Prompt photon production in deep inelastic scattering at HERA

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The ZEUS Detector at HERA

Protons: 920 GeV
Electron/Positrons: 27.5 GeV

Data
• HERA II period (2004-2007)
• Integrated Luminosity: 326 pb⁻¹

MC
• PYTHIA (signal)
• ARIADNE (background)
Deep inelastic scattering

• Kinematics:
  • $Q^2 = -q^2$ – virtuality 4-momentum transfer
  • $y = \frac{P \cdot q}{P \cdot k}$ – inelasticity measure fraction of the lepton energy lost in the interaction
  • $x = \frac{Q^2}{2P \cdot q}$ – Bjorken scaling momentum fraction carried by the incoming parton

• DIS:
  • $Q^2 > 1 \text{ GeV}^2$
  • Found electron

Neutral current scattering

\[ Q^2 = sxy \]
\[ \sqrt{s} = 318 \text{ GeV} \]
Motivation

• A study of prompt photons can give a check of the proton's parton distribution functions.
• Photons are a possible background to new physics processes
• A study of the dynamics of prompt photon emission can be used to probe different theoretical models such as the $k_t$-factorisation model and pQCD approaches
• It is interesting to know how dynamics changes with virtuality scale
Prompt photons

- Photons which are produced promptly in the collision - before quarks and gluons form hadrons

**QQ - photons**
- Prompt photons are emitted from a quark as part of hard process

**LL - photons**
- Photon is radiated from an incoming or outgoing lepton
Event selection

- Prompt photon selection
  - $4 < E_T^\gamma < 15$ GeV
  - $-0.7 < \eta_\gamma < 0.9$ – in BCAL
  - $E_{EMC} / (E_{EMC} + E_{HAD}) > 0.9$
  - $\Delta R(\eta, \phi) < 0.2$
  - $E_\gamma / E_{jet with \gamma} > 0.9$

- Jet selection
  - $E_T^{jet} > 2.5$ GeV
  - $-1.5 < \eta_{jet} < 1.8$
  - Jet with $E_T^{jet}_{T,\text{max}}$

- Some Kinematics:
  - $10 < Q_{el}^2 < 350$ GeV$^2$
  - $E_{e,corr} > 10$ GeV
  - $140^\circ < \theta_{el} < 180^\circ$
  - $35 < E - p_z < 65$, GeV

BCAL is finely segmented in the Z direction
A previous publication (Physics Letters B 715 (2012) 88-97) has covered $x$, $Q^2$, $E_T^\gamma$, $\eta_\gamma$, $E_T^{jet}$ and $\eta_{jet}$.
Study of photon-jet and photon-electron variables

- \( x_\gamma = \frac{\sum_{\text{jet,}} \gamma (E-p_z)}{2y_f B E_e} \)
- \( x_p = \frac{\sum_{\text{jet,}} \gamma (E+p_z)}{2E_p} \)
- \( \Delta \eta = \eta_{\text{jet}} - \eta_\gamma \)
- \( \Delta \phi = \phi_{\text{jet}} - \phi_\gamma \)
- \( \Delta \phi_{e,\gamma} = \phi_e - \phi_\gamma \)
- \( \Delta \eta_{e,\gamma} = \eta_e - \eta_\gamma \)

A similar kind of analysis was previously done for photoproduction \((Q^2 < 1 \text{ GeV}^2)\)

Energy-weighted mean width of the electromagnetic shower (cluster) in calorimeter relative to its centroid:

\[
\langle \delta Z \rangle = \frac{\sum_i |z_i - z_{\text{cluster}}| \cdot E_i}{l_{\text{cell}} \sum E_i}
\]

- Improved the fit
- Corrected signal shape
Summary of uncertainties

• Uncertainties sources:
  • $\Delta \mathcal{L}$ – not included
  • $\Delta N$ – statistical errors on QQ and LL MC samples
  • $\Delta Acc$ – acceptance uncertainty, $\sim 3$-4\% effect
    (max 22\% in high $x_p$)
  • $\Delta a$ – uncertainty of fit parameter, $\sim 1$\% effect

• Typical mean statistical uncertainty is 13\% with maximum 26\% for first bin of $x_\gamma$ and last bin of $x_p$

• Typical mean systematic uncertainty is 10\% with maximum 50\% in last bin of $x_p$
Cross Sections

• For a given observable Y, the production cross section:

\[ \frac{d\sigma}{dY} = \frac{N(\gamma_{QQ})}{A_{QQ} \cdot \mathcal{L} \cdot \Delta Y} + \frac{d\sigma_{LL}^{MC}}{dY} \]

- \( N(\gamma_{QQ}) \) - number of QQ photons extracted from the fit,
- \( \Delta Y \) - bin width,
- \( \mathcal{L} \) - total integrated luminosity,
- \( d\sigma_{LL}^{MC} \) - cross section for LL photons
- \( A_{QQ} \) - ratio of the number of events reconstructed to those generated in a given bin
Cross Sections compared to weighted LO MC

ZEUS preliminary 15-001

\[
\begin{align*}
\frac{d\sigma}{dx}\, (pb) &\quad \frac{d\sigma}{dx_p}\, (pb) &\quad \frac{d\sigma}{d\Delta\phi}\, (pb) \\
x_y &\quad x_p &\quad \Delta\phi \, (deg.)
\end{align*}
\]
Comparison with Baranov-Lipatov-Zotov (BLZ) theory

(PHYSICAL REVIEW D 81, 094034 (2010))
Conclusion

• Prompt photons in DIS have been measured
• The fitting procedure was improved to estimate the CS
• Experimental differential cross sections have been obtained for $x_\gamma, x_p, \Delta \eta, \Delta \varphi, \Delta \eta_{e,\gamma}, \Delta \varphi_{e,\gamma}$ observables
• Pythia describes the shape of the data reasonably well when rescaled by a factor 1.6, as in the previous ZEUS DIS publication.
• We compared results with $k_t$-factorisation model that show a fair agreement of the kinematic distributions of the data with exception of $x_\gamma$ and $\Delta \eta$. Further investigations needed to understand the results