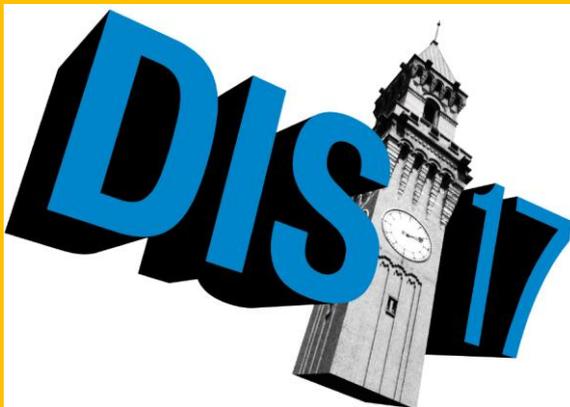


Diffractive production of isolated photons with the ZEUS Detector at HERA

Peter Bussey
University of Glasgow

for the ZEUS Collaboration



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.

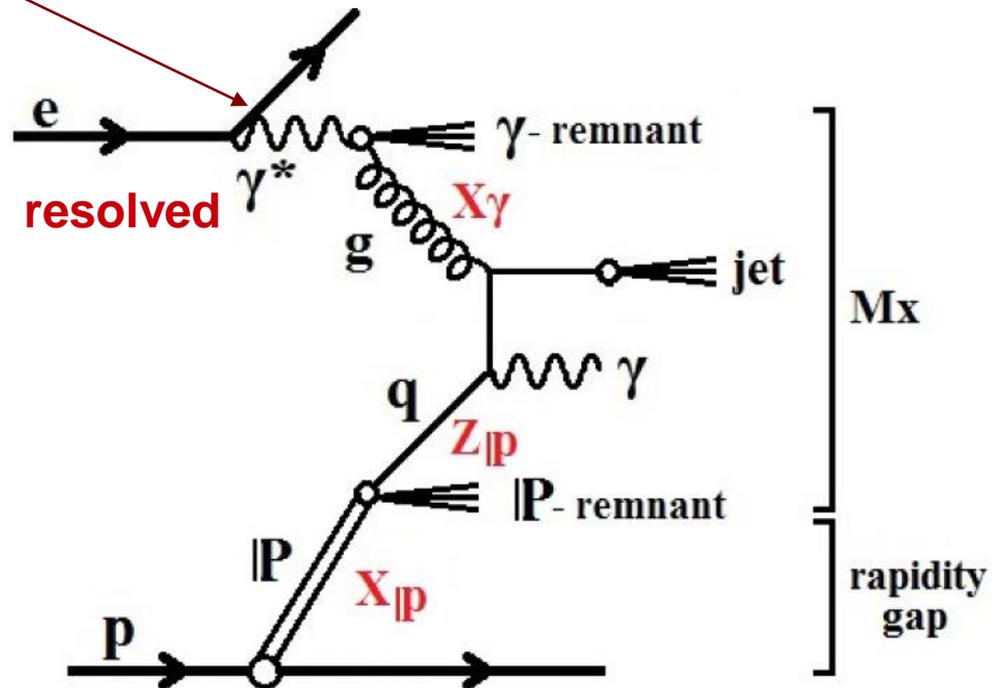
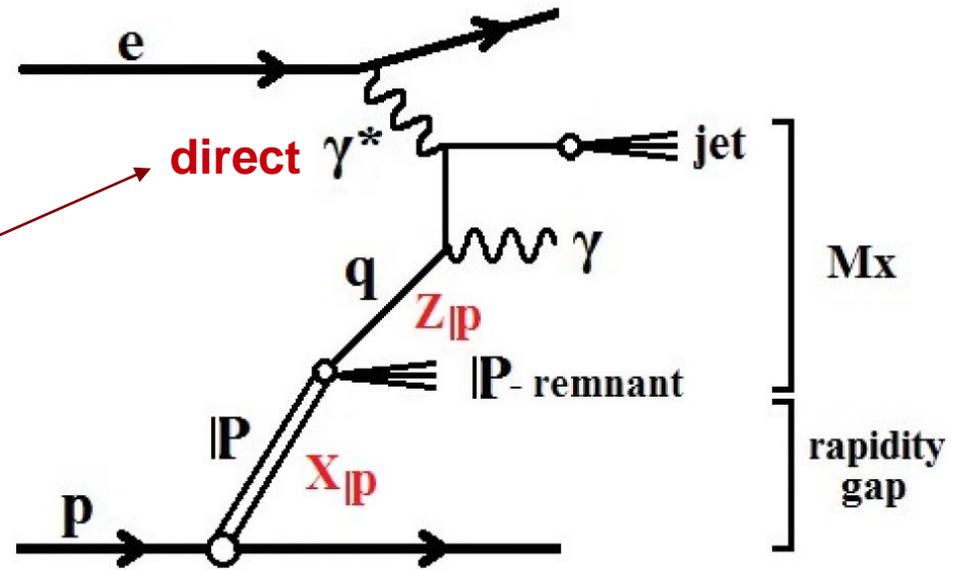
Here we study “prompt” photons arising from a diffractive process.

Examples of lowest-order resolved-Pomeron 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 have a quark content.



More kinematics:

x_{IP} = fraction of proton energy taken by Pomeron, measured as

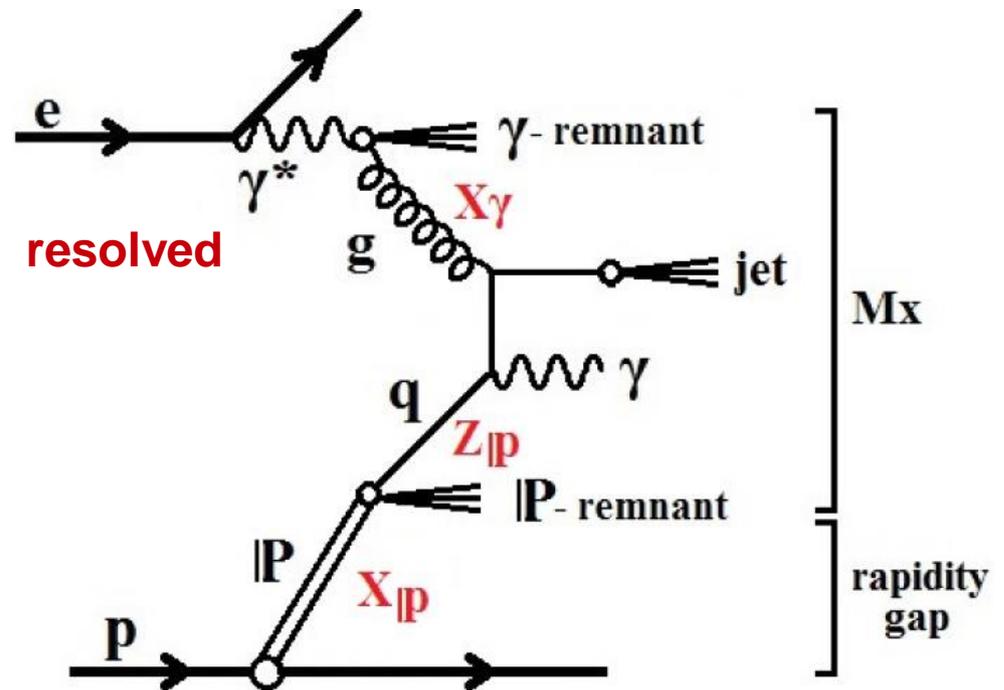
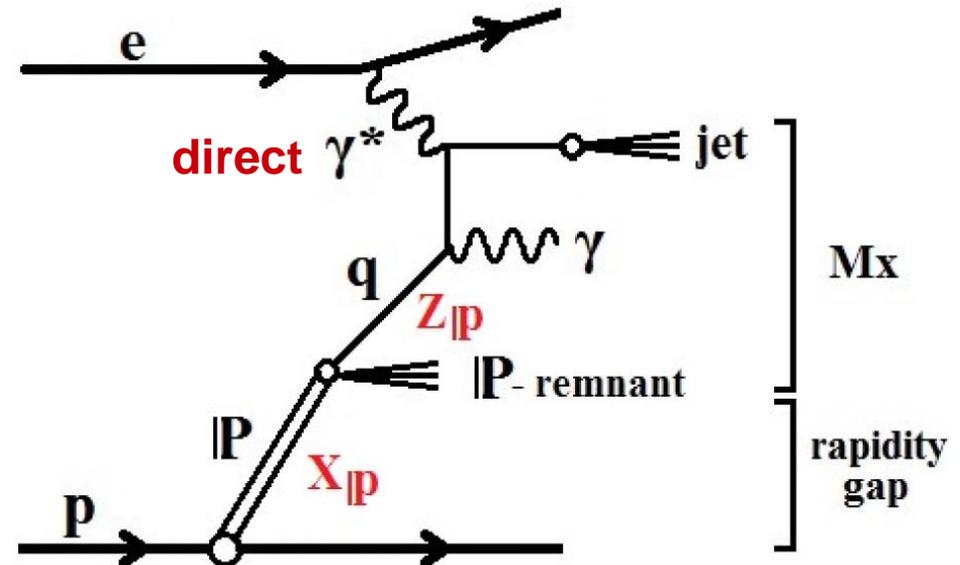
$$\frac{\sum_{\text{all EFOs}} (E + p_z)}{2 E_p}$$

z_{IP} = fraction of Pomeron $E+p_z$ taken by photon + jet measured as

$$\frac{\sum_{\gamma + \text{jet}} (E + p_z)}{\sum_{\text{all EFOs}} (E + p_z)}$$

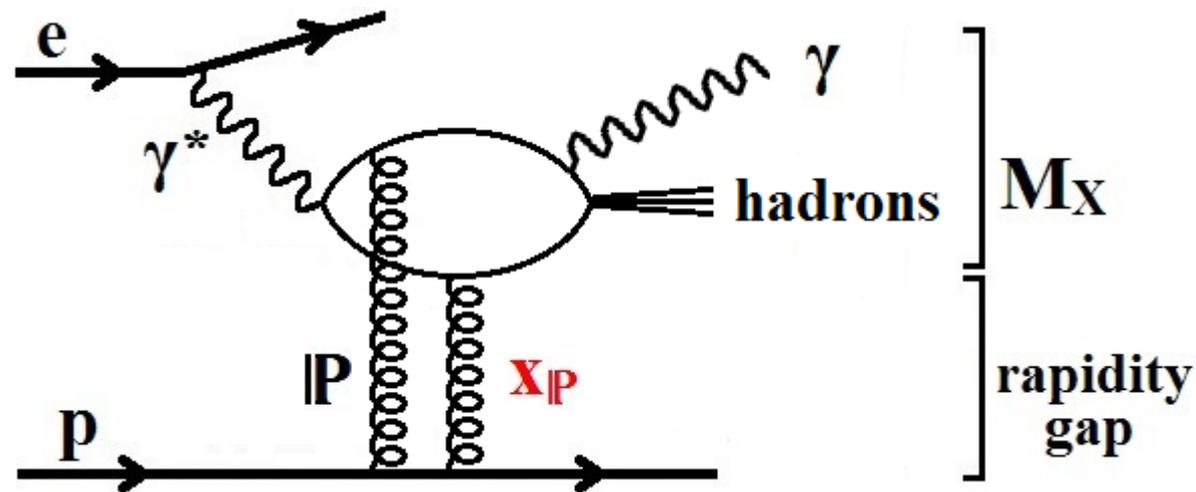
η_{max} = maximum pseudorapidity of observed outgoing particles ($E > 0.4$ GeV) (ignore forward proton).

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



Possible direct Pomeron interactions require a different type of diagram.

e.g.



Direct photon + direct Pomeron

Resolved photons also a possibility.

N.B. The proton may become dissociated in diffractive processes

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

Some motivations:

- *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

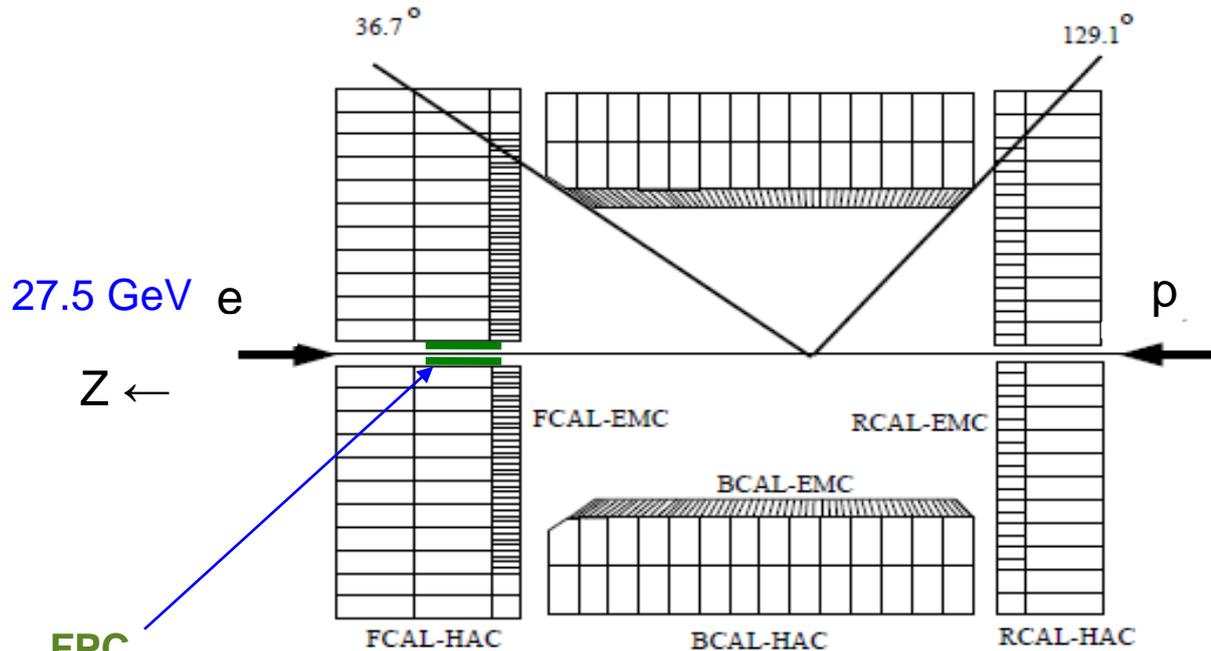
Diffractive photoproduced dijets:

(H1) Eur. Phys. J. 6 ((1999) Eur. Phys. J. 421, 70 (2008)15

(ZEUS) Eur. Phys. J 55 (2008) 171

The ZEUS detector

HERA-I data: 1998-2000
 HERA-II data: 2004-2007

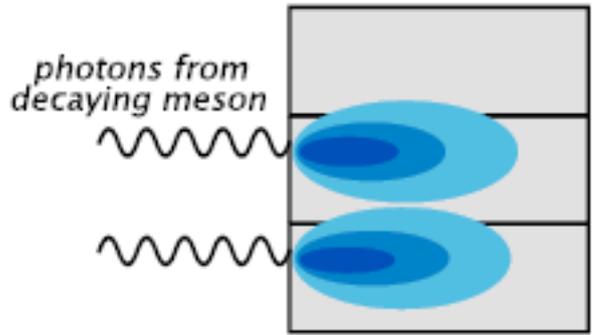
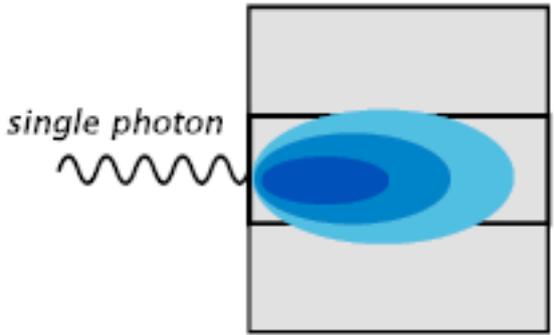


Hard scattered photons are measured in the BCAL, which is finely segmented in the Z direction.

EMC = electromagnetic section

FPC
 Forward Plug Calorimeter)
 (HERA-I)

Replaced by a beam focussing Magnet In HERA-II



ZEUS photoproduced prompt photon analysis.

Hard photon candidate:

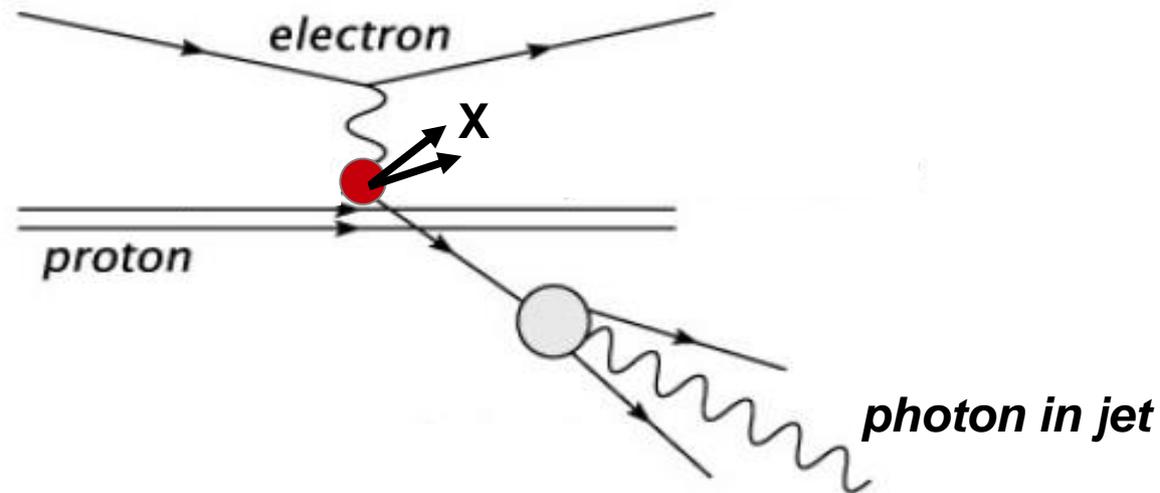
- found with energy-clustering algorithm in BCAL: $E_{\text{EMC}} / (E_{\text{EMC}} + E_{\text{HAD}}) > 0.9$
- $E_{\text{T}}^{\gamma} > 5 \text{ GeV}$
- $-0.7 < \eta^{\gamma} < 0.9$ where $\eta \equiv$ pseudorapidity. (i.e. in ZEUS barrel calorimeter)
- **Isolated.** In the “jet” containing the photon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

Jets

- use k_{T} -cluster algorithm
- $-1.5 < \eta^{\text{jet}} < 1.8$
- $E_{\text{T}}^{\text{jet}} > 4 \text{ GeV}$

A cut $0.2 < y_{\text{JB}} < 0.7$ removes most DIS events.

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.

Reduce large background from neutral mesons.

The diffractive analysis.

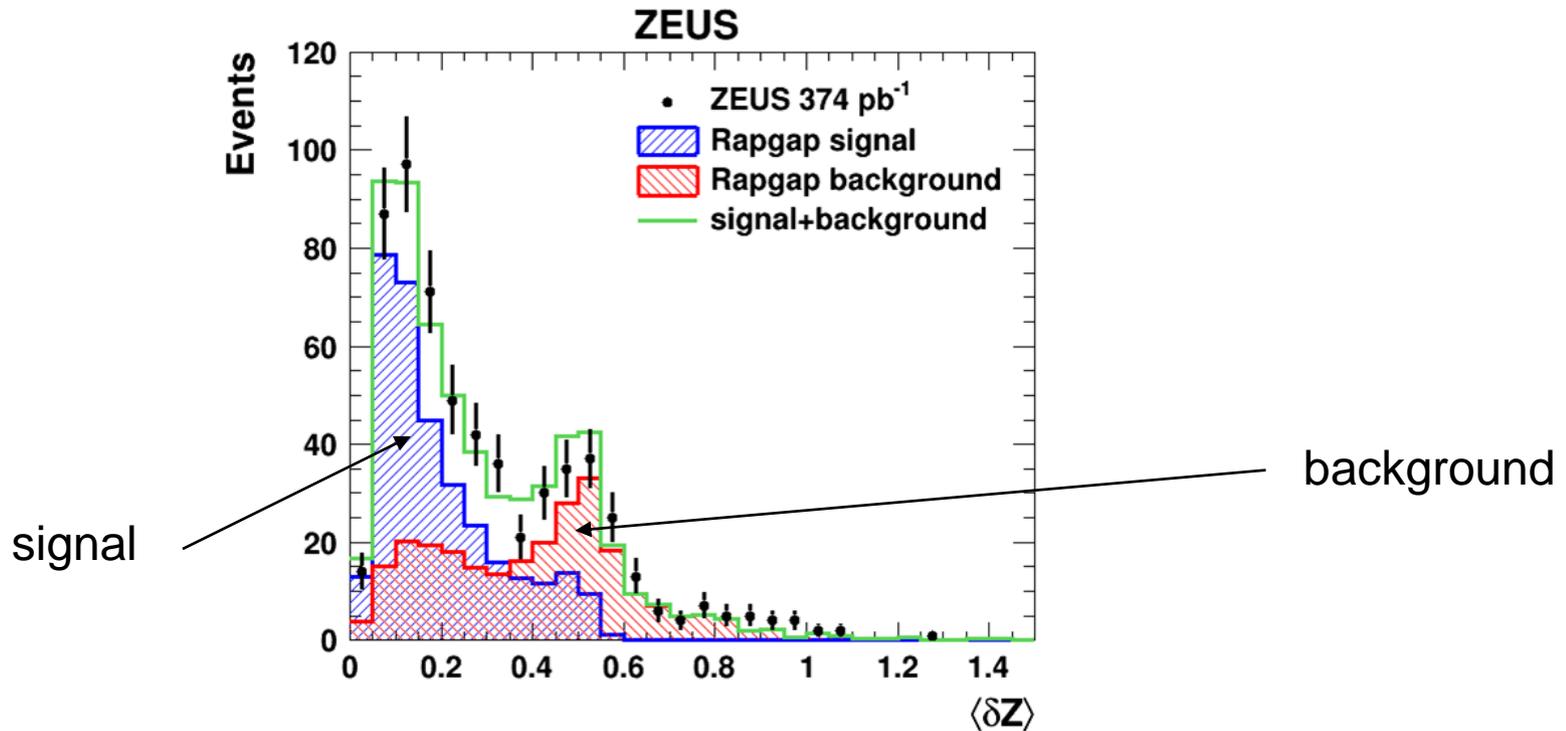
- 1) The forward scattered proton is not measured in these analyses.
- 2) Non-diffractive events are characterised by a forward proton shower. To remove them, require $\eta_{\max} < 2.5$ and $x_{\text{IP}} < 0.03$
 η_{\max} is evaluated from ZEUS energy flow objects (EFOs), which combine tracking and calorimeter cluster information.
These cuts at hadron level define a “visible” diffractive cross section.
- 3) Remove remaining DIS events and Bethe-Heitler and DVCS events (photon + electron final state).
Exclude events with identified electron or ≤ 5 EFOs
- 4) Remaining non-diffractive events neglected, could be 0-10% of our cross sections. Treated as a systematic.
- 5) **HERA I** data: use the FPC to remove much non-diffractive background. It also suppressed many proton dissociation events.

Use HERA-I data to measure total cross section. 82 pb⁻¹

Use HERA-II data to study shapes of distributions. 374 pb⁻¹

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

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



$$\langle \delta Z \rangle = \text{E-weighted mean of } |Z_{\text{CELL}} - Z_{\text{Mean}}|.$$

Peaks correspond to photon and π^0 signals, other background is η + multi- π^0 .

In each bin of each measured physical quantity, fit for **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.

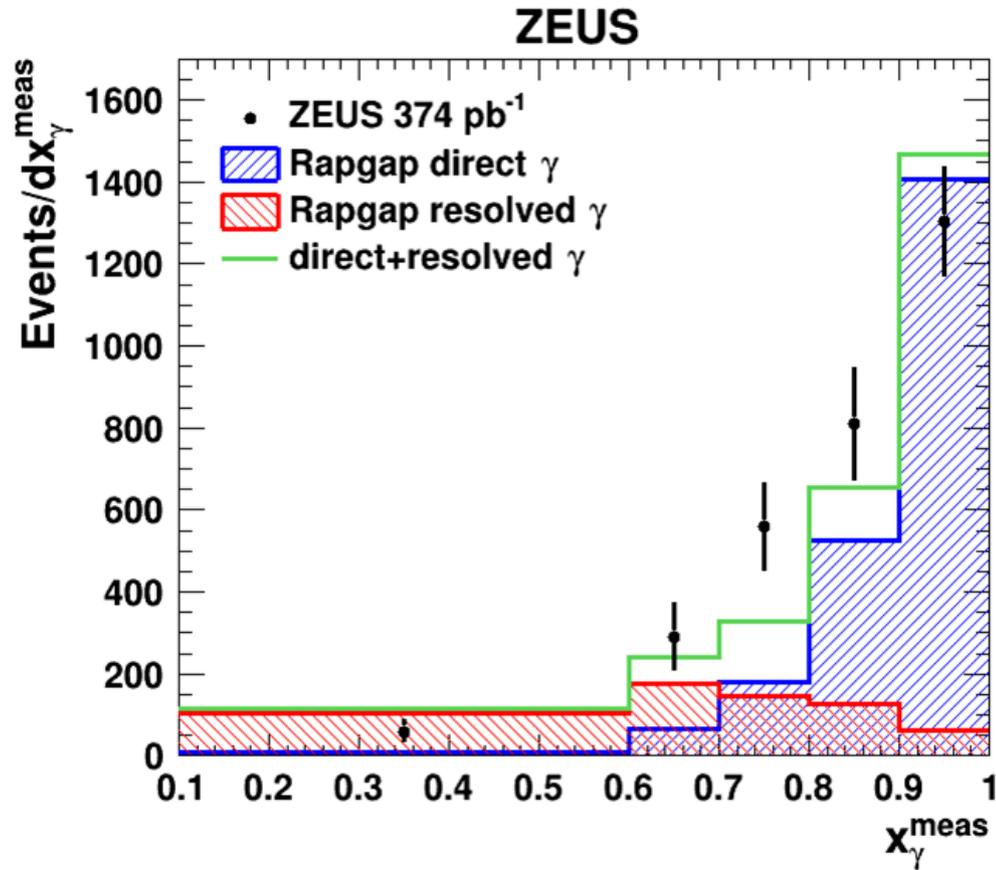
Some higher orders are modelled by initial and final state leading-logarithm parton showers.

Fragmentation uses the Lund string model as implemented in PYTHIA.

The H1 2006 DPDF fit B set is used to describe the density of partons in the diffractively scattered proton.

For resolved photons, the SASGAM-2D pdf is used.

Fit the x_γ distribution to direct and resolved RAPGAP components.
 A 70:30 mixture is found and used throughout.



$$x_\gamma^{\text{meas}} = \frac{\sum_{\gamma + \text{jet}} (E - p_z)}{\sum_{\text{all EFOs}} (E - p_z)}$$

Plot z_{IP}^{meas} and compare with Rapgap

Shape does not agree.

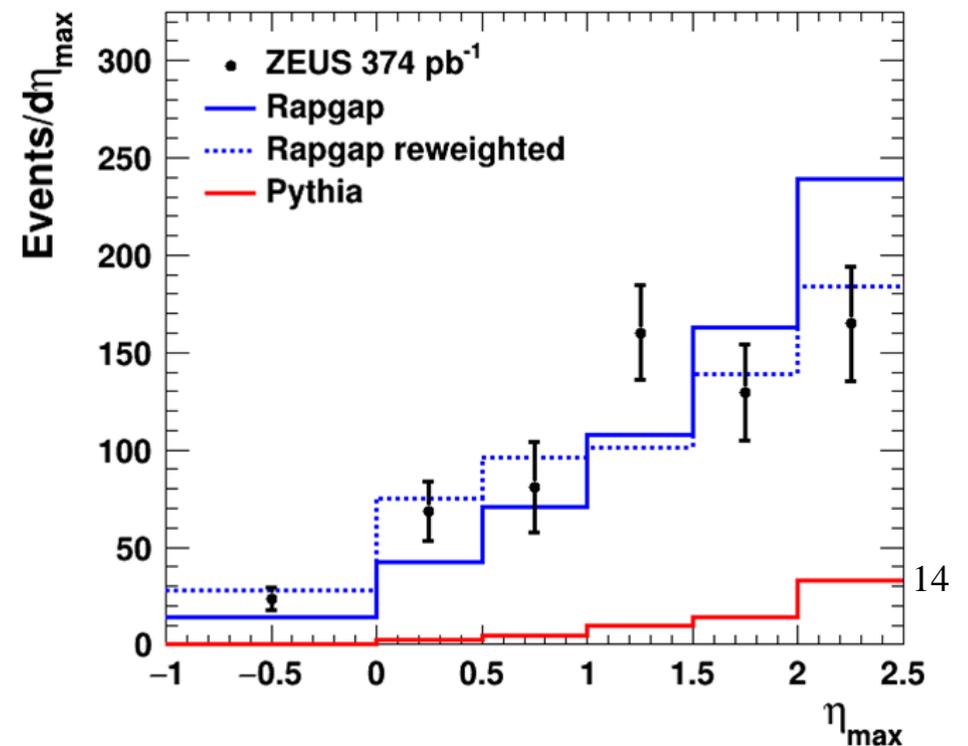
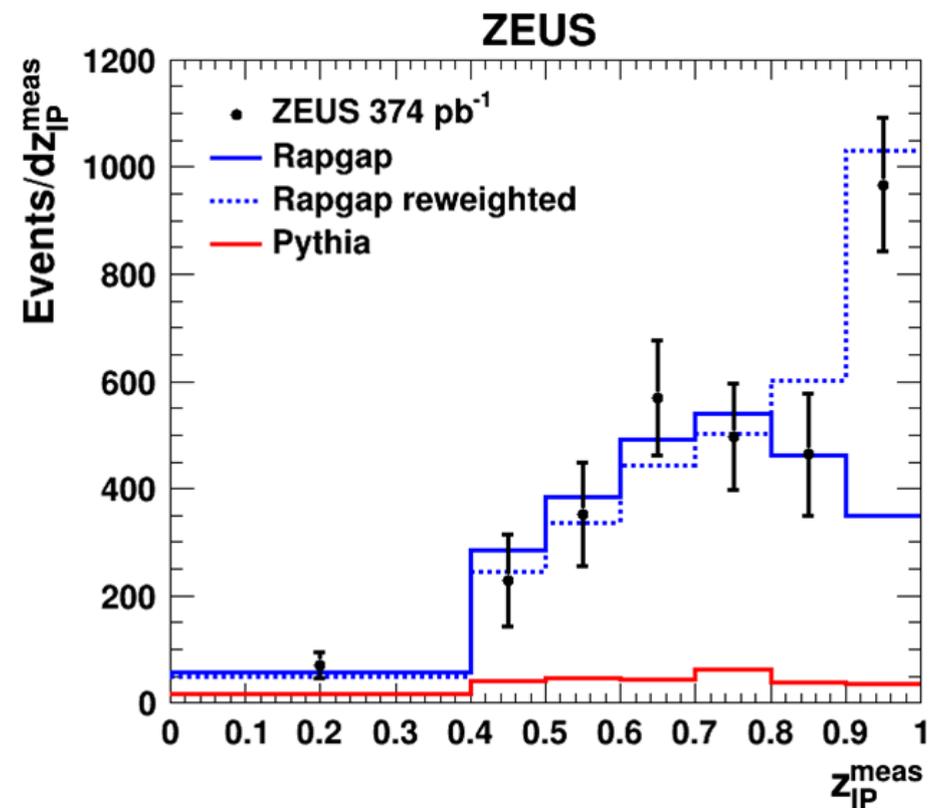
An excess is seen in the top bin.

Can reweight Rapgap to describe the shape.

Unweighted Rapgap here normalised to $z_{IP}^{meas} < 0.9$ data. Otherwise, unless stated, Rapgap is normalised to the full plotted range of data.

The η_{max} distribution is described better by the reweighted Rapgap.

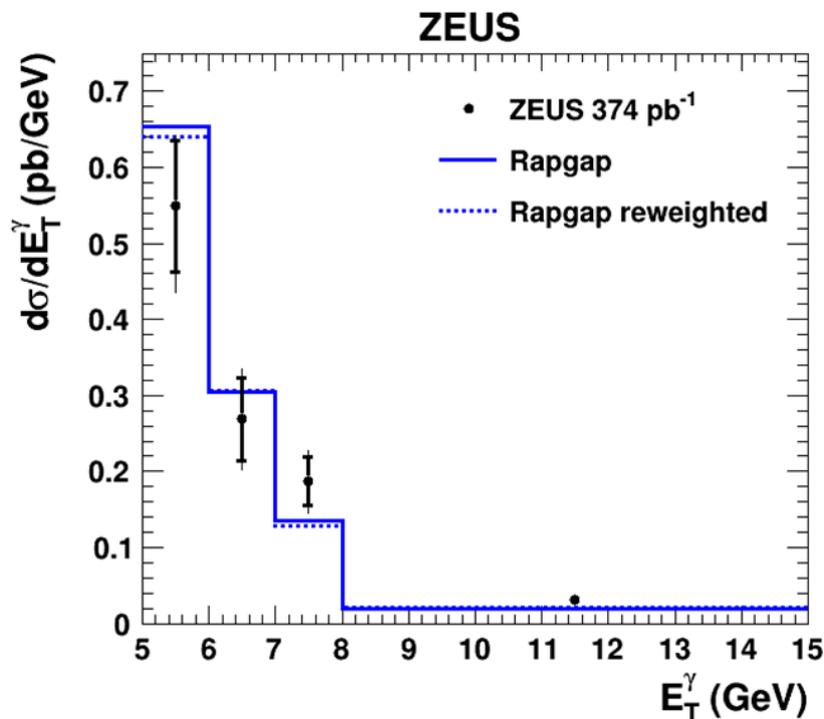
Red histogram shows what 10% of non-diffractive Pythia photoproduction (subject to present cuts) would look like. (Not added into the Rapgap.)



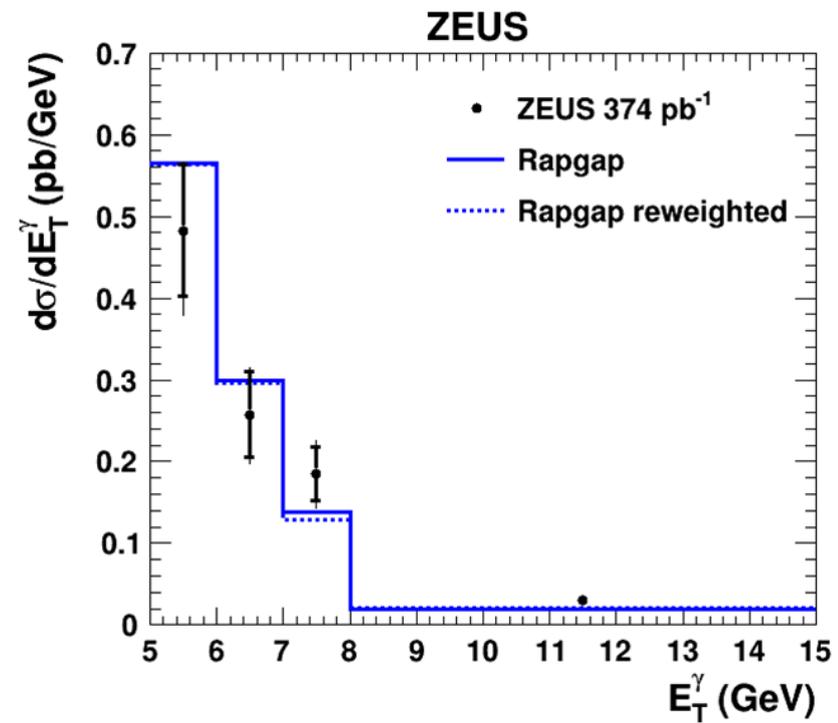
Results

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 non-diffractive subtraction uncertainty.

Transverse energy of photon.



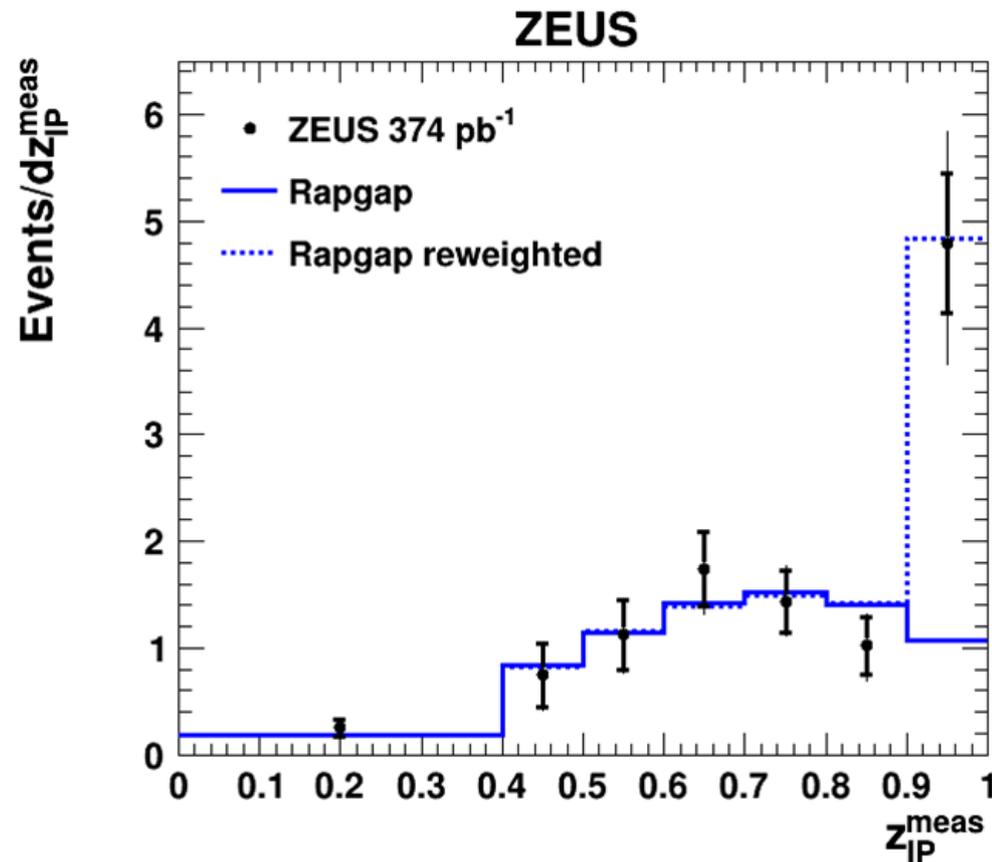
Inclusive photon



Photon + jet

Shape of data well described by Rapgap. **Most photons are accompanied by a jet.**

Cross section in $z_{IP}^{meas} = \Sigma_{\gamma + jet}(E + p_z) / \Sigma_{all\ EFOs}(E + p_z)$



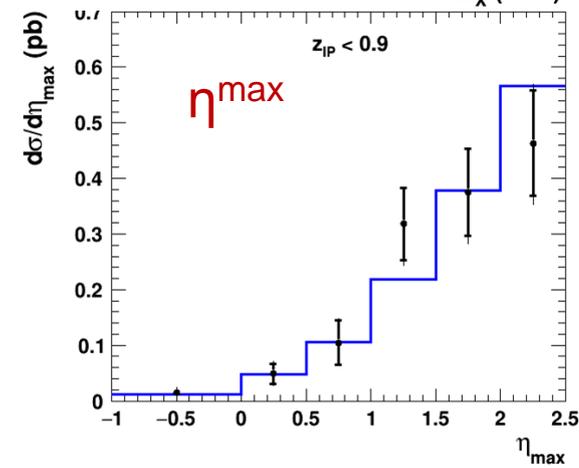
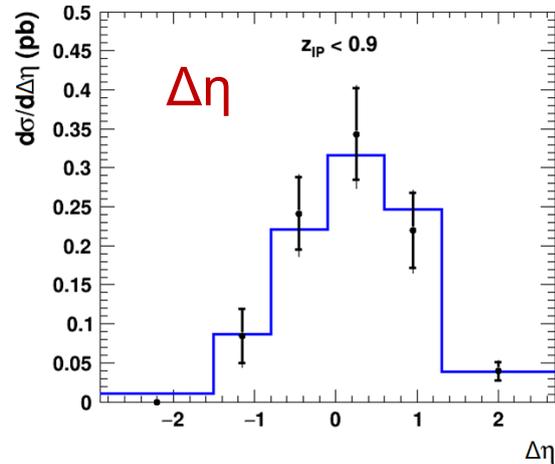
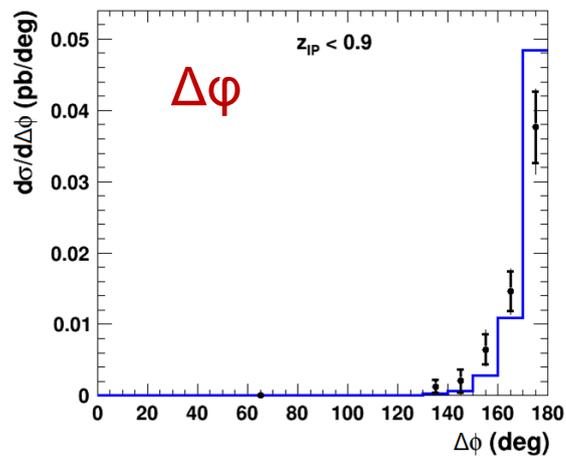
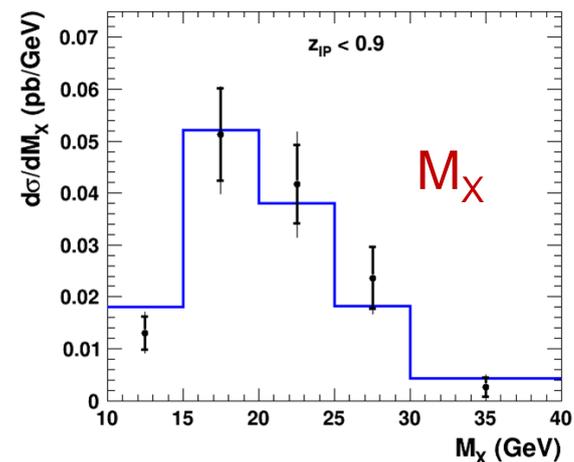
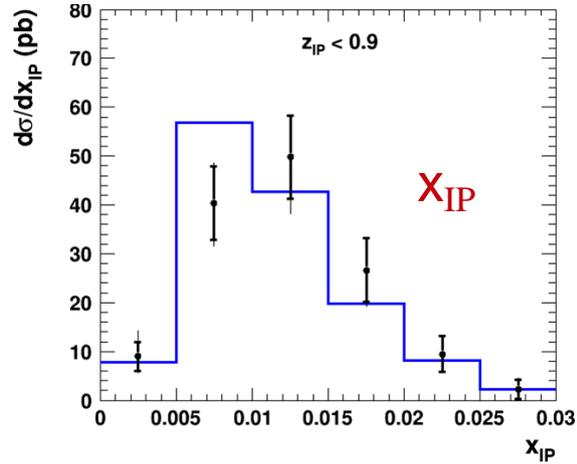
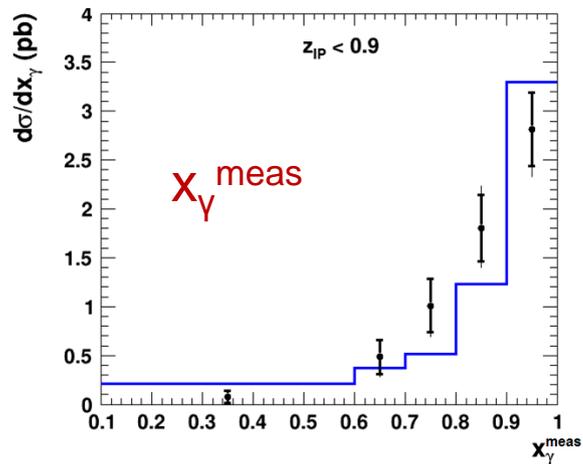
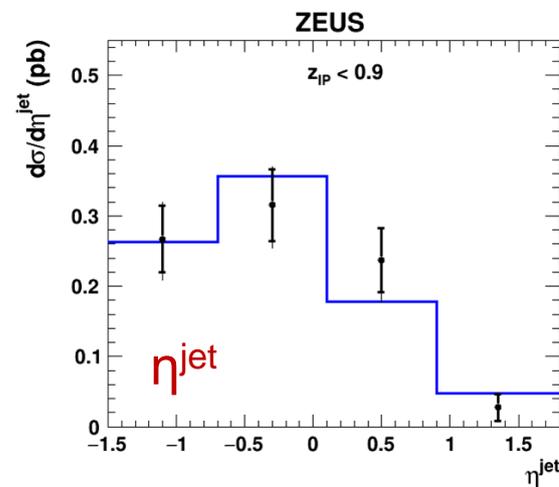
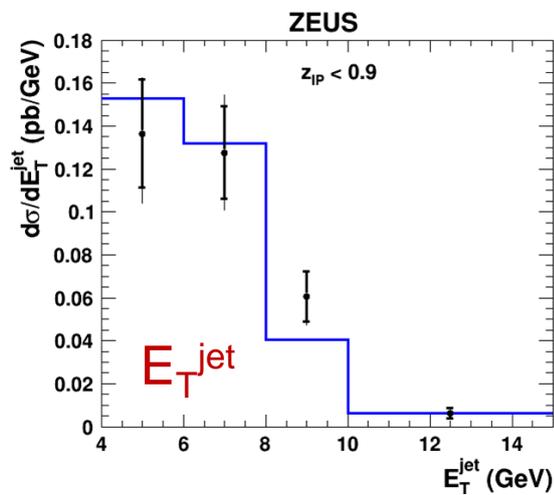
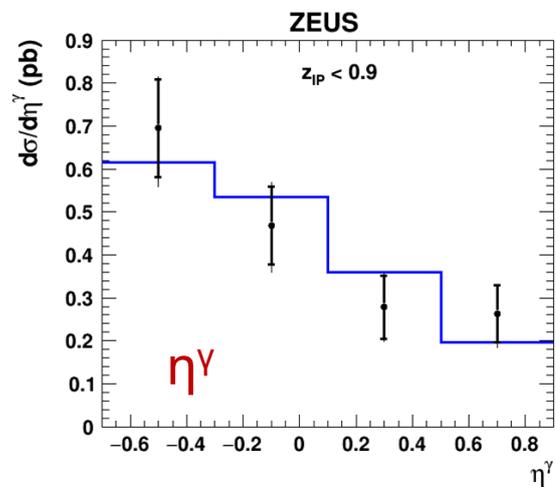
Evidence for direct Pomeron interactions

Photon-electron events have been removed.
 Other backgrounds estimated and found to be at a low level

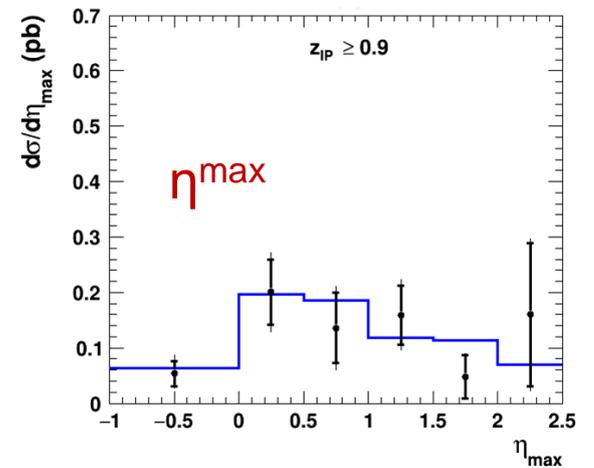
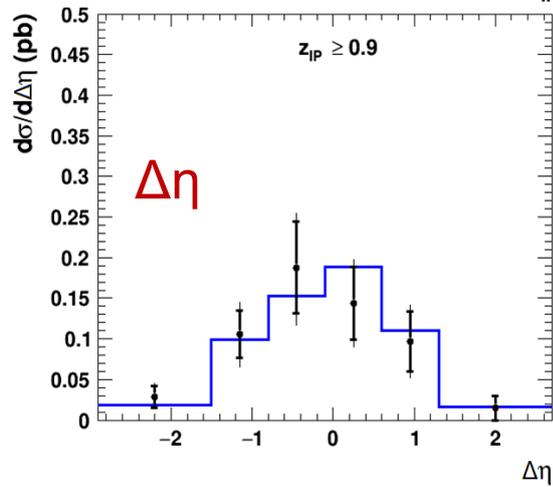
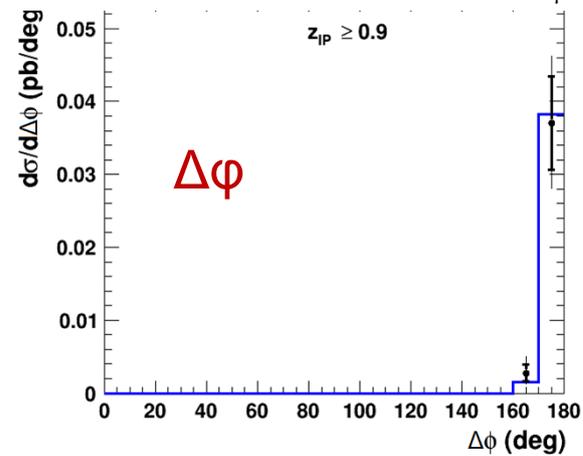
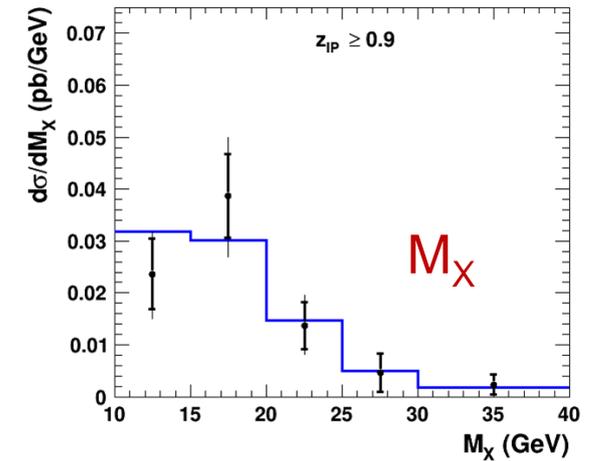
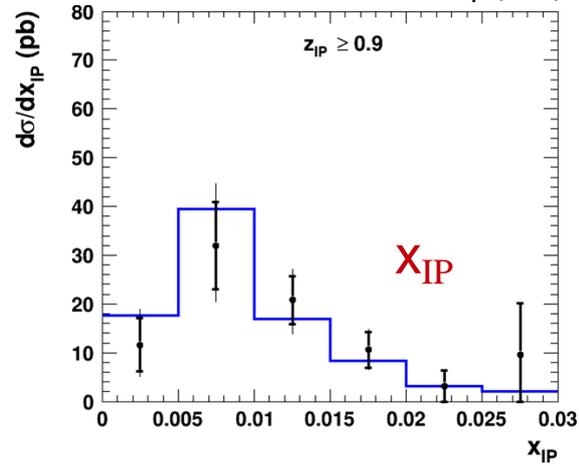
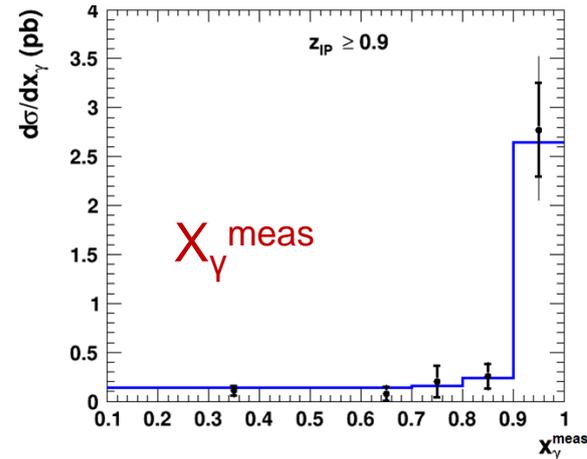
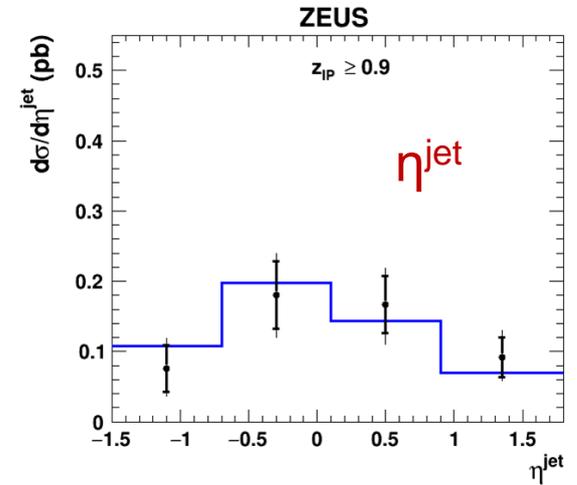
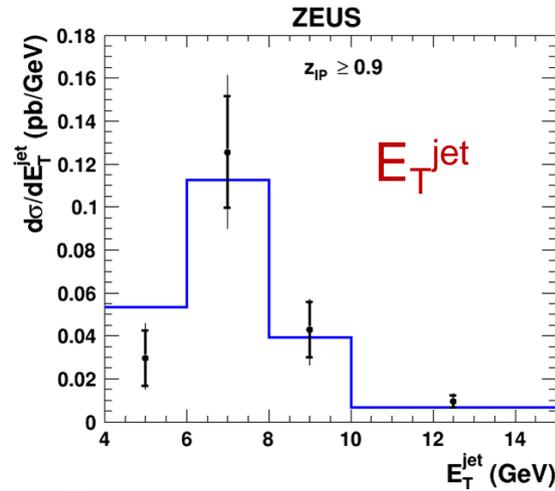
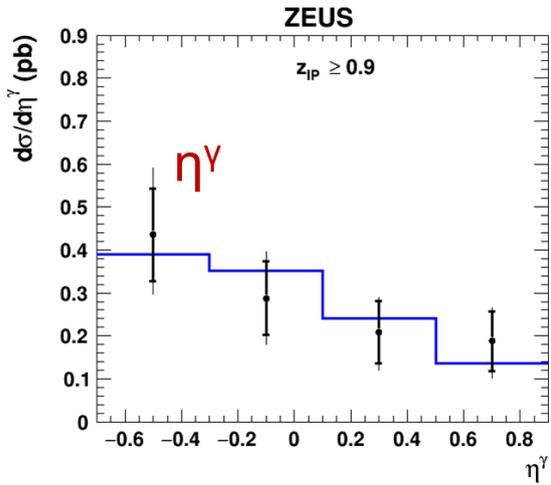
Using HERA-I data, integrated cross section for $z_{IP}^{meas} < 0.9 = 0.68 \pm 0.14^{+0.06}_{-0.07}$ pb

Rapgap gives 0.68 pb. No allowance for proton dissociation which is $\sim 16 \pm 4\%$.

Cross sections for region $z_{IP}^{meas} < 0.9$ Rapgap is normalised to data in this region.



Cross sections for region $z_{\text{IP}}^{\text{meas}} \geq 0.9$ Rapgap is normalised to data in this region.



Summary

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

Cross sections for a diffractive region defined by cuts on η_{\max} and x_{IP} have been evaluated.

Most of the detected photons are accompanied by a jet.

The variable $z_{\text{IP}}^{\text{meas}}$ shows a peak at high values that implies the presence of processes not currently modelled in RAPGAP.

This gives evidence for a direct-Pomeron process

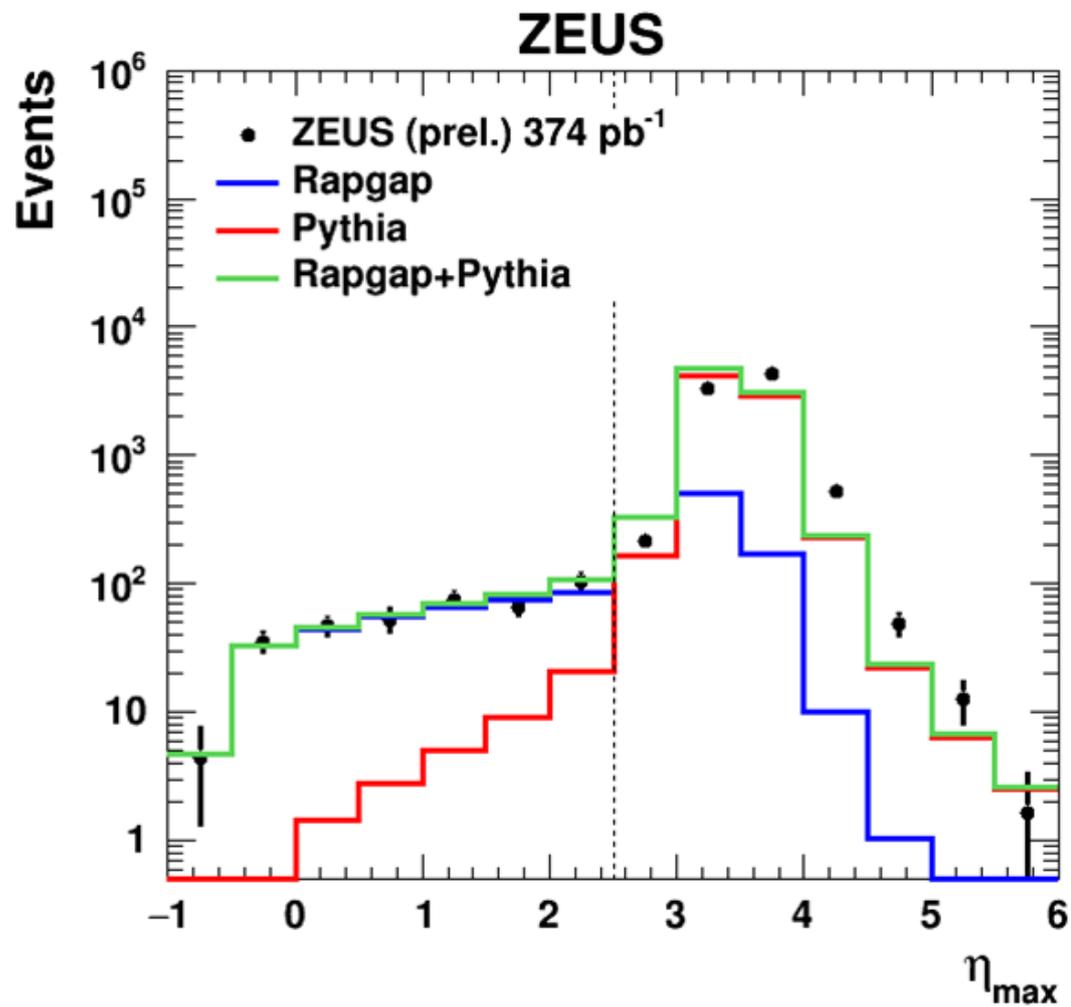
Dominantly in the direct-photon channel.

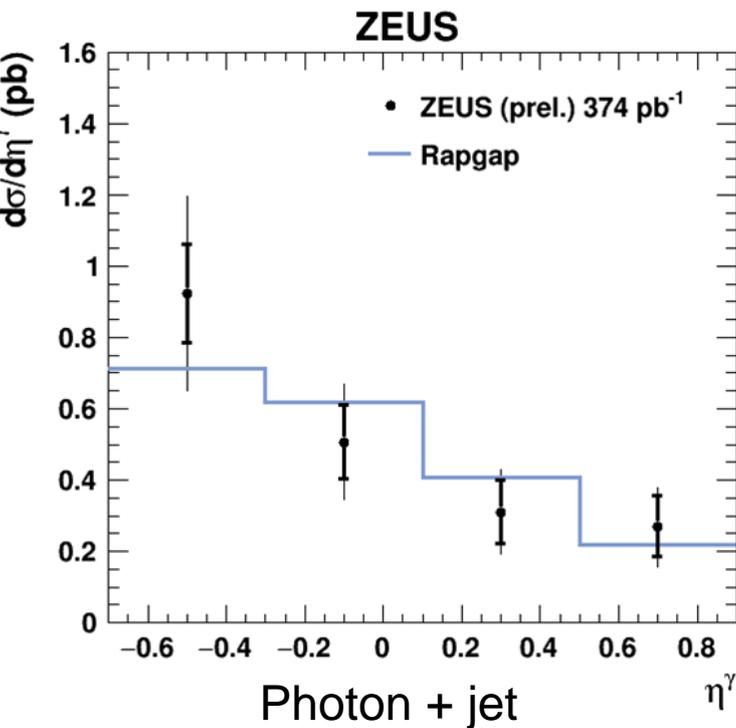
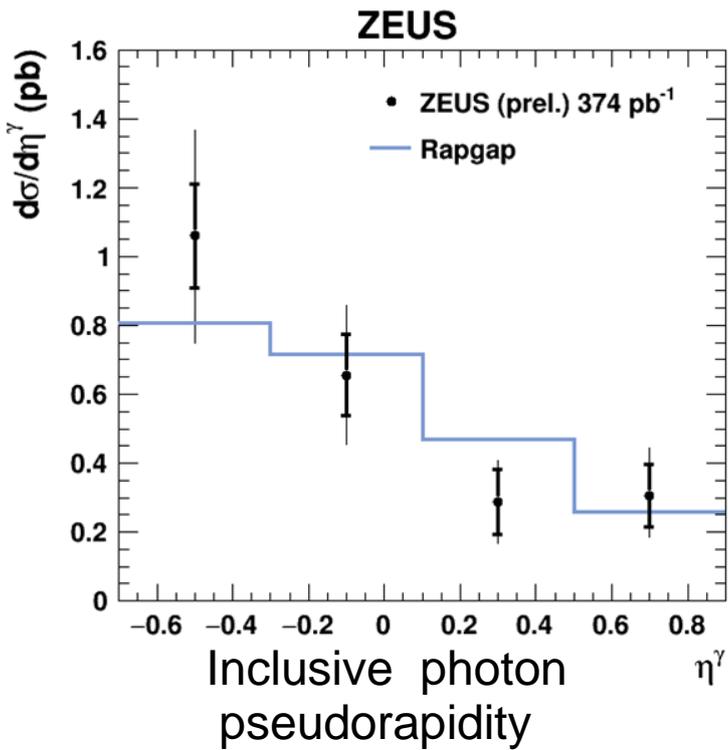
In both regions of $z_{\text{IP}}^{\text{meas}}$ the cross sections of the kinematic variables are well described in shape by Rapgap, confirming a common set of PDFs in diffractive DIS (where they were determined) and photoproduction at

$z_{\text{IP}}^{\text{meas}} < 0.9$.

Backups

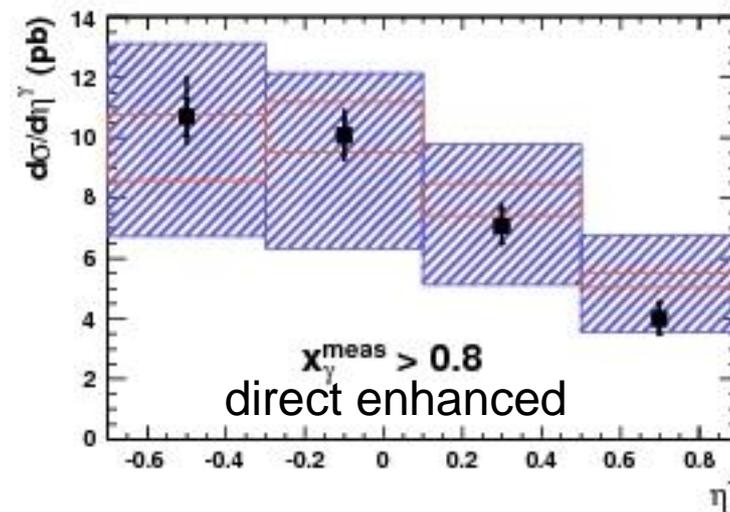
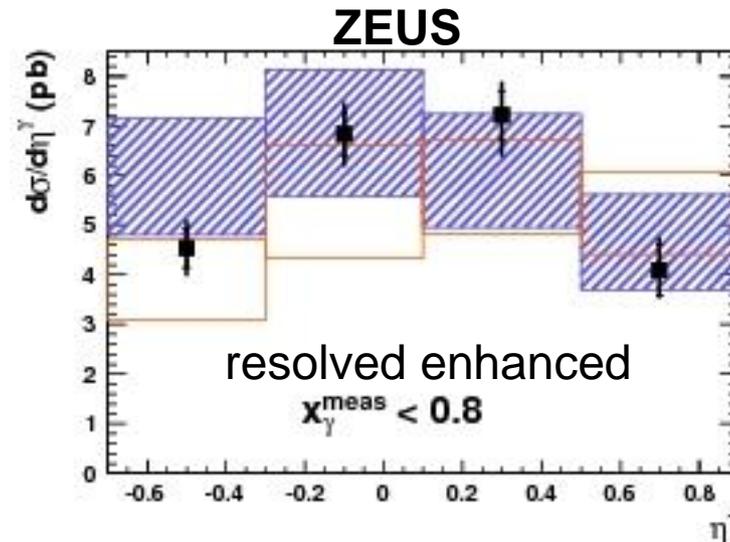
etamax distribution for HERA-2.



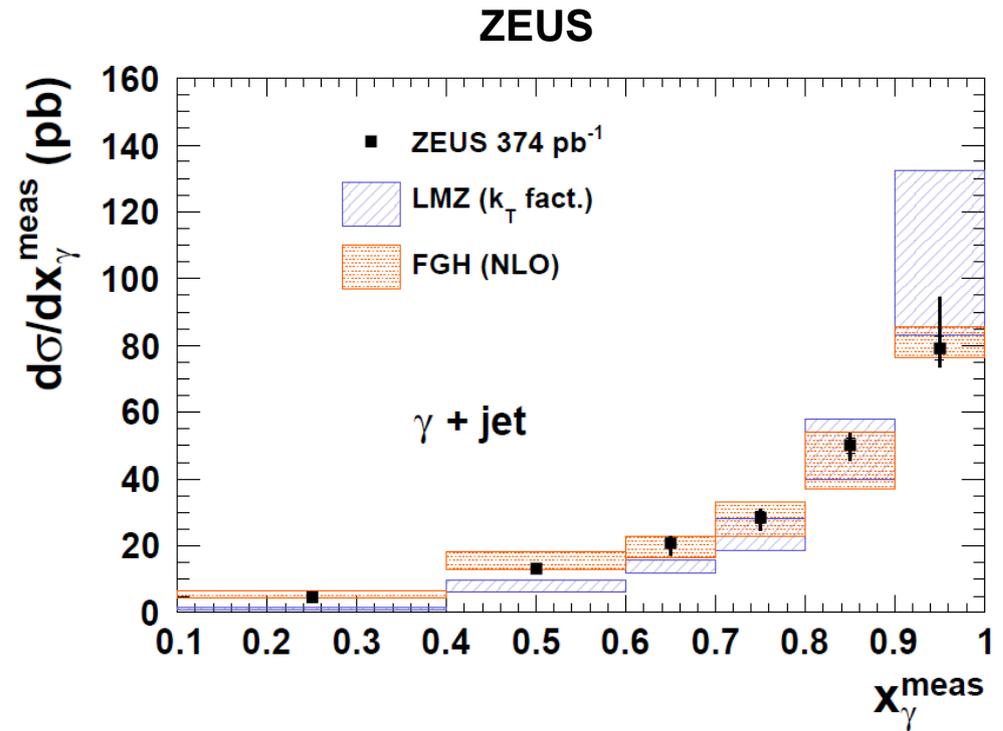
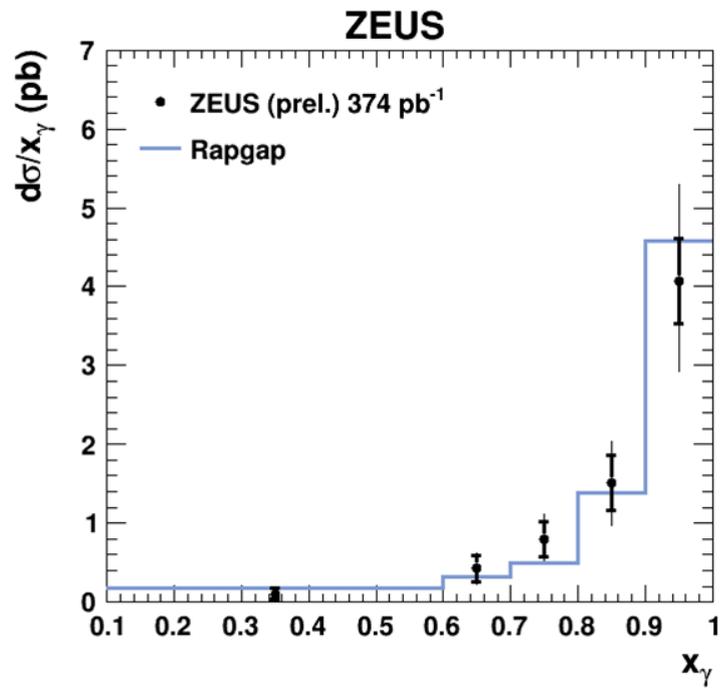


Compare diffractive photon distribution with those from nondiffractive process.

Diffractive more resembles direct but seems slightly more forward.



Compare diffractive distribution with that for nondiffractive photoproduction:



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