Exclusive photoproduction at HERA

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exclusive diffraction

experimentally: very clean process in wide kinematic range

| VM  | Vector Meson or $\gamma$ | $\rho, \omega, \phi, J/\psi, \psi', \Upsilon$ |
| Q$^2$ | photon virtuality | $Q^2 = -q^2 = -(k - k')^2$ |
| W   | c.m. energy of $\gamma p$ system | $W = (q + p)^2$ |
| t   | (4-mom. transfer)$^2$ at p-vertex | $t = (P - P')^2$ |

$\rightarrow$ **VM at HERA**: transition between soft and hard regime

$\rightarrow$ simultaneous study of **different scales**: $Q^2, |t|, M_{VM}^2$
diffractive vector meson production

VM = $q\bar{q}$ dipol, exchange of $\geq 2$ gluons (color singlet - QCD Pomeron)

large $Q^2, M_{VM}^2$ or $|t| \Rightarrow$ small $q\bar{q}$ and interaction size

hard interaction $\Rightarrow$ perturbative QCD applicable, factorization holds

'Exclusive' VM electroproduction:
- steep rise of $\sigma(W)$, $\sigma \sim \frac{\alpha_s(Q^2)}{Q^2} [xg(x, Q^2)]^2, x \approx Q^2/W^2$
- universal $t$ dependence: $\sim \exp^{-b_2g|t|}, b_2g \sim 4-5\text{ GeV}^{-2}$ and $\alpha_{FP}' \approx 0$
- possible SCHC violation

'Proton dissociative' VM photoproduction;
- $d\sigma/d|t| \sim |t|^{-n}$
- 2-gluon exchange - no energy dependence
gluon ladder exchange – energy dependence:  
  - weak (DGLAP)
  - strong (BFKL)
vector mesons in photoproduction ($Q^2 = 0 \text{ GeV}^2$)

$$\gamma p \rightarrow VM + p \ (VM = \rho, \phi, \omega, J/\psi, \psi, \Upsilon)$$

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

Low mass ($\rho, \phi, \omega$)
- $M_{VM}^2 \approx 1 \text{ GeV}^2$
- no hard scale
- weak $W$ dependence

High mass ($J/\psi, \psi, \Upsilon$)
- hard scale
- strong $W$ dependence

- The larger $M_{VM}$ the harder process (steeper $W$ dependence)
- Vector meson mass sets hard scale
**production – energy dependence**

accepted by Phys. Lett. B (Ref. No. PLB-D-09-00488)

- **pQCD models – W-slope prediction:**
  - FMS LO: \( \delta \approx 1.7 \)
  - MNRT NLO: \( \delta \approx 1.2 \)
  - data: \( \delta = 1.2 \pm 0.8 \)

**Sensitivity to:**
- (RSS model) vector meson wave function: data seem to prefer Gauss to Coulomb
- hard scale value: in IKS model scale is between \( 1.3 < \mu < 7 \) GeV

**ZEUS**

- **ZEUS 468 pb\(^{-1}\)**
- \( Q^2 < 1 \) GeV\(^2\)
- \( 60 < W < 220 \) GeV

**FMS – Frankfurt, McDermott, Strikman (CTEQ4L)**
**MNRT NLO – Martin, Nockles, Ryskin, Teubner**
**IKS – Ivanov, Krasnikov, Szymanowski**
**RSS – Rybarska, Schaefer, Szczurek**

D.Szuba, 18.07.09
\( \delta (Q^2 + M_{VM}^2) \)

Large \( Q^2 \) and \( M_{VM} \) sets hard scale

Steep slope observed for all VM in the presence of hard scale

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

\( \delta \) rises with \( Q^2 + M_{VM}^2 \)

Transition from soft to hard regime with increasing of hard scale
large $|t|$ domain

Diffractive photoproduction of J/$\psi$ mesons with large momentum transfer at HERA (ready for publication)

\[ \gamma p \rightarrow J/\psi Y \]

ZEUS

\[ Q^2 \sim 0 \]
\[ 2 < |t| < 20 \text{ GeV}^2 \]
\[ 30 < W < 160 \text{ GeV} \]
\[ z > 0.95 \]


\[ z = \frac{P \cdot \psi}{P \cdot q} \]
\[ y_P = \frac{P \cdot (P - P')}{{q'} \cdot P} \]
\[ z = 1 - y_P \]

pQCD models:

\[ \frac{d\sigma}{dt} \sim t^{-n} \]
\[ \sigma \sim W^\delta \]

H1

\[ Q^2 \sim 0 \]
\[ 4 < |t| < 36 \text{ GeV}^2 \]
\[ 175 < W < 247 \text{ GeV} \]
\[ y_P < 0.05 \]
large $|t|$: $|t|$-dependence

- $d\sigma/d|t|$ falls steeply with $|t|
- pQCD expectation: $\frac{d\sigma}{d|t|} \sim |t|^{-n}$

$H1$ Diffractive Scattering of $\gamma$ at large $|t|$
energy dependence and Pomeron trajectory

soft pomeron (DL):
\[ \alpha_{IP}(t) = 1.08 + 0.25t \]

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

\[ \frac{d\sigma}{dt} \propto \left( \frac{W}{W_0} \right)^{\delta} \]

\[ \alpha_{IP}(t) = \alpha(0) + \alpha_{IP} \cdot t \]

\[ \alpha_{IP}(0) = 1.084 \pm 0.031^{+0.025}_{-0.018} \]

\[ \alpha_{IP}' = -0.014 \pm 0.007^{+0.004}_{-0.005} \text{ GeV}^{-2} \]

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energy dependence and Pomeron trajectory

A Measurement of the Pomeron Trajectory based on Elastic Rho Photoproduction (H1 preliminary)

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

Regge theory inspired

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

Soft pomeron (DL):

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

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\[ \alpha_{IP}(0) = 1.0871 \pm 0.0026 \pm 0.0030 \]

\[ \alpha'_{IP} = 0.126 \pm 0.013 \pm 0.012 \text{ GeV}^{-2} \]
large $|t|$: $d\sigma/d|t|$ vs theory

- BFKL LL calculations steeper than data
- DGLAP work up to $|t|=5 \text{ GeV}^2$ but later falls slower than data
- FSZ gives good description up $|t|=12 \text{ GeV}^2$


DGLAP–GLMN LL:

BFKL LL – EMP LL:

FSZ:
large $|t|$: $\sigma$ vs theory

- DGLAP (GLMN LL) describes data very well up to $|t|=5$ GeV$^2$
- BFKL (EMP LL, $\alpha_s=0.16$) and FSZ are too steep

- BFKL describes $W$ dependence

H1 Diffractive Scattering of $\gamma$ at large $|t|

\[
\delta = 2.73 \pm 1.02^{+0.56}_{-0.78}
\]
summary

• New measurements of vector mesons and high-\(p_t\) photons
• The \(\Upsilon\) cross section rises as \(W^\delta\) and \(\delta\) grows with the universal hard scale \(Q^2+M^2_{\text{VM}}\)
• pQCD motivated fit \(d\sigma/dt \sim t^{-n}\) for large \(|t|\) does not describe data in the full kinematic range (J/\(\psi\))
• Effective Pomeron trajectory has smaller slope than that extracted from soft hadron-hadron scattering for large \(|t|\) (J/\(\psi\)) as well as for elastic \(\rho\) production
• None of the models in large \(|t|\) domain can reproduce the data in the full kinematic range (J/\(\psi\) / \(\gamma\))