000 (82 pb$^{-1}$)
- two pions and electron are measured in the detector
- no additional activity above noise level

Kinematical range:
- $0.4 < M_{\pi\pi} < 2.5$ GeV
- $2 < Q^2 < 80$ GeV$^2$
- $32 < W < 180$ GeV
- $|t| < 0.6$ GeV$^2$

Number of events ~63k
Q² dependence of Vector Mesons

Kowalski, Motyka, Watt with Golec-Biernat Wuesthoff Saturation

Marin, Ryskin, Teubner model: does not provide normalisation (uncertainty on the quark invariant mass corresponding to the meson recombination)

Very good agreement between both experiments

**KMW**: the shape of ρ and φ elastics cross sections are well described
Normalisation of predictions is low by 10% for ρ and higher 25% for φ

**MRT**: good description of Q² dependence
Differential Elastic Cross Section as Function of $t$

**High Energy Period**

- Differential elastic cross section fitted with an exponential.
  - $b$-slope for (error includes statistical and systematic uncertainty)
    - high energy period $(5.77 \pm 0.19) \text{ GeV}^{-2}$
    - low energy period $(4.75 \pm 0.5) \text{ GeV}^{-2}$

**Low Energy Period**

- Shallower $b$-slope for low energy period expected because of lower $W_{\gamma p}$ region and positive shrinkage of pomeron trajectory.
- $b$-slopes cannot directly be compared to published H1 values because cross section were measured as function of $p_{t, \psi}^2$.

Remark: The normalisation uncertainty of 9% is not included in the error bars of the data points, but was taken into account for the fit. (This is the same for all cross sections.)
\[ \sigma \propto (Q^2 + M^2)^n \]

Results in agreement with previous measurements as well as with General Parton Model and Dipole Model.
<table>
<thead>
<tr>
<th>Par.</th>
<th>ZEUS(prel)</th>
<th>PDG</th>
</tr>
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<tbody>
<tr>
<td>$M_{\rho}$</td>
<td>$771 \pm 2^{+2}_{-1}$</td>
<td>$775.49 \pm 0.34$</td>
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<tr>
<td>$\Gamma_{\rho}$</td>
<td>$155 \pm 5 \pm 2$</td>
<td>$149.4 \pm 1$</td>
</tr>
<tr>
<td>$M_{\rho'}$</td>
<td>$1360 \pm 20^{+20}_{-30}$</td>
<td>$1465 \pm 25$</td>
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<tr>
<td>$\Gamma_{\rho'}$</td>
<td>$460 \pm 30^{+40}_{-45}$</td>
<td>$400 \pm 60$</td>
</tr>
<tr>
<td>$\beta$</td>
<td>$-0.27 \pm 0.02 \pm 0.02$</td>
<td></td>
</tr>
<tr>
<td>$M_{\rho''}$</td>
<td>$1770 \pm 20^{+15}_{-20}$</td>
<td>$1720 \pm 20$</td>
</tr>
<tr>
<td>$\Gamma_{\rho''}$</td>
<td>$310 \pm 30^{+25}_{-35}$</td>
<td>$250 \pm 100$</td>
</tr>
<tr>
<td>$\gamma$</td>
<td>$0.10 \pm 0.02^{+0.02}_{-0.01}$</td>
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