Prompt photon production in diffractive photoproduction at HERA as measured by ZEUS
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First measurement of isolated photons in diffractive photoproduction for ZEUS

- “clean processes”: prompt photon are free from fragmentation and hadronization corrections and sensitive to selected diagrams

Previous HERA analyses of similar processes:

- Photoproduction of Isolated Photons, inclusively and with a Jet, ZEUS

Non diffractive $\gamma$

A ZEUS analysis of isolated photons in DIS presented by Volodymyr Myronenko at this workshop
Kinematic – diffractive production of a prompt photon

- Prompt photons must couple to a charged particle line, so the quark content of the exchanged colourless object (the Pomeron IP) is tested.

- $x_\gamma = \text{fraction of momentum of the incoming photon participating to the hard process. Direct photon if } x_\gamma = 1, \text{ resolved photon if } x_\gamma < 1$

- $x_{IP} = \text{fraction of the proton energy taken by the colourless exchange } < 0.03$

- $z_{IP} = \text{fraction of the Pomeron energy participating to the hard interaction.}$
diffractive photoproduction of isolated photons - the “direct Pomeron”

- HERA: collisions of electron at 27.5 GeV against protons of $/920$ GeV

- A diagram of a hard interaction of a direct photon with a direct colourless object producing a prompt photon and a jet, $z_{|P|} \sim 1$

- Testing colourless exchange
- Test of QCD factorization both at photon and Pomeron vertices
- Comparison with perturbative QCD calculations is possible
Selection: diffractive photoproduction of isolated photons

- Photoproduction: No scattered electron observed $0.2 < y_{\text{JB}} < 0.7$, usual cut
- Events triggered by energy released in calorimeter
- Diffraction: No energy in the forward region, $\eta_{\text{max}}^{\text{EFO}} < 2.5$
- Jets are reconstructed with $k_T$ algorithm $-1.5 < \eta_{\text{jet}} < 1.8$, $E_{\text{Tjet}} > 4 \text{ GeV}$
- Photons identified in Barrel ElectroMagnetic Calorimeter, finely segmented in the $Z$ direction $E_{\text{T}\gamma} > 5 \text{ GeV}$, $-0.7 < \eta < 0.9$, “isolated”, $E_{\text{T}\gamma} > 0.9 E_{\text{Tjet}}$

HERA I data (1998-2000): a forward plug calorimeter allowed the rejection of proton dissociative processes

HERA II data (2004-2007): forward calorimeter replaced by a magnet, $\Rightarrow$ additional background scattered within the detector, making challenging the measurement of diffractive cross sections
Reconstruction of kinematic variables

- $x_{\gamma} = \text{fraction of momentum of the incoming photon participating to the hard process. Direct photon if } x_{\gamma} = 1$
  \[ x_{\gamma}^{\text{meas}} = \frac{E_{\gamma} + E_{\text{jet}} - p_{Z}^{\gamma} - p_{Z}^{\text{jet}}}{E_{\text{all}} - p_{Z}^{\text{all}}} \]

- $x_{P} = \text{fraction of the proton energy taken by the colourless exchange}$
  \[ x_{P} = \frac{(E_{\text{all}} + p_{Z}^{\text{all}})}{2E_{p}} \]

- $z_{IP} = \text{fraction of the Pomeron energy participating to the hard interaction. Direct Pomeron if } z_{IP} \sim 1$
  \[ z_{IP}^{\text{meas}} = \frac{E_{\gamma} + E_{\text{jet}} + p_{Z}^{\gamma} + p_{Z}^{\text{jet}}}{E_{\text{all}} + p_{Z}^{\text{all}}} \]
Background: photons from decays of neutral mesons are subtracted

- Large background from photons from $\pi^0$ or $\eta + \text{multi } \pi^0$
- The $\delta Z$ distribution of the EM calorimeter cells in the barrel detector allows to separate photons from $\pi^0$
- For each measured quantities, for each bin, the background from photons from $\pi^0$ or $\eta + \text{multi } \pi^0$ is fitted and subtracted statistically
- Large background from neutral mesons reduced
Cross section definition

- Integrated luminosity $456 \text{ pb}^{-1}$ (82 in HERA I + 374 in HERA II)
- Photoproduction: $Q^2 < 1 \text{ GeV}^2$; $0.2 < y < 0.7$, no electron
- Diffraction: $\eta_{\text{max}} < 2.5$ of Energy Flow Objects and $x_	ext{IP} < 0.03$
- Photons: $5 < E_T^\gamma < 15 \text{ GeV}$, $-0.7 < \eta^\gamma < 0.9$, “isolated”, $E_\gamma > 0.9 E_{\text{jet}}$
- Cross sections measured with or without asking for an additional jet with $4 < E_T^{\text{jet}} < 35 \text{ GeV}$, $-1.5 < \eta^{\text{jet}} < 1.8$

- Additional background from Bethe-Heitler process and Deeply Virtual Compton Scattering removed asking at least 5 energy-flow objects
- Cross section evaluated using normalisation from the HERA I sample, where p-dissociation contribution reasonably known
Monte Carlo simulation

- Based on leading order parton-level QCD matrix elements
- Some higher order modeled by initial and final state leading-log parton showers
- Fragmentation from PYTHIA Lund model

- Resolved pomeron model: diffractive parton densities used are the H1 2006 DPDF fit B, extracted in DIS diffractive scattering, for \( z_{IP} < 0.9 \)
- Resolved photons: pdf SASGAM-2D used

- RAPGAp has no direct Pomeron contribution
Photon vertex: direct and resolved contribution

- MC generates separately direct and resolved photon processes, and need to be re-weighted to the $x_\gamma$ distribution of the data
- $x_\gamma$ distribution is compatible with a mixture 70% direct photon process + 30% resolved photon

$x_\gamma$ for diffractive photoproduction of 2-jets

Evidence for direct Pomeron interaction

- Measured $z_{\perp p}$ not described by RAPGAP MC
- Data show excess of “direct Pomeron” processes
- Non-diffractive contribution (red histogram) is flat in $z_{\perp p}$
- RAPGAP reweighted for $z_{\perp p} > 0.9$, re-weighting improves description of $\eta_{\text{max}}$ distribution
Diffractive isolated photoproduction: $\eta_Y$, $x_P$, $M_x$

- Data distribution well described in general by RAPGAP MC, not sensitive to $z_{IP}$ reweighting
Inclusive photon and photon + jet; $E_T^{\gamma}$

- Most of the events have isolated photon + jet
- Cross section measured both for inclusive prompt photon and photon + jet
- In both samples, distributions are well described by RAPGAP
Cross sections evaluated for inclusive Photon and photon + jet samples As a function of many kinematic variables

- Cross section is $1.21\pm0.19^{+0.14}_{-0.14}$ pb for inclusive photon and $1.10\pm0.19^{+0.09}_{-0.13}$ pb for photon + jet

- Cross section for $z_{IP}<0.9$ is $0.68\pm14^{+0.06}_{-0.07}$ pb, including proton dissociation (~16%)

- Cross section estimated by RAPGAP is 0.68 pb, but without proton dissociation contribution
Cross sections for $z_{IP} < 0.9$, “resolved Pomeron region”
Cross sections for $z_{IP}>0.9$, “direct Pomeron” region
Summary

- ZEUS measured isolated ("prompt") photons in diffractive photoproduction, for the first time
- Most of the detected photons are with an accompanying jet
- Cross sections measured in a diffractive region defined for $\eta_{\text{max}}$ and $x_{\text{IP}}$
- The variable $z_{\text{IP}\text{meas}}$ shows a peak at high values that implies:
  i. evidence for a direct-Pomeron process dominantly in the direct photon channel
  ii. the presence of processes not currently implemented in the MC RAPGAP
- The cross sections of the different kinematic variables in photoproduction are well described in shape by MC RAPGAP, which implement a common set of diffractive PDFs (measured in diffractive DIS events)