DVCS and prompt photon production at HERA

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ULB

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Introduction

→ First QCD absolute prediction in Diffraction

→ No VM wave function uncertainty

→ Access to GPDs

→ Interference with Bethe-Heitler (purely QED process) - Access to full process amplitude

→ Direct probe of the hard process - interesting test of QCD

→ Small hadronisation uncertainty

→ Good energy measurement

→ Two signatures: w/wo jet

(→) sensitivity to proton and photon PDFs
DVCS - QCD predictions

- Fully calculable in QCD

LO

\[ e \rightarrow \gamma \rightarrow e \]
\[ x - \xi \rightarrow x + \xi \]
\[ p \rightarrow p \]

NLO

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

- NLO leading twist (+ twist three) calc. by A. Freund and M. McDermott

**DGLAP region:** \(|x| > \xi\)
\[ \mathcal{H}^q(x, \xi, t; \mu^2) = q(x; \mu^2) e^{-b|t|} \]
q singlet

\[ \mathcal{H}^g(x, \xi, t; \mu^2) = x g(x; \mu^2) e^{-b|t|} \]
gluons

**ERBL region:** \(|x| < \xi\)

MRST2001 and CTEQ6

\[ \rightarrow Q^2 \text{ and } \xi \text{ generated dynamically} \]

\[ b \text{ from the data} \]
Colour Dipole Models

In the proton rest frame

- $\gamma^*$ fluctuates in $q\bar{q} + q\bar{q}g + ...$

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

- $\psi^{in}$ and $\psi^{out}$ calculable

- $\sigma_d$ is modeled

Donnachie-Dosch: hard + soft $IP$

Favart-Machado: GBW saturation model applied to DVCS (with and without DGLAP evolution: BGBK)

- Complementary to pure QCD (Breit frame) approach, to test non-pert $\rightarrow$ pert. transition and saturation models.
Analysis strategy

- **DVCS**

\[ e^+ \rightarrow p \]

\[ \gamma\text{-sample} \]

- **Bethe-Heitler**

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ZEUS - Control and Signal samples

Control-sample ⇐
Well known cross section
⇒ detector response is understood

γ-sample ⇐
BH + DVCS (MC) good description

DVCS ⇐
After BH subtraction: pure DVCS
\( \sigma_{ep} \rightarrow \sigma_{\gamma^* p} \) correcting by the flux factor.
First measurement of the $t$ slope

combined samples:

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

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

Fit $W^\delta$:

indication of a hard regime (comparable to $J/\Psi$)
$\sigma(\gamma^* p \rightarrow \gamma p)$ [nb]

**H1-ZEUS Comparison**

- Agreement

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

- $n = 1.54 \pm 0.09 \pm 0.04$
- $n$ smaller than for VM ($n(\rho) = 2.60 \pm 0.04$)

**Comparison to NLO QCD:**

- Band width provided by $b$ measurement.

- Good description by QCD-NLO calculations

- No need for intrinsic skewing
Comparison to Dipole Models:

- Good normalisation and shape description

- Improvement in FM when DGLAP evol. included

- Still improved if $b(Q^2)$ used as observed for $\rho$

direct ≈ resolved contribution

Multiple int. spoil isolation cut → reduced σ.

NLO pQCD (Fontanaz, Guillet, Heinrich / Krawczyk, Zembruski): good shape desc. but Norm. too low 30-40%

MC: shape OK but Normalisation to low by 40-50%

142 < W < 266 GeV

$Q^2 < 1 \text{ GeV}^2$

$\mathcal{L} = 105 \text{ pb}^{-1}$
Prompt Photon with Jet in Photoproduction

- NLO pQCD: good description of shapes and better descrip. of Normalisation.

- Multiple interactions more important at low $x_\gamma$ (resolved contribution).

- NLO less important then for inclusive.

Same cuts + $E_T^{jet} > 4.5$ GeV

DESY-04-118
MC PYTHIA and HERWIG factor 2 and 8 too low (not shown).

65% of photon emitted by electron (low rapidity)

Hadronisation corrections expected to be 30-40%.

NLO pQCD (Kramer, Spiesberger): at parton level
good description except at low $E_T^\gamma$ (large stat error) and in most forward direction.

$Q^2 > 35$ GeV$^2$
$E_T^{jet} > 6$ GeV
$-1.5 < \eta_{jet} < 1.8$
$\mathcal{L} = 121$ pb$^{-1}$

Conclusions

Prompt Photon: study of pQCD

- no hadronisation of the photon, good energy measurement.
- NLO QCD calculation in reasonable agreement but a bit too low Norm. except in jet case in photoproduction.
- PYTHIA and HERWIG MC always undershoot the data.

DVCS cross sections as a function of $Q^2$, $W$ and $t$ have been measured.

- First $t$ slope measurement. Allows absolute theoretical prediction.
- in good agreement with NLO QCD predictions, based on GPD model: no intrinsic skewing.
- set constrains on gluon and sea GPDs.
- in agreement with different dipole model predictions.
## Compl. Prompt Photon MC and PDFs

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DVCS - Cross Section Measurement

- $e - p$ Cross Section extraction

$$\frac{d^3\sigma_{bin}[ep \rightarrow e\gamma p]}{dQ^2 \, dW \, dt} = \frac{(N_{bin} - N_{BH} - N_{p.dis.})}{\epsilon \cdot A \cdot \Delta Q^2 \cdot \Delta W \cdot \Delta t \cdot L} \cdot (1 + \delta_{rad})$$

- $ep \rightarrow \gamma p$ Cross Section (BH subtraction and photon flux factor)

$$\frac{d^3\sigma[ep \rightarrow e\gamma p]}{dy \, dQ^2 \, dt} (Q^2, y, t) = \Gamma(Q^2, y) \frac{d\sigma[\gamma^*p \rightarrow \gamma p]}{dt} (Q^2, y, t),$$

- Main corrections and systematics (up to):

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<td>Proton diss background:</td>
<td>16 ± 8%</td>
<td>22 ± 4%</td>
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<td>$\Delta$ acceptance &amp; bin cent. corr, cuts:</td>
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<td>10%</td>
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<td>Energy scale uncertainty:</td>
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