Deeply virtual Compton scattering and prompt photon production at ZEUS and H1 experiments

International Conference on the Structure and Interactions of the Photon
Warsaw, Poland, 31 August - 4 September, 2005
**Prompt Photon Production at HERA**

\[ e + p \rightarrow e + \gamma + X \]

- **DIRECT (LO)**
  - \( Q^2 \)
  - Point like coupling to quark
    - Direct probe of hard process
    - Test of QCD
  - Small (No) hadronization effects
    - (In contrast to jet production)
- **RESOLVED (LO)**
  - \( (-\sim) \) Sensitivity to proton and photon PDFs.
  - Two signatures:
    - Inclusive prompt photon
    - Prompt photon + jet

Photon 2005, Warsaw, 01/09/2005

Xavier Janssen – p.2/18
**Prompt \( \gamma \) - Data Selection**

**Photoproduction:** H1 + ZEUS \( Q^2 < 1 \text{ GeV}^2 \)  
**DIS:** ZEUS \( Q^2 > 35 \text{ GeV}^2 \)

- Isolated photon candidate:
  - \( E_T^\gamma > 5 \text{ GeV} \)
  - \(-1 \ (-0.7) < \eta^\gamma < 0.9 \)  
  - no associated track
  - cone \( R = \sqrt{\Delta \Phi^2 + \Delta \eta^2} = 1 \) with \( E_T^\gamma / E_T^{\text{cone}} > 0.9 \)

- At least 2 tracks:
  - remove DVCS+Bethe-Heitler
  - reduce fragmentation proc.

- For prompt \( \gamma + \text{Jet sample} \):
  - \( E_T^{\text{jet}} > 4.5 (6) \text{ GeV} \)
  - \(-1 \ -1.5 < \eta^{\text{jet}} < 2.3 \)  
  - \(-1.5 < \eta^{\text{jet}} < 1.8 \)
Experimental difficulty: photons from hadronic background ($\pi^0$, ...) → Signal extraction on basis of shower shape in calorimeters
• Agreement between H1 and ZEUS

• **MC:** **PYTHIA** (**HERWIG**): shape OK but 30 (40) % too low
  Multiple interactions and hadronization corr. reduce \( \sigma \)
  (**cf Isolation cut**)

• **NLO pQCD:** Fontannaz, Guillet & Heinrich / Krawczyk & Zembrzuski
  → good shape description but too low by 30 %
Prompt $\gamma + \text{Jet} - \text{Photoproduction}$

- **NLO pQCD:**
  - Good description of shapes and normalisation
  - Jet requirement result in a better description and smaller LO/NLO difference than in inclusive case
- Multiple interactions and hadronization corr.: Smaller effect than in inclusive case
**Prompt $\gamma$ + Jet - Photoproduction**

- **Prompt photon + jet**
  - **c)**
    - Fractional part of incoming photon energy taking part in interaction
    - $x_\gamma$  
    - $x_p$  
    - Fraction of proton's momentum involved in hard scattering

- **NLO pQCD + Multiple interactions describe the data**
- **MI and h.c. matter for resolved $\gamma$ contribution ($x_\gamma < 0.5$)**

---

Photon 2005, Warsaw, 01/09/2005  
Xavier Janssen – p.7/18
- **PYTHIA (HERWIG)**: factor 2 (8) too low
- $E_T^\gamma$ well described by PYTHIA and PYTHIA
- Poor description of $\eta^\gamma$ by PYTHIA
- Wide angle QED bremsstrahlung not included in MCs
**Prompt $\gamma + $Jet - DIS**

- **NLO pQCD (Kramer-Spiesberger):** provides good description except maybe at low $E_T^\gamma$ (but large errors)
- Large contribution from wide angle bremsstrahlung needed
Deeply Virtual Compton Scattering

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

- Factorization theorem:
  - First Diffractive process fully calculable in QCD
- No VM wave function uncertainty
- Access to Generalized Parton Distributions (GPDs)

Diffraction: \( e + p \rightarrow e + X + Y \)
Deeply Virtual Compton Scattering

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

- Factorization theorem:
  \[ \rightarrow \text{First Diffractive process} \]
  fully calculable in QCD

- No VM wave function uncertainty

- Access to Generalized Parton
  Distributions (GPDs)
Deeply Virtual Compton Scattering

\[ e + p \longrightarrow e + \gamma + p \]

- Factorization theorem:
  - First Diffractive process fully calculable in QCD
  - No VM wave function uncertainty
  - Access to Generalized Parton Distributions (GPDs)

- Interference with Bethe-Heitler which is a pure QED process.
  - Access to Amplitudes in Asymmetries
DVCS - QCD predictions

\[ H^{q,g}(x, \xi, t) \xrightarrow{\xi \to 0} q(x), g(x) \]
\[ \tilde{H}^{q,g}(x, \xi, t) \xrightarrow{t \to 0} \Delta q(x), \Delta g(x) \]

+ E, \tilde{E}: no PDF equivalent

GPDs encodes info about transverse motion of partons and about their correlations

At low \(x\), DVCS is mainly sensitive to \(H^g(x, \xi, t)\)

NLO leading twist calcl. by A. Freund and M. McDermott
**DVCS - Data Selection**

**γ sample**

**DVCS + Bethe-Heitler**

<table>
<thead>
<tr>
<th></th>
<th>H1</th>
<th>ZEUS</th>
</tr>
</thead>
<tbody>
<tr>
<td>$E_1 &gt;$</td>
<td>15 GeV</td>
<td>10 GeV</td>
</tr>
<tr>
<td>$p_{T_2} &gt;$</td>
<td>1 GeV</td>
<td>3 GeV</td>
</tr>
<tr>
<td>$E_2 &gt;$</td>
<td>0.5 GeV</td>
<td>0.2 GeV</td>
</tr>
<tr>
<td>$E_3 &lt;$</td>
<td>no track, Fwd</td>
<td>no track</td>
</tr>
<tr>
<td>Lumi</td>
<td>$46.5 \text{ pb}^{-1}$ ($e^+$)</td>
<td>$95 \text{ (e$^+$) pb}^{-1}$ $16.7 \text{ (e$^-$) pb}^{-1}$</td>
</tr>
</tbody>
</table>
**DVCS - Data Selection**

**Control sample**
Mainly Bethe-Heitler

<table>
<thead>
<tr>
<th>H1</th>
<th>ZEUS</th>
</tr>
</thead>
<tbody>
<tr>
<td>$E_1 &gt;$</td>
<td>15 GeV</td>
</tr>
<tr>
<td>$p_{T_2} &gt;$</td>
<td>1 GeV</td>
</tr>
<tr>
<td>$E_2 &gt;$</td>
<td>3 GeV</td>
</tr>
<tr>
<td>$E_3 &lt;$</td>
<td>0.5 GeV</td>
</tr>
<tr>
<td>elast.</td>
<td>no track, Fwd</td>
</tr>
<tr>
<td>Lumi</td>
<td>46.5 $pb^{-1}$ ($e^+$)</td>
</tr>
<tr>
<td></td>
<td>95 ($e^+$) $pb^{-1}$</td>
</tr>
<tr>
<td></td>
<td>16.7 ($e^-$) $pb^{-1}$</td>
</tr>
</tbody>
</table>

---

Photon 2005, Warsaw, 01/09/2005

Xavier Janssen – p.12/18
DVCS - Control Plots

ZEUS

- Control sample:
  Well described by MC
  → Detector understood

- $\gamma$ sample:
  Good description by BH + DVCS MC

→ DVCS cross section:
  1. Subtract Bethe-Heitler
     \[ \int d\phi \text{ Interf.} = 0 \]
  2. $\sigma_{ep} \rightarrow \sigma_{\gamma^*p}$ ( / flux factor)
First measurement of $t$-dependence

Exponential fit in $t$: $\frac{d\sigma}{dt} \propto \exp(-bt)$

$\rightarrow b = 6.02 \pm 0.35 \pm 0.39 \text{ GeV}^{-2}$ at $Q^2 = 8 \text{ GeV}^2$

No $Q^2$ dependence observed within errors
**DVCS - $Q^2$ and $W$ dependences**

**Fit in $Q^2$:** $\propto (Q^2)^{-n}$

$n = 1.54 \pm 0.09 \pm 0.04$

**W dependence for 2 $Q^2$ values**

**Fit:** $\propto W^\delta$

$\delta = 0.77 \pm 0.23 \pm 0.19$

→ indicates hard regime
cf. $J/\psi$ production
**DVCS - Comparison to QCD predictions**

H1 and ZEUS data are in agreement.

Comparison to NLO QCD:
- Band width reduced by $b$ slope measurement
- Good description by NLO QCD calculations.
- Sensitivity to GPDs parametrization?
**DVCS - ... and to Color Dipole Models**

In proton rest frame:

\[ \gamma^* \] fluctuates in \( q\bar{q} + q\bar{q}g + \ldots \)

\[ A = \int dR^2 \, dz \, \Psi^{in} \sigma_{dipole} \Psi^{out} \]

- \( \Psi^{in} \) and \( \Psi^{out} \) calculable
- \( \sigma_{dipole} \) modeled

**Donnachie-Dosch:** hard + soft \( IP \)


**Favart-Machado:**

GBW Saturation model


→ Describe shape and norm.

→ F-M slightly better (when including DGLAP)

Photon 2005, Warsaw, 01/09/2005
CONCLUSION

DVCS cross sections measurements versus $Q^2$, $W$ and $t$:

- First $t$ slope measurement $\rightarrow$ Constraint theory normalisation
- NLO QCD predictions based on GPDs in agreement with data
- Sensitivity to different GPD models
- Color Dipole models also in agreement with data

Prompt photon production

- Small hadronisation effects $\rightarrow$ Alternative to Jets to study QCD
- PYTHIA and HERWIG undershoot all measurements
- NLO pQCD undershoot inclusive Prompt $\gamma$ photoproduction
- (Prompt $\gamma$ + Jet) data are better described by NLO pQCD