Diffractive productionof Isolated Photons with the ZEUS Detector at HERA.

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DIS 2015 International Workshop, Dallas, 29 April 2015

High-p_T photons produced in ep scattering are of several categories:

- Radiated from the incoming or outgoing lepton
- Produced in a hard partonic interaction
- Radiated from a quark within a jet
- A decay product of a hadron within a jet

Photons in first two categories are relatively isolated from other outgoing particles. Second type often called "prompt" photons.

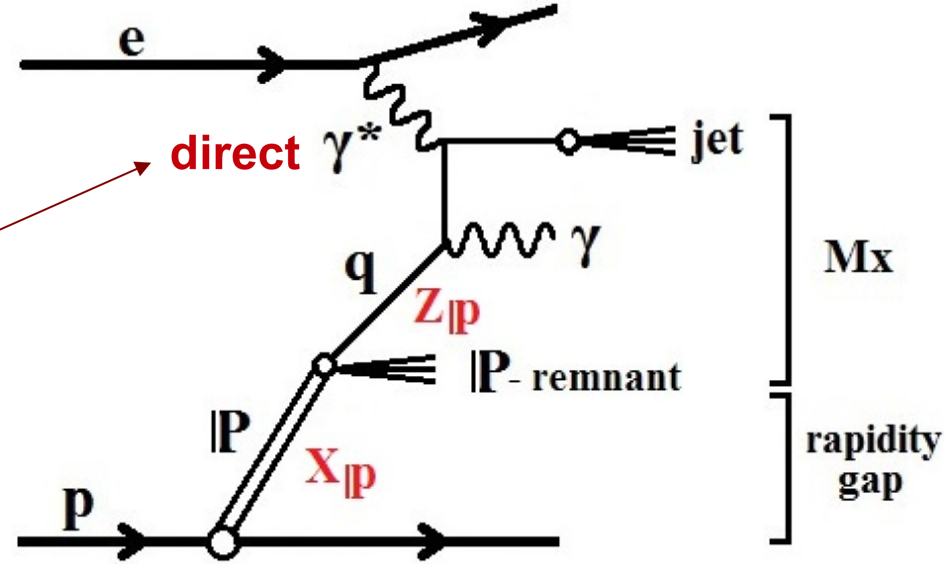
Here we study "prompt" photons arising from a diffractive process.

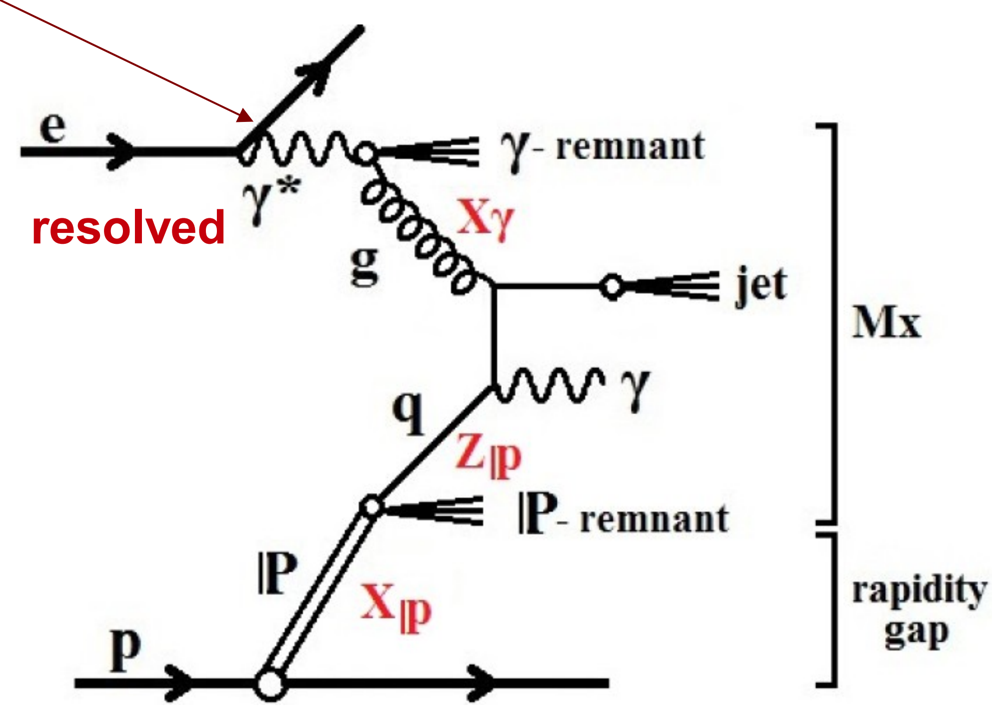
Examples of lowest-order diagrams
by which diffractive processes may generate a prompt photon

Direct incoming photon gives all its energy to the hard scatter ($x_\gamma = 1$).

Resolved incoming photon gives fraction x_γ of its energy.

An outgoing photon must couple to a charged particle line and so the exchanged colourless object ("pomeron") must be resolved in these lowest-order processes.





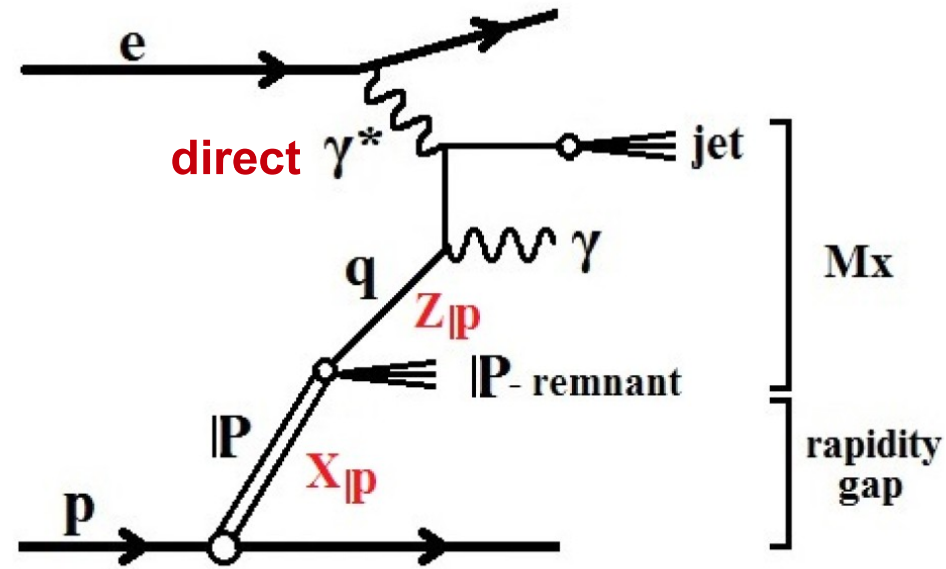
More kinematics:

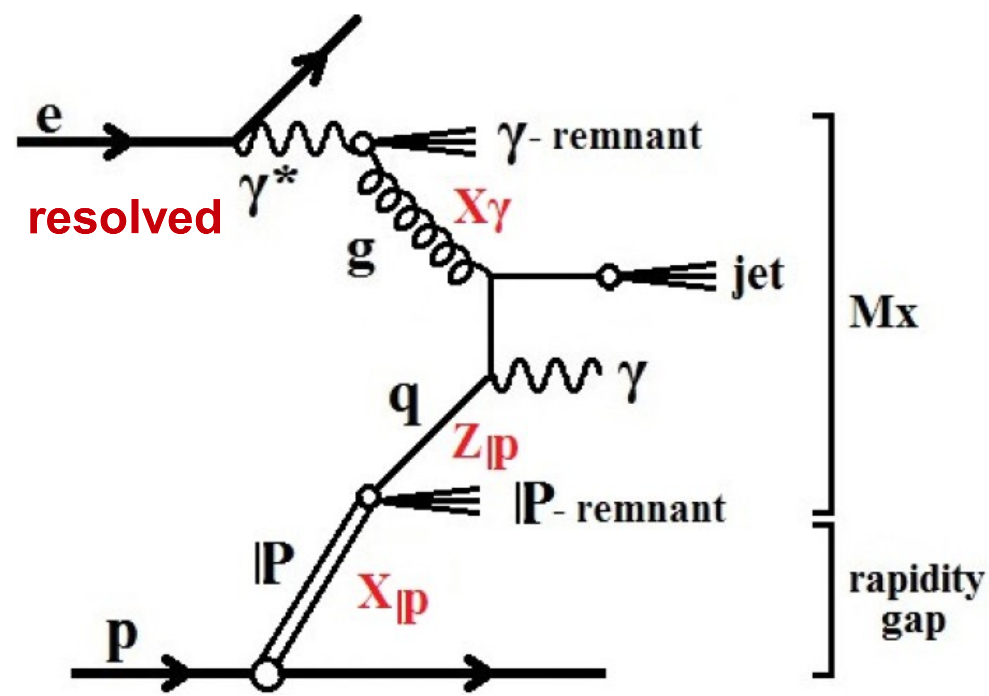
x_{IP} = fraction of proton energy taken by pomeron.

z_{IP} = fraction of pomeron energy taken in scatter.

η_{max} = maximum value of pseudorapidity of outgoing particles in scatter (Ignore forward proton.)

Diffractive processes are characterised by a low value of η_{max} and/or a low value of x_{IP}.





Here we measure prompt diffractive photons without and with a jet, using the ZEUS detector.

Some motivations for these measurements:

- *Prompt photons emerge directly from the hard scattering process and give a particular view of this.*

- *Allows tests of pomeron models and explores the non-gluonic aspects of the pomeron and pomeron-photon physics in general.*

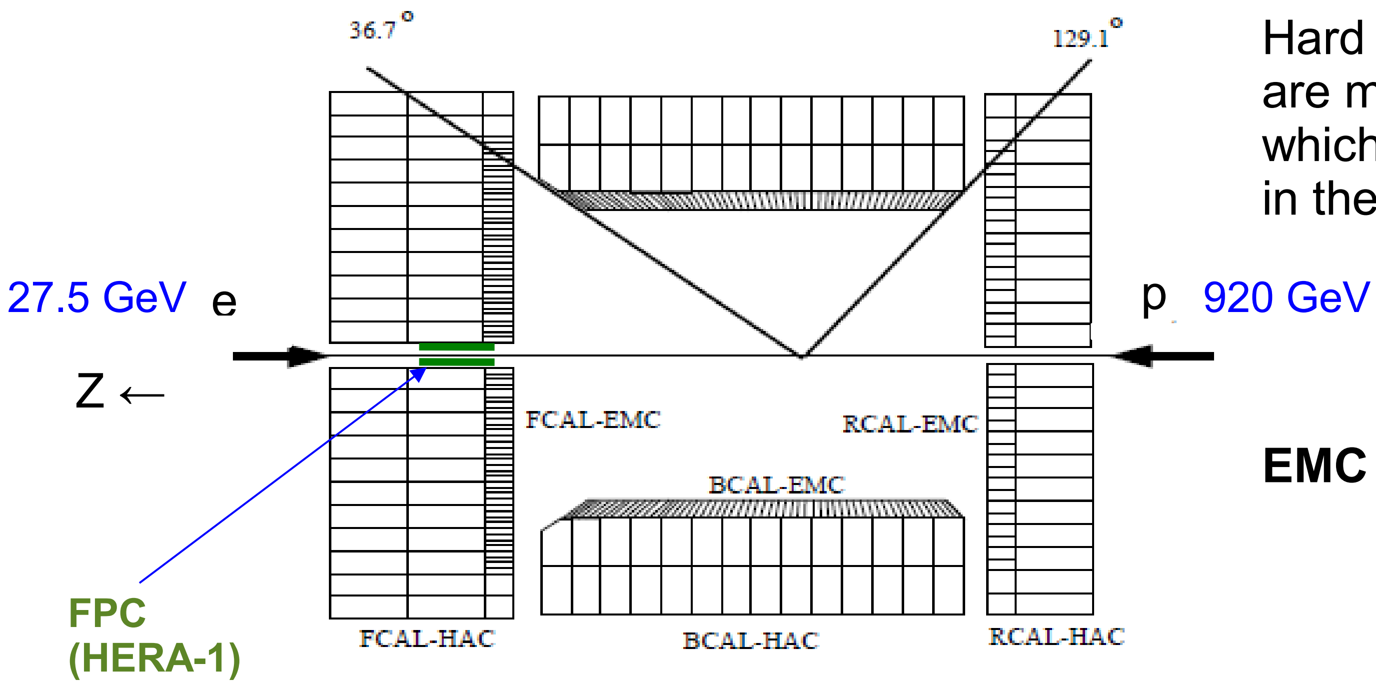
ZEUS publications of prompt photons in photoproduction:
Phys. Lett. 730 (2014) 293   JHEP 08 (2014) 03

H1 on inclusive diffractive prompt photons in photoproduction:
Phys. Lett. 672 (2009) 219

Diffractive photoproduced dijets:
(H1) Eur. Phys. J. 6 ((1999) Eur. Phys. J. 421, 70 (2008)15
(ZEUS) Eur. Phys. J 55 (2008) 171

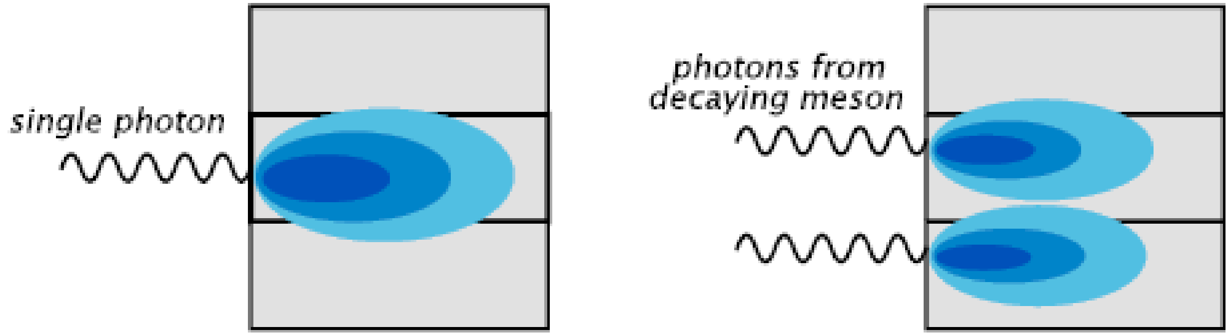
The ZEUS detector

HERA-1 data: 1998-2000
HERA-2 data: 2004-2007

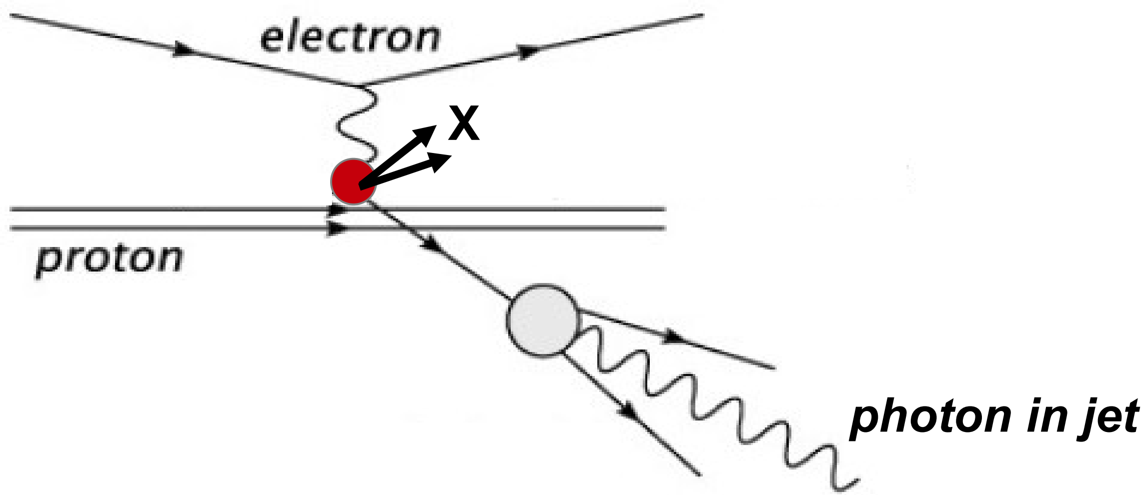


Hard scattered photons are measured in the BCAL, which is finely segmented in the Z direction.

EMC = electromagnetic section



Why we isolate the measured photon:



Photons in or near jets require a quark fragmentation function which is not easy to determine – requires non-perturbative input.

Also, the background from neutral mesons is large.

The ZEUS diffractive prompt photon analysis.

Uses 374 pb^{-1} of HERA 2 data and 91 pb^{-1} of HERA 1 data.

Hard photon candidate:

- found with energy-clustering algorithm in BCAL: $E_{EMC}/(E_{EMC} + E_{HAD}) > 0.9$
- $E_T^{\gamma} > 5$ GeV
- $-0.7 < \eta^{\gamma} < 0.9$ where $\eta \equiv$ pseudorapidity.
  (i.e. within ZEUS barrel calorimeter)
- **Isolated.** In the "jet" containing the photon candidate, the photon must contain at least 0.9 of the "jet" E_T

Jets

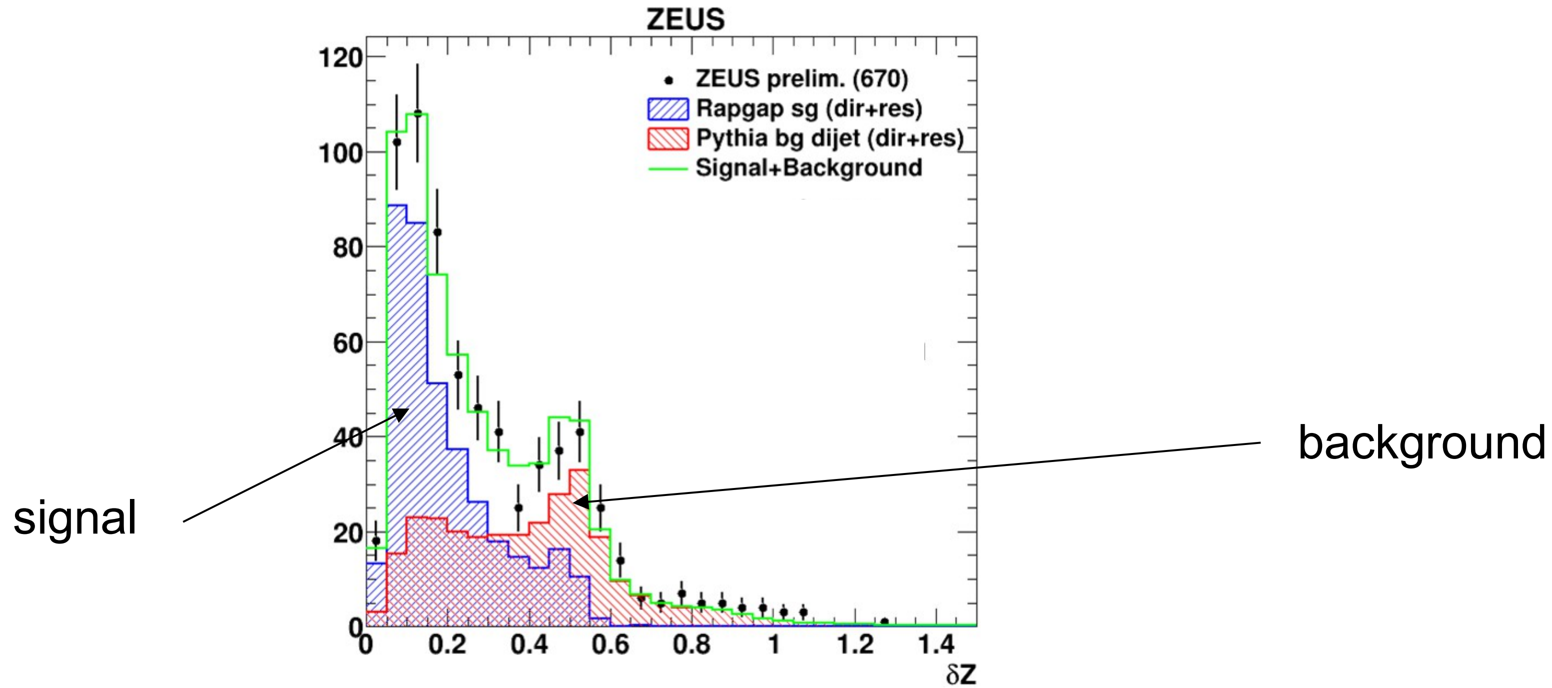
- use k_T-cluster algorithm
- $-1.5 < \eta^{jet} < 1.8$
- $E_T^{jet} > 4$ GeV.

The HERA1 data used a Forward Proton Counter surrounding the beam line which removed much nondiffractive background from the event sample.

Use HERA1 data to provide overall normalisation.
Use HERA2 data to measure shapes of distributions.

Photon candidates: groups of signals in cells in the BEMC.
Each has a Z-position, Z_{CELL}. E_T-weighted mean of Z_{CELL} is Z_{Mean}.

Task: to separate photons from background of candidates from photon decays of neutral mesons.



<dZ> = E_T-weighted mean of $|Z_{CELL} - Z_{Mean}|$.
Peaks correspond to photon and π^0 signals, other background is η + multi-π^0.

In each bin of each measured physical quantity, fit photon signal + hadronic bgd.

Monte Carlo simulation

Uses the **RAPGAP** generator
(H. Jung, Comp. Phys. Commun. 86 (1995) 147)

Based on leading order parton-level QCD matrix elements.
Some higher orders are modelled by initial and final state leading-logarithm parton showers.
Fragmentation is performed using the Lund string model as implemented in PYTHIA.

The H1 2006 Set-B DPDF set is used to describe the parton density in the diffractively scattered proton.
For resolved photons, the SaSG 1D LO pdf is used.

The ZEUS diffractive analysis

This is a photoproduction analysis; events with a scattered electron are removed, also those with a final-state.jet that resembles an electron.

1) The forward scattered proton is not measured in the HERA-2 analyses.

2) To remove nondiffractive events, characterised by a forward proton shower, we consider two main variables: η_{max} and x_{IP}

η_{max} is evaluated from ZEUS energy flow objects (EFOs), which combine tracking and calorimeter cluster information.

x_{IP} is evaluated as $\Sigma(E + p_z)_{\text{all EFOs}} / 2 E_p$

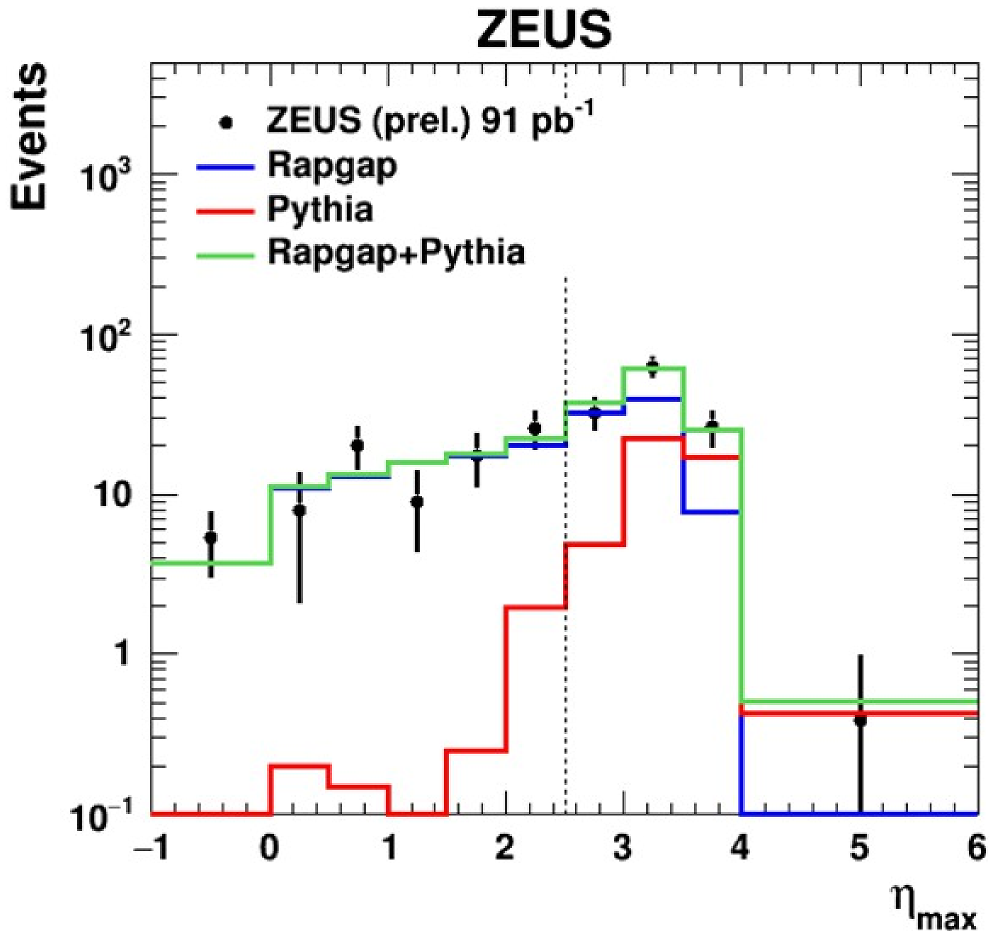
Require $\eta_{max} < 2.5$ and $x_{IP} < 0.03$

These and the other cuts at the hadron level define our cross sections.

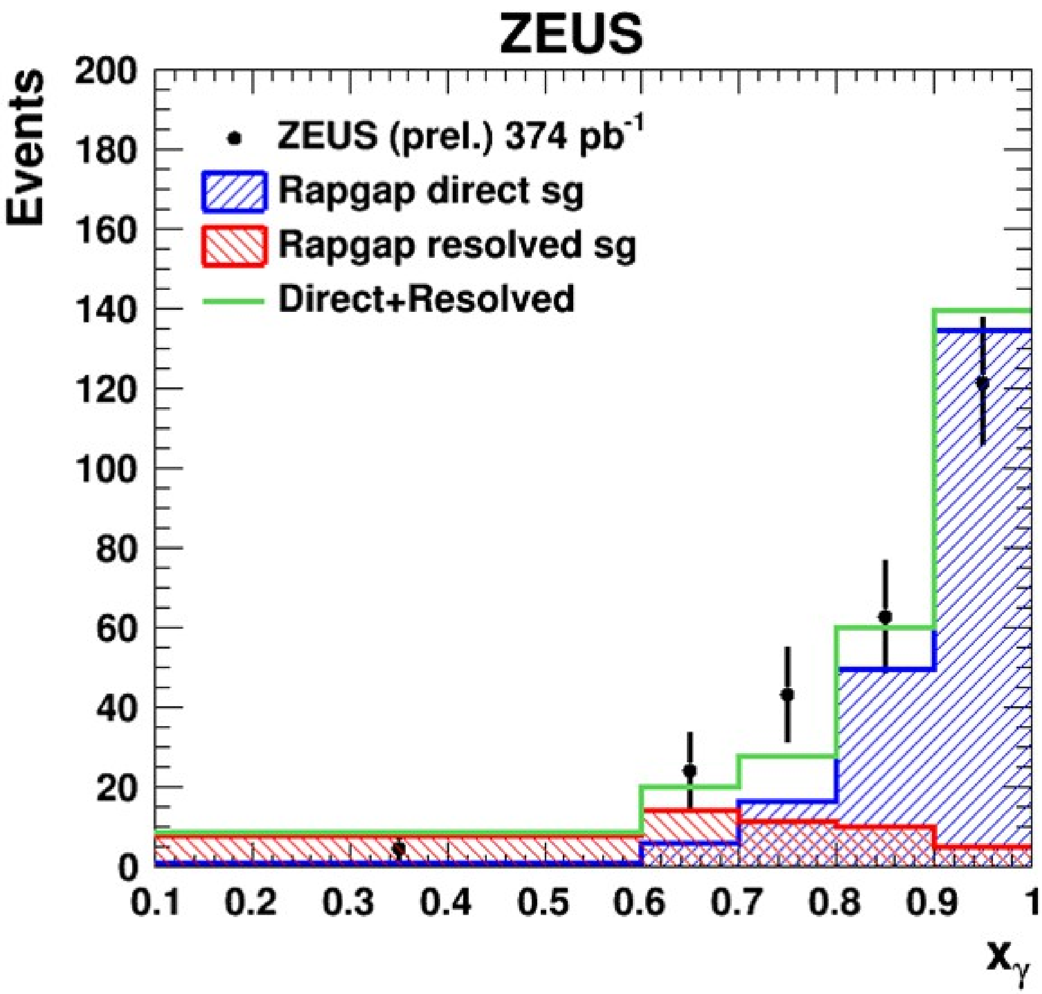
3) RAPGAP does not fit the η_{max} distribution very well: apply reweighting when evaluating the acceptances using the RAPGAP model.

4) It is necessary to subtract contribution from nondiffractive events that pass the diffractive cuts.

After cuts and reweighting, the η_{max} distribution is satisfactory in the diffractive region. The very forward region is well modelled in HERA-1 (below) but not in HERA2. There is a nondiffractive contribution, larger for Herwig than Pythia. We rescale the cross sections to the total measured with HERA-1 where these contributions are much smaller. **Allow a substantial systematic.**



A**fter** nondiffractive subtraction (mean of Pythia and Herwig, 23% of total), fit the x_γ distribution to direct and resolved RAPGAP components.
An 80:20 mixture is found and used throughout.

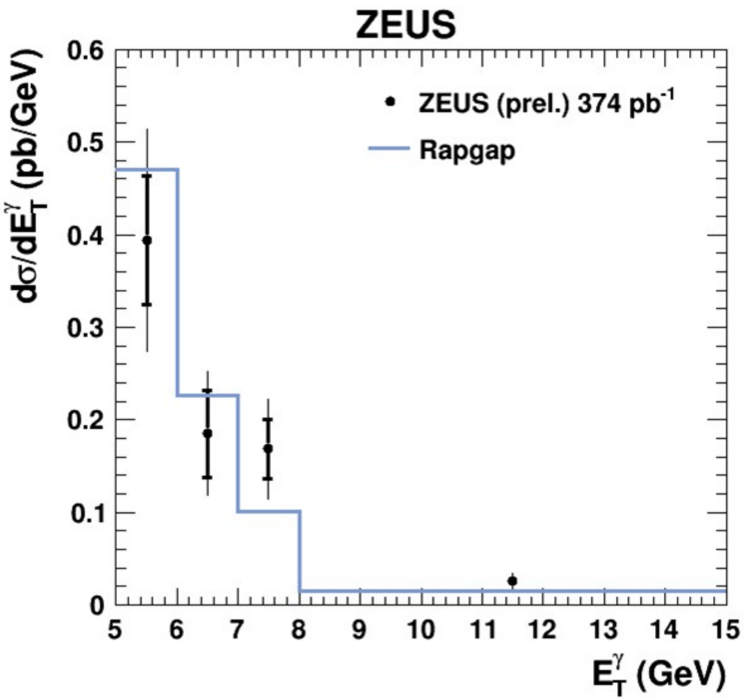


$$x_\gamma = \Sigma_{\gamma + jet}(E - p_z) \ / \ \Sigma_{all\ EFOs}(E - p_z)$$

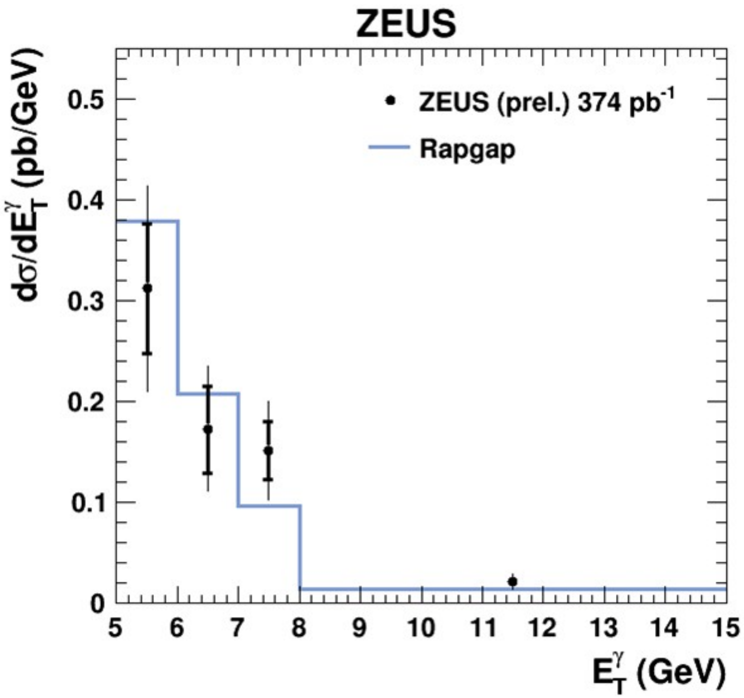
Results

Cross sections compared to RAPGAP normalised to total observed cross section.
Inner error bar is statistical. Outer (total) is correlated across all points and includes normalisation and nondiffractive subtraction uncertainty.

Transverse energy of photon.

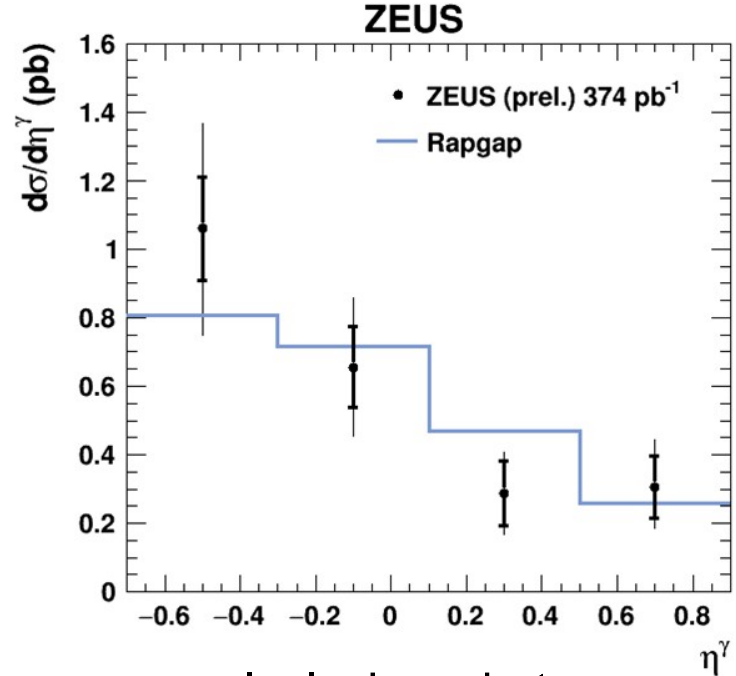


Inclusive photon

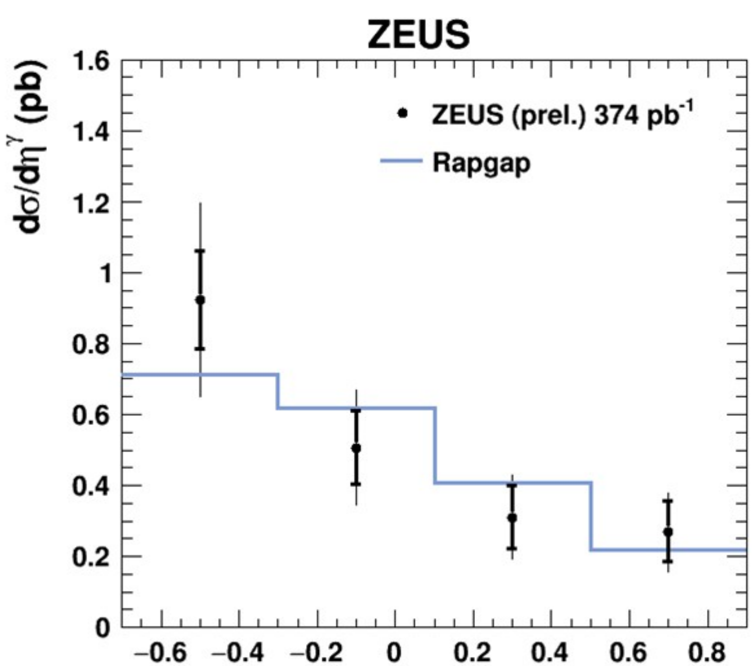


Photon + jet

Shape of RAPGAP is fairly well described. Most photons are accompanied by a jet.



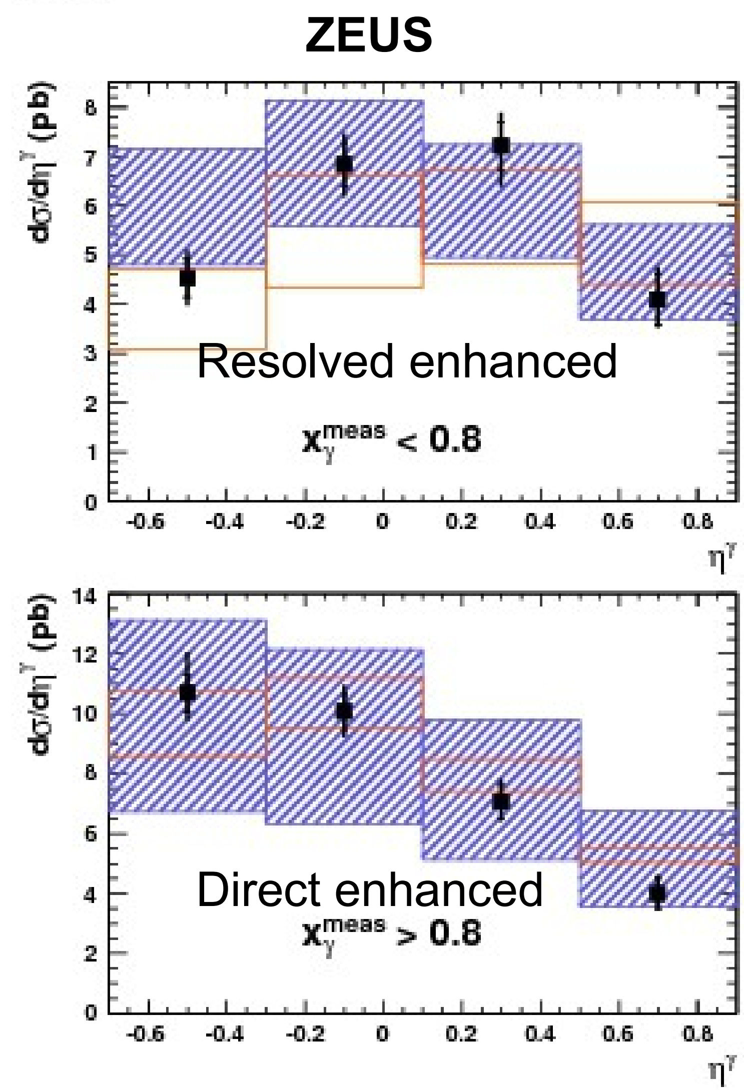
Inclusive photon pseudorapidity



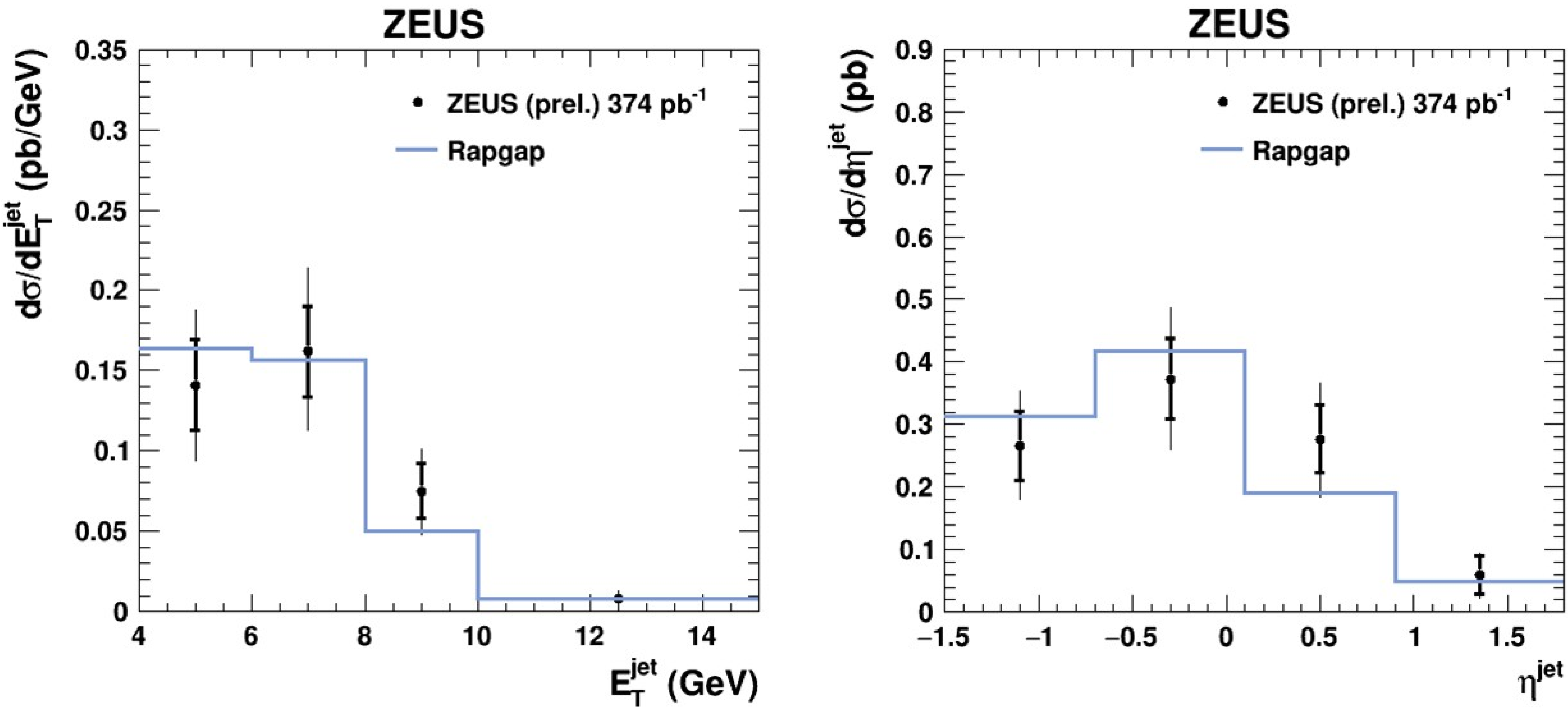
Photon + jet

Compare diffractive photon distribution with those from **nondiffractive** processes.

Diffractive more resembles direct but seems slightly more forward.

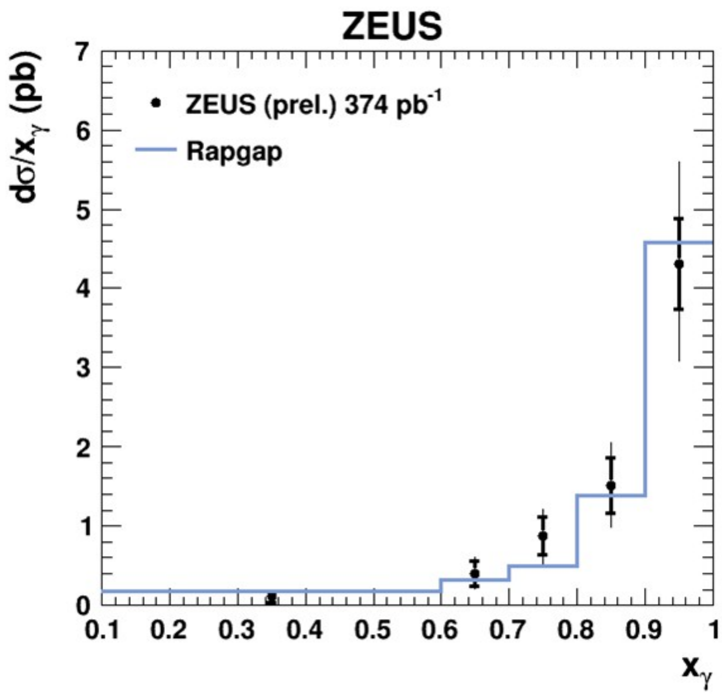


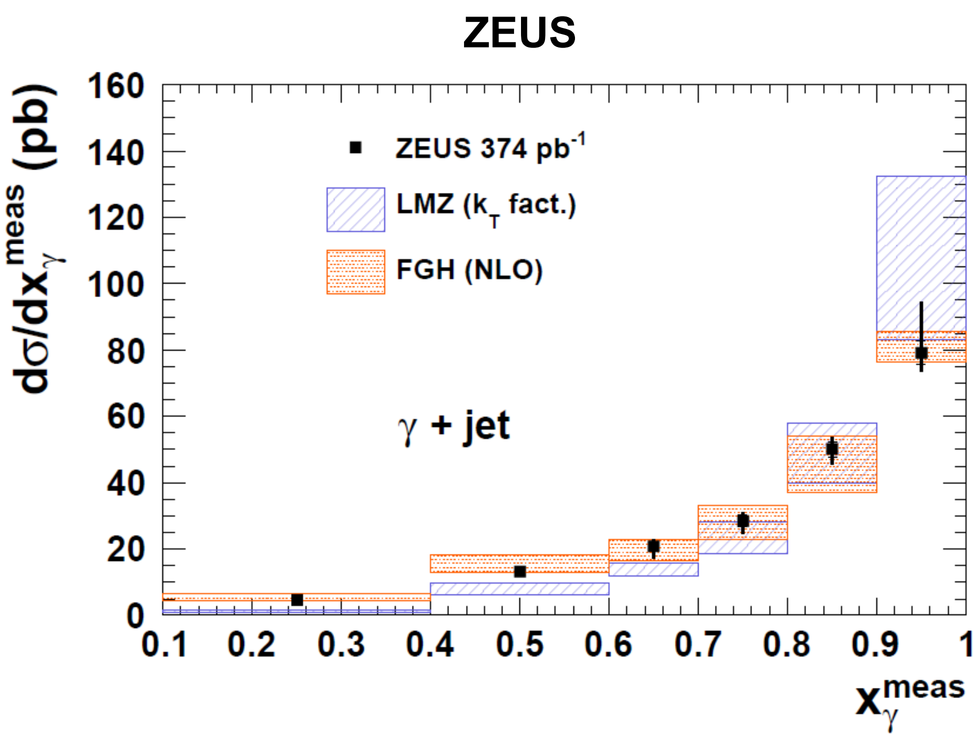
Transverse energy and pseudorapidity of accompanying jet.



Rapgap gives a reasonable description of both variables.

Compare diffractive distribution of x_γ with that for nondiffractive photoproduction:

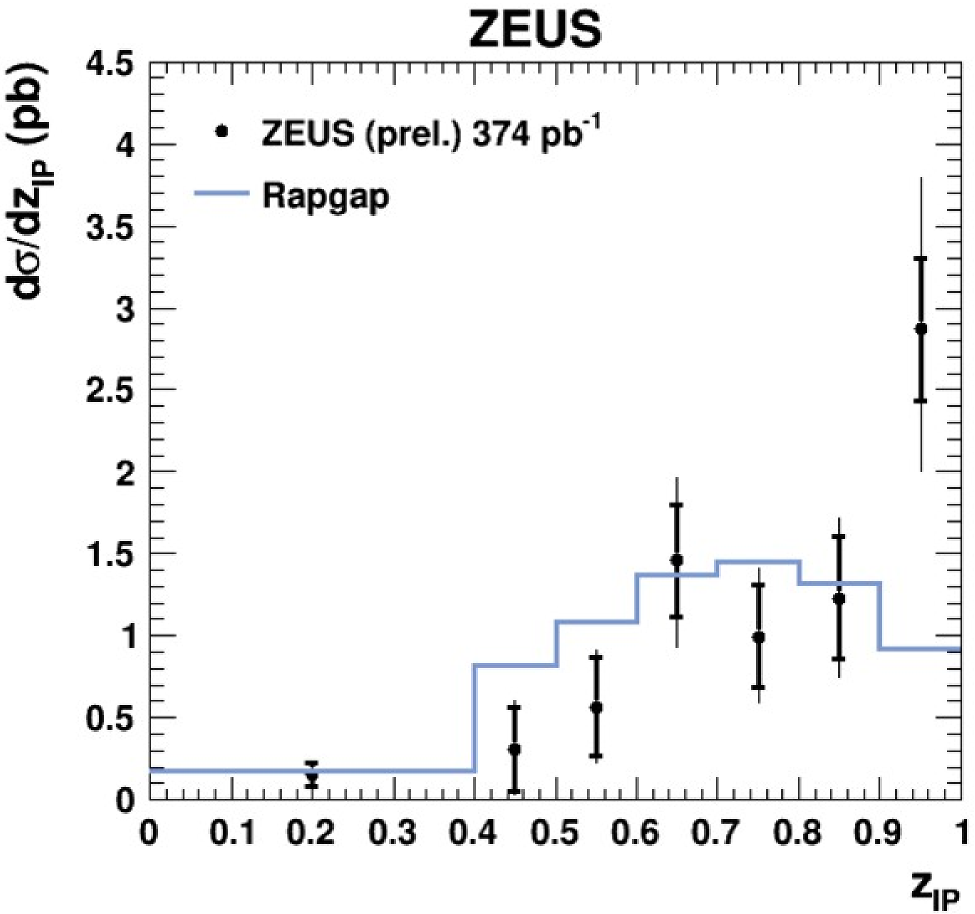




The diffractive process (left) is more strongly direct-dominated than the nondiffractive (right).
Rapgap gives a good description.

The distribution in $z_{IP} = \Sigma_{\gamma + jet}(E + p_z) / \Sigma_{all\ EFOs}(E + p_z)$

shows a significant feature that is not described by RAPGAP.



The nondiffractive contribution is smooth in this region and does not account for the peak. The reweighting does not account for it. A few percent of the 100 peak events could come from an initial-state radiative DIS process.

Conclusions

ZEUS have measured isolated ("prompt") photons in diffractive photoproduction, for the first time with an accompanying jet.

Cross sections for a region defined by kinematic cuts and cuts on η_{max} and x_{IP} are presented.

Most of the detected photons are accompanied by a jet.

The data are strongly dominated by the direct photoproduction process.

RAPGAP describes the shapes of most of the kinematic variables reasonably well.

However the variable z_{IP} shows a peak at high values that would imply the presence of processes not currently modelled in RAPGAP. Further studies will continue!

Backups

etamax distribution for HERA-2.