Prompt photon production at HERA

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• Photoproduction

• DIS

• Test theories
  Collinear and $k_T$ factorisation

A reliable probe of dynamics
2 hard scales: $Q^2$ and $E_{T\gamma}$

Saxon, DIS10, Firenze
Photoproduction: $\gamma$ emitted by quark
direct $\gamma q \rightarrow \gamma q$, resolved $gq \rightarrow \gamma q$

Theory: NLO QCD

Collinear factorisation+DGLAP evol:
Krawczyk @ Zambrzuski: (KZ) include
higher terms ($\sim \alpha_s^2$). No intrinsic $k_T$.
GRV pdfs $p, \gamma$

Fontannaz, Guillet & Heinrich (FGH)
additional higher order corrections
MRST01, AFG2

$k_T$ factorisation: Lipatov & Zotov (LZ),
direct+resolved integrated parton
densities - KMR, GRV

Hadronisation corrections ($\gamma$+jet)
PYTHIA (rewighted) estimate $\sim 0.92$
Two steps: Isolated EM cluster $\rightarrow$ single $\gamma$

1) Isolate EM-cluster ($\geq 1$ photon)

2) Find single $\gamma$. Eliminate $\pi^0, \eta^0 \rightarrow \gamma\gamma$

ZEUS:
(a) Shower width:
$\pi^0 \rightarrow \gamma\gamma$, opening angle
$\theta > 2m(\pi)/E(\pi)$
2 cluster width parameters

(b) single-$\gamma$ shower has lower conversion efficiency in presampler

H1:
6-parameter discriminant fit

$E(\text{EM-cluster})/E(\gamma\text{-jet}) > 0.9$
\(\gamma\)-jet = jet found by inclusive $k_T$ algorithm ($R_0 = 1.0$) and includes the EM-cluster

Cluster of 1 or more $\gamma$
**H1**: isolated photons identified by shower shape (6 variables)

Photoproduction  

Saxon, DIS10, Firenze
Discriminant combines 6 shape features

Kinematic range:
**Photon:** $6 < E_T(\gamma) < 15 \text{ GeV}$
$-1.0 < \eta < 2.4$
$E_T(\gamma)/E_T(\gamma-\text{jet}) > 0.9$
$Q^2 < 1 \text{ GeV}^2$
$0.1 < y_{JB} < 0.7$

**Jets:** $E_T(\text{jet}) > 4.5 \text{ GeV}$
$-1.3 < \eta_{\text{jet}} < 2.3$

**MC:** PYTHIA6.2, string frag, incl hard gluon in final state.
CTEQ6L & SASG-1D struct. fns, multiparton interactions.
HERWIG alternate
H1 photoproduction prompt photons

Theory: FGH Collinear factorisation+DGLAP evolution LZ $k_T$ factorisation
Corrected for hadronisation, multiple interactions

Saxon, DIS10, Firenze
**H1 photoprod prompt (γ+jet)**

$E_T$ and $\eta$, for $\gamma$ and jet separately.

Comparisons to theory

LZ Favoured by $\eta(\gamma)$ but not by $\eta$(jet)
Note - different $E_T$ cuts affect low $E_T$ shape comparison. H1, Z seem to agree $\eta(\gamma)$ favours LZ. H1 $\eta$(jet) disfavours LZ.
H1 photoprod prompt ($\gamma$+jet)

**Prompt Photon plus Jet Cross Section**

\[ x_{\gamma}^{LO} = \frac{E_\gamma e^{-\eta_{\text{jet}}} + e^{-\eta_{\gamma}}}{2yE_e} \]

\[ x_{p}^{LO} = \frac{E_\gamma e^{\eta_{\text{jet}}} + e^{\eta_{\gamma}}}{2E_p} \]
H1 photo. (γ-jet) correlations

- Photon – jet correlations in direct (resolved) enhanced phase space

Direct process more back-to-back
Sensitivity to soft gluon emission in the highest Δφ bin in the resolved case
- fixed order FGH calculation not reliable
- $k_T$ factorisation absorbs soft gluons in pdf
LZ missing diagrams are expected in tails of resolved cross sections

Nowak

Data not well described by theory

Saxon, DIS10, Firenze
ZEUS DIS signal extraction using shower width in fine granularity projective geometry

$d\zeta$ plot resolves $1\gamma$ and $2\gamma$ peaks

\[
\langle \delta Z \rangle = \frac{\sum_i E_i |Z_i - Z_{\text{cluster}}|}{W_{\text{cell}} \sum_i E_i}
\]

$\Delta \zeta$ plot resolves $1\gamma$ and $2\gamma$ peaks
ZEUS DIS inclusive $\gamma$: compare MC (LL+1.6xQQ)


$E_e > 10$ GeV
$139.8^\circ < \theta_e < 171.8^\circ$
$10 < Q^2 < 350$ GeV$^2$
($Q^2$ meas from $e,e'$)
$4 < E_T^\gamma < 15$ GeV
$-0.7 < \eta^\gamma < 0.9$
$W_x > 5$ GeV
$E(EMC)/E(jet) > 0.9$
(jets: $k_T$ algorithm with $R = 1.0$)

MC describes $E_T^\gamma, \eta^\gamma$ well but falls below data at low $Q^2$ and at low-$x$

2 hard scales: $Q^2, E_T^\gamma$
Prompt photons in DIS: $k_T$ factorisation?

H1: Eur Phys J C54 (2008) 371

$k_T$-factorisation

SP Baranov, AV Lipatov, NP Zotov

eq^* \rightarrow e\gamma q

KMR unintegrated quark densities in $p$
Expect differences from collinear fact.
At low $\ln(Q^2)$ and high $\ln(1/x)$

LL - hard radiation from leptons

QQ - hard radiation from quarks

QL interference term
small and neglected here.

Consider 'enhanced' LL
from MRST + QQ from GGP

Calcuted by MRST group
Sensitive to photon content of proton.

Prediction: LL + QQ + $D_{q\rightarrow \gamma}(z)$
LO($\alpha^3$) from A. Gehrmann-De Ridder, T. Gehrmann and E. Poulsen.
ZEUS DIS inclusive $\gamma$: $GGP, QQ_{GGP+MRST}^{LL}$

describe $E_T, \eta$ but not $Q^2, x$

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$W_x > 5$ GeV

$E(EMC)/E(jet) > 0.9$

(jets: $k_T$ algorithm with $R = 1.0$)
DIS inclusive $\gamma$: collinear & $k_T$-factorisation predictions compared to H1 data

- H1 own fit using GGP
- BLZ fit

Success for BLZ

Saxon, DIS10, Firenze
DIS inclusive $\gamma$: $k_T$-factorisation predictions compared to ZEUS data

$E_T^\gamma$

← ZEUS own fit using GGP

↓ BLZ fit

η$^\gamma$

η$^\gamma$

Q$^2$

Q$^2$

Success for BLZ

Saxon, DIS10, Firenze
BLZ not better at high $Q^2$ (H1 data) as expected (?)
Prompt photons probe reaction dynamics: summary

**H1 photoprod ($\gamma$+jet)**
- Extended $\eta$-range

**ZEUS DIS inclusive**
- Collinear fact'zn fails

**Baranov, Lipatov, Zotov**
- $k_T$-fact'zn success

- $\gamma$/jet correlations
- Test theories
- Low $x$, low $Q^2$ poor fit
- GGP, MRST poor fit
- BLZ good fit

Saxon, DIS10, Firenze