Elastic Vector Meson Production and DVCS at HERA

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For the H1 and ZEUS Collaborations

New Results in

- $\phi$ electroproduction
- $J/\psi$ photo- and electroproduction
- DVCS

Lisboa, Portugal
21-27 July, 2005
Regge Approach: "Soft Pomeron" exchange

- Slow rise of $\sigma$ with increasing $W$
  \[ \sigma \propto W^{0.22} \]
- Shrinkage of forward peak with increasing $W$
  \[ \frac{d\sigma}{dt} \propto e^{bt} \left( W/W_0 \right)^{4(\alpha'_{IP}(t)-1)} \]
  \[ \alpha'_{IP}(t) = \alpha'_{IP}(0) + \alpha'_{IP} t \quad (\alpha'_{IP} = 0.25) \]
  \[ b = b_0 + 4 \alpha'_{IP} \ln \left( W/W_0 \right) \]

S-Channel Helicity Conservation, SCHC

pQCD Approach: Exchange of Gluons

- Steep rise of $\sigma$ with increasing $W$
  increasing gluon density in the proton at small $x$
  \[ (xW^2 \approx Q^2) \]
- No (or little) shrinkage of the diffractive peak
- SCHC violation

pQCD needs a hard scale: $Q^2$, $M_{VM}^2$, $t$, $(Q^2 + M_{VM}^2)$

Elastic Vector Meson Production

$Q^2$ Photon Virtuality

Photoproduction: $Q^2 \sim 0$
(Mom. transfer at $p - \text{vertex}$)$^2$
large $|t| \Rightarrow$ Proton dissociates

$W$ CM – energy of $\gamma p$ – system
DATA

1998-2000 $e^{\pm}p$

65.1 pb$^{-1}$

$\sim$4000 events

$\phi \rightarrow K^+K^-$

$2 < Q^2 < 70$ GeV$^2$  \( \langle Q^2 \rangle = 5 \text{ GeV}^2 \)

$35 < W < 145$ GeV

$|t| < 0.6$ GeV$^2$

(suppress $p-dissociation$ bkgr.)
EXCLUSIVE ELECTROPRODUCTION OF $\phi$ MESONS

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

Fit in bins of $Q^2$

Weak dependence on $Q^2$

$b \sim 5 - 6 \text{ GeV}^{-2}$

relate to radii of scattering particles

$b \propto R_p^2 + R_{q\bar{q}}^2 \quad R_p^2 \sim 4 \text{ GeV}^{-2}$

$$\sigma(W) \sim W^\delta$$

Fit in bins of $Q^2$

No dependence on $Q^2$

$\delta \sim 0.4$

$\phi$ production: Data confirm transition from soft to hard scattering
**Exclusive Electroproduction of $\phi$ Mesons**

\[
d\sigma/d|t| \sim W^\delta
\]

\[
= W^{4(\alpha(t)-1)}
\]

Fit in bins of $|t|$

Extract the “effective” trajectory

\[
\alpha(t) = 1.10 + (0.08 \pm 0.09 \pm 0.08) \, t
\]

Value of $\alpha'$ smaller than the “soft pomeron” value (0.25)
Decay Angular Distributions

Provide information about the Spin Density Matrix Elements

\( r_{00}^{04} \): probability to produce longitudinal \( \phi \), from either transverse or longitudinal \( \gamma^* \)

\[
d\sigma/d\cos\theta^* \propto 1 + r_{00}^{04} + (1 - 3r_{00}^{04}) \cos^2 \theta^*
\]

Assuming SCHC,

\[
R = \frac{\sigma_L}{\sigma_T} = \frac{1}{\epsilon} \frac{r_{00}^{04}}{1 - r_{00}^{04}}
\]

\( \sigma = \sigma_T + \epsilon \sigma_L \)

(\( \epsilon \approx 0.99 \))

\( \sigma_L \) and \( \sigma_T \) separately measurable
$R$ increases with increasing $Q^2$.

$Q^2$ dependences different for $\sigma_L$, $\sigma_T$.

At large $Q^2$, $\sigma_L$ dominates over $\sigma_T$.

pQCD models * agree with trend of data.

* Forshaw, Shaw, Martin, Ryskin, Teubner

**Data**

1999-2000 \( 55 \text{ pb}^{-1} \)

**Electroproduction:**
- \( 2 < Q^2 < 80 \text{ GeV}^2 \) \( \langle Q^2 \rangle = 8.9 \text{ GeV}^2 \)
- \( 40 < W < 160 \text{ GeV} \)
- \( J/\psi \rightarrow \mu^+\mu^- \)

**Photoproduction:**
- \( 40 < W < 305 \text{ GeV} \)
- \( J/\psi \rightarrow \mu^+\mu^- \), \( e^+e^- \)
- **Topologies in detector:**
  - Track-Track, Track-Cluster, Cluster-Cluster

**All samples:** \( |t| < 1.2 \text{ GeV}^2 \)
(Suppress p-dissociation background)
Exclusive Photo- and Electroproduction of $J/\psi$ Mesons

$W$—dependence

Fit $\sigma(W) \propto W^{\delta}$

in photoproduction and in bins of $Q^2$

No $Q^2$—dependence, $\delta \sim 0.75$

$J/\psi$ “pointlike” already in photoproduction

Data sensitive to Gluon distribution in proton
**W − t—dependence**

2-dimensional fits,

\[ d\sigma/dt(W, t) \propto e^{b_0t} W^\delta \]

where \( \delta = 4(\alpha(t) - 1) \)

\[ \alpha(t) = \alpha_0 + \alpha' t \]

“effective” Pomeron trajectory

1-dimensional fits,

\[ d\sigma/dt \propto W^\delta \text{ in bins of } t \]

(curves in figures)

\[ d\sigma/dt \propto e^{b(W)t} \text{ in bins of } W \]
“effective” Pomeron trajectory

Photoproduction:
\[ \alpha(t) = 1.224 \pm (0.164 \pm 0.028 \pm 0.030)t \]

Electroproduction:
\[ \alpha(t) = 1.183 \pm (0.019 \pm 0.139 \pm 0.076)t \]

Within errors, the trajectories are similar

Shrinkage: Seen in Photoproduction

Cf. alternative \( d\sigma/dt \propto e^{b(W)t} \)
\[ \implies b \text{ increases with } W \]
Helicity Analysis

\(Q^2\) — and \(t\) — dependence of Spin Density Matrix Elements

Data agree with S-Channel Helicity Conservation

\[\Rightarrow\text{ Use } r_{00}^{04}\text{ to extract }\sigma_L\text{ and }\sigma_T\]
At large $Q^2$, $\sigma_L \sim \sigma_T$

**MRT**

pQCD predictions:

Separate calculation of $\sigma_T$ and $\sigma_L$

Good description of data

At large $Q^2$, data sensitive to Gluon distribution

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**Martin, Ryskin, Teubner**

*EPS HEP2005, Lisboa, Portugal, July 21-27, 2005*
**Deeply Virtual Compton Scattering**

**DVCS:** \(e + p \rightarrow e + p + \gamma\)

- Simplest scattering process
- Fully calculable in pQCD since no Vector meson Wave-function
- Skewedness \(\xi\) non-zero since \(\gamma^*\)-mass non-zero
- Access to GPDs (Generalized Parton Distributions)
- Access to Scattering Amplitude
  - via Interference with the Bethe-Heitler process
  - via Asymmetry measurements with different beam charges and polarizations
Deeply Virtual Compton Scattering

**DATA**

1996-1997, 1999-2000  \( e^+ p \)
\[ E_{e^+} = 27.6 \text{ GeV}, \]
\[ E_p = 820, 920 \text{ GeV} \]
\[ 11.5, 35 \text{ pb}^{-1} \]
\[ \sim 1240 \text{ events} \]
\[ 2 < Q^2 < 80 \text{ GeV}^2 \] (1996-1997)
\[ 4 < Q^2 < 80 \text{ GeV}^2 \] (1999-2000)
\[ 3 < W < 140 \text{ GeV} \]
\[ |t| < 1 \text{ GeV}^2 \]

**DVCS sample:**  \( e^+ \) in SpaCal, \( \gamma \) in LAr

**BH Control sample:**  \( \gamma \) in SpaCal, \( e^+ \) in LAr

\[ \sigma = \sigma_{DVCS} + \sigma_{BH} + I_{BH,DVCS} \]

\( \sigma_{BH} \) calculable, using proton form factors: subtract

\( I \) depends on angle \( \phi \): here \( I \sim 0 \)

\[ \Rightarrow \sigma_{DVCS} \text{ can be measured} \]
Deeply Virtual Compton Scattering

$t -$ dependence
Measured for the first time
Combined value at $\langle Q^2 \rangle = 8 \text{ GeV}^2$:

$$b = 6.02 \pm 0.35 \pm 0.39 \text{ GeV}^{-2}$$

Model calculations: Normalisation possible!
(Previously used $b = 7 \pm 2 \text{ GeV}^{-2}$)

$W -$ dependence
Steep, similar to $J/\psi$
Combined value at $\langle Q^2 \rangle = 8 \text{ GeV}^2$:

$$\delta = 0.77 \pm 0.23 \pm 0.19$$
Deeply Virtual Compton Scattering

pQCD Calculations

- NLO leading twist, hard scale $Q^2$
- Use measured $t$: normalisation possible
- Factorize into hard scattering and non-perturbative GPDs
- GPDs depend on
  - Longitudinal momentum fraction $\xi$
  - Momentum exchange at $p-$vertex, $t$
- Starting point of GPDs: normal PDFs, here CTEQ6, MRST2001
- Dynamic generation of $\xi$; No intrinsic Skewedness

Fair description of data
Potential sensitivity to GPDs

* Freund, McDermott, Strikman
SUMMARY

Elastic Vector Meson Production

- New Measurements:
  - Electroproduction of $\phi$
  - Photo- and Electroproduction of $J/\psi$,
  - as function of $W$, $Q^2$ and $t$

- “Effective” trajectories determined from $W − t$—dependence: harder than “soft Pomeron”

- $\sigma_L$ and $\sigma_T$ measured via Helicity Analysis

- pQCD and $Q^2$—dependence: Fair descriptions of $J/\psi$ and $\phi$ data

DVCS

- New measurement of the cross section, as function $W$, $Q^2$ and $t$
- First measurement of $t$—dependence: $\Longrightarrow$ Normalisation of models possible
- Data potentially sensitive to GPDs: pQCD NLO calculations agree well with measurements
- Colour Dipole models also describe the data
Colour Dipole Model Calculations

- Factorize DVCS amplitude:
  - $\gamma^*$ fluctuates to $q\bar{q}, q\bar{q}g...$
  - dipole interacts with proton
- Probe transition soft $\rightarrow$ hard interactions
- $\sigma_{\text{dipole}}$ modelled in several ways

Fair description of data

Donnachie, Dosch    Favart, Machado