PROMPT PHOTONS IN DIFFRACTIVE PHOTOPRODUCTION

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

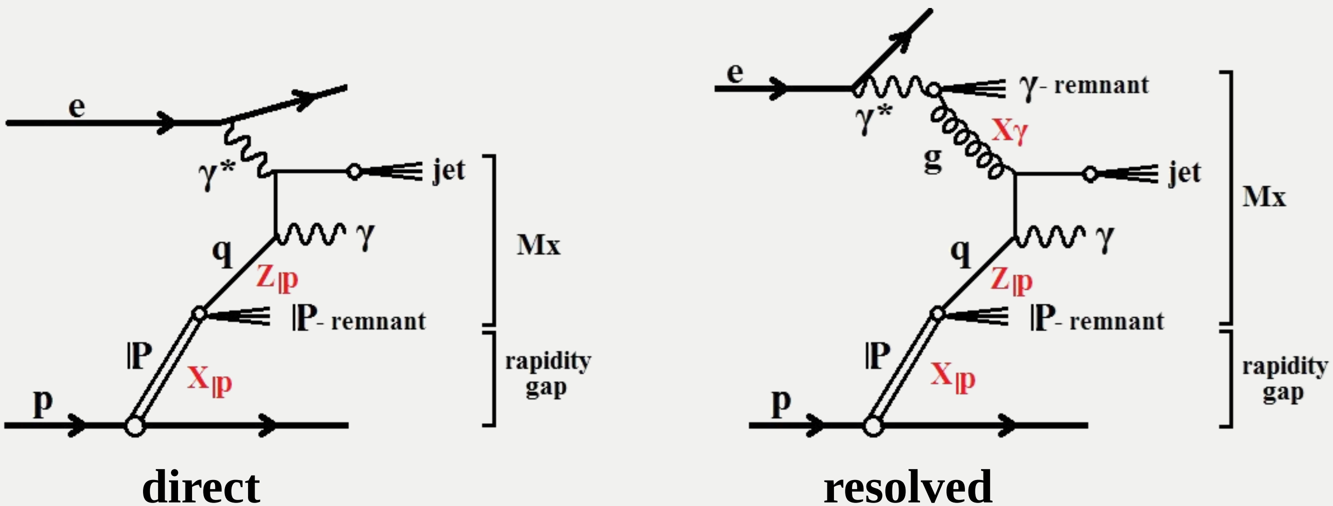
1) radiated from fragmentation within a jet;
2) radiated from the incoming or outgoing lepton;
3) produced in a initial partonic interaction:
   a) via hard interaction, $Q^2 > 1$ GeV^2 (DIS);
   b) via diffractive hard interaction by means of pomeron exchange, $Q^2 > 1$ GeV^2 (diffractive DIS);
   c) via soft interaction, $Q^2 < 1$ GeV^2 (photoproduction);
   d) via diffractive soft interaction by means of pomeron exchange, $Q^2 < 1$ GeV^2 (diffractive photoprodaction).

- Photons in these categories are relatively isolated from other outgoing particles. Third type is often called "prompt" photons.
- Here we study the "prompt" photons arising from process 3d (diffractive photoprodaction). The fist and second types are regarded as background to the third processes.

Objective

Diffractive events can be explained as the process where the scattered proton escapes in the forward direction while emitting a colorless object, the pomeron, which interacts with the electron via a photon. Such events are characterized by low momentum transfer from proton to the pomeron and a large rapidity gap between the hadrons system M_X and the proton. ***Our objective is to identify the diffractive events which are the subset of prompt photon events with low x_{IP} and η_{max}.***

From the theoretical point of view the ep-collision can proceed via two mechanisms: *direct* and *resolved:*



Kinematics quantities characterizing the diffractive photoproduction:

- x_γ - fraction of the photon energy carried by the interacting parton ($x_\gamma \approx 1$ for direct, $x_\gamma < 1$ for resolved);
- z_{IP} - fraction of pomeron momentum participating in hard process;
- x_{IP} - fraction of the proton momentum carried by the pomeron;
- η_{max} - maximum value of pseudorapidity of outgoing particles in scatter.

Motivation

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

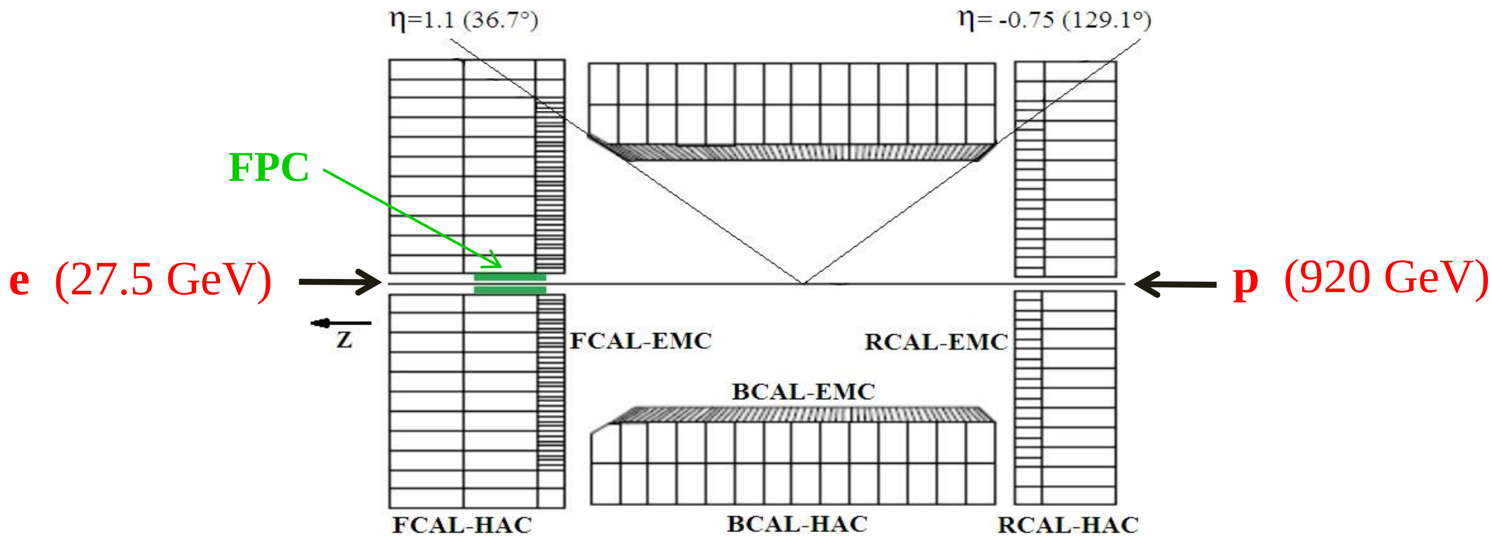
- Allows the probe of partonic structure of colorless object pomeron.

- Gives information about the quark and gluon content of the exchanged virtual photon.

Latest ZEUS and H1 publications:

- ZEUS publications of prompt photons in photoproduction:
  Phys. Lett. 730 (2014) 293, JHEP 08 (2014) 023
- H1 on inclusive diffractive prompt photons in photoproduction:
  Eur. Phys. J. C66 (2010) 17
- Diffractive photoproduced dijets:
  (H1) Eur. Phys. J. C6 (1999) 421, Eur. Phys. J. C70 (2010) 15
  (ZEUS) Eur. Phys. J. C55 C70 (2008) 177

ZEUS detector

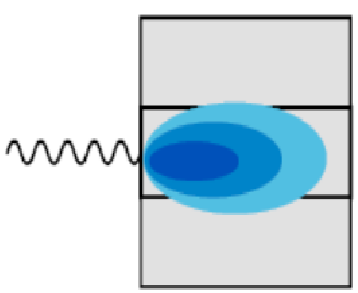


CAL – high-resolution uranium-scintillator calorimeter;
FCAL – forward CAL;
BCAL – barrel CAL;
RCAL – rear CAL;
HAC – hadronic calorimeter cells;
EMC – electromagnetic calorimeter cells;
FPC – forward plug calorimeter (1998-2000);

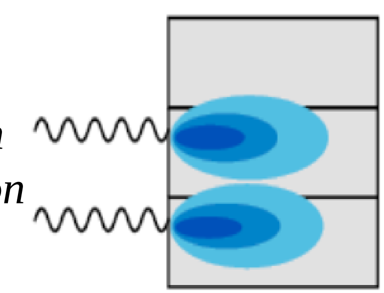
HERAI data: 1998-2000 (91 pb^{-1})
HERAII data: 2004-2007 (374 pb^{-1})

Prompt photons are measured in the BCAL which is finely segmented in the Z direction

single photon



photons from decaying meson
$\pi^0 \rightarrow \gamma\gamma$



The prompt photon analysis

Prompt photon candidate	Jet
1) $E^{\gamma}_{EMC}/(E^{\gamma}_{EMC}+E^{\gamma}_{HAC}) > 0.9$	1) use k_T -cluster algorithm
2) $5 < E^{\gamma}_{T} < 15$ GeV	2) $4 < E^{jet}_{T} < 35$ GeV
3) $-0.7 < \eta^{\gamma} < 0.9$	3) $-1.5 < \eta^{jet} < 1.8$
4) $E^{\gamma}/E^{jet} > 0.9$	

The diffractive analysis

Diffractive prompt photon candidate
1) $\eta_{max} < 2.5$
2) $x_{IP} < 0.03$
3) $E_{FPC} < 1$ GeV (in HERAI case)

$\boldsymbol{\eta_{max}}$ is evaluated from ZEUS energy flow objects (EFOs), which combine tracking and calorimeter cluster information;

$\mathbf{E_{FPC}}$ is energy deposit in forward plug calorimeter (FPC);

$$\mathbf{x_{IP}} = \frac{\sum_i (E_i + p_{Zi})}{2E_{proton}}$$ - sum over all EFOs.

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 modeled by initial and final state leading-logarithm parton showers.
- Fragmentation is performed using the Lund string model as implemented in PYTHIA.
- Parton density of proton: H1 2006 Set-B NLO DPDF.
- Parton density of resolved photon: SaSG 1D LO PDF (parameterization of Schuler, Sjöstrand)
- Parton density of pomeron: H1 2006 Set-B NLO DPDF.

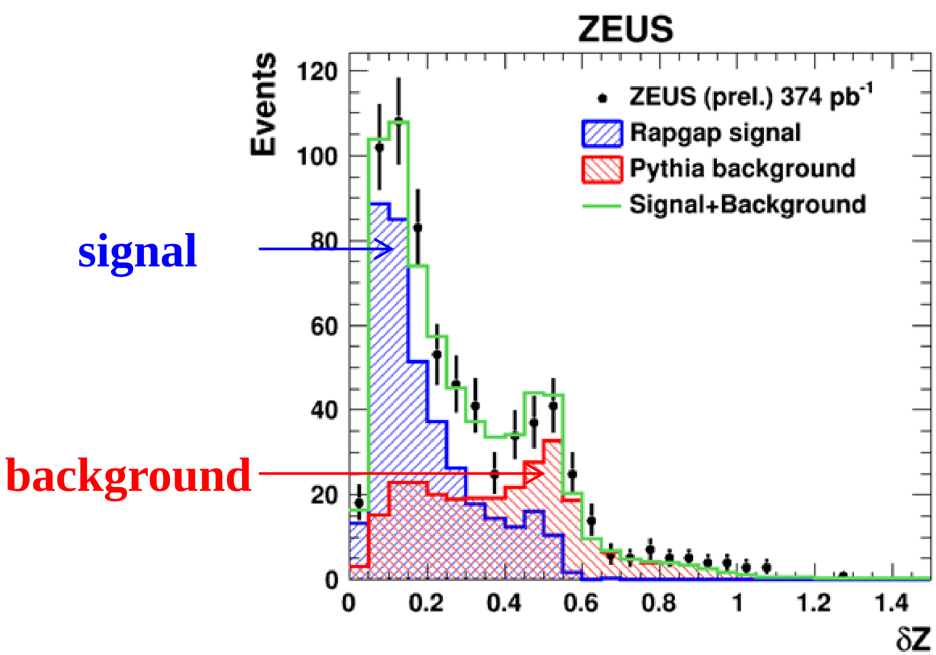
The PYTHIA and HERWIG MC samples were used for modeling the usual non-diffractive photoproduction.

RAPGAP does not fit the η_{max} distribution very well, apply reweighting when evaluating the acceptances:

$$w = \begin{cases} 1 - 0.5(\eta_{max} - 1), & w \geq 0.45 \\ 0.45, & w < 0.45 \end{cases}$$

Procedures and methods

- The applying of diffractive cuts to experimental data does not guarantee to get pure diffractive signal after selection. There is always some amount of non-diffractive background - the prompt photons originated in usual photoproduction. One must extract this contribution. We perform this extraction using information from MC simulations of usual non-diffractive events (PYTHIA and HERWIG MC generators).
- Our ***general method*** to distinguish the signal from hadronic background is based on MC fit of the dZ distribution (δZ - *energy weighted mean width of the electromagnetic cluster in Z direction*). This fit allows us statistically separate prompt photon left peak (signal) from π^0 decay right peak (background).



$$\delta Z = \frac{\sum_i E_i |Z_{cluster} - Z_i|}{w_{cell} \sum_i E_i}$$ - sum over signals in cluster

In each bin of each measured physical quantity we fit photon signal + hadronic background

HERAI, η_{max} data (fitted photons) and MC distributions

γ+jet selection

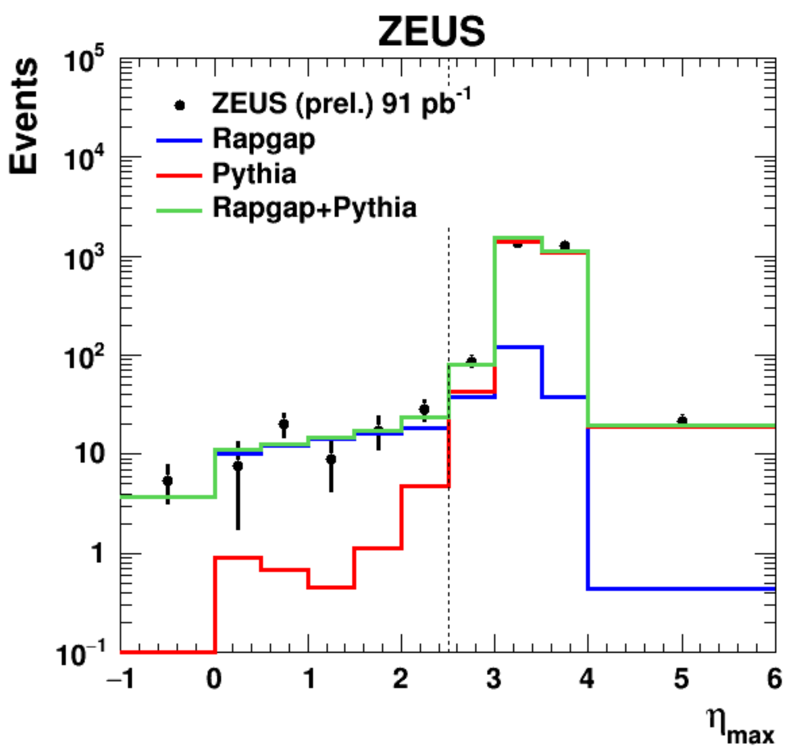
black dots – data (photoproduction photons);

blue – RAPGAP signal (reweighted), 80/20 sum, approximately normalized to fit the diffractive region of the η_{max} distribution;

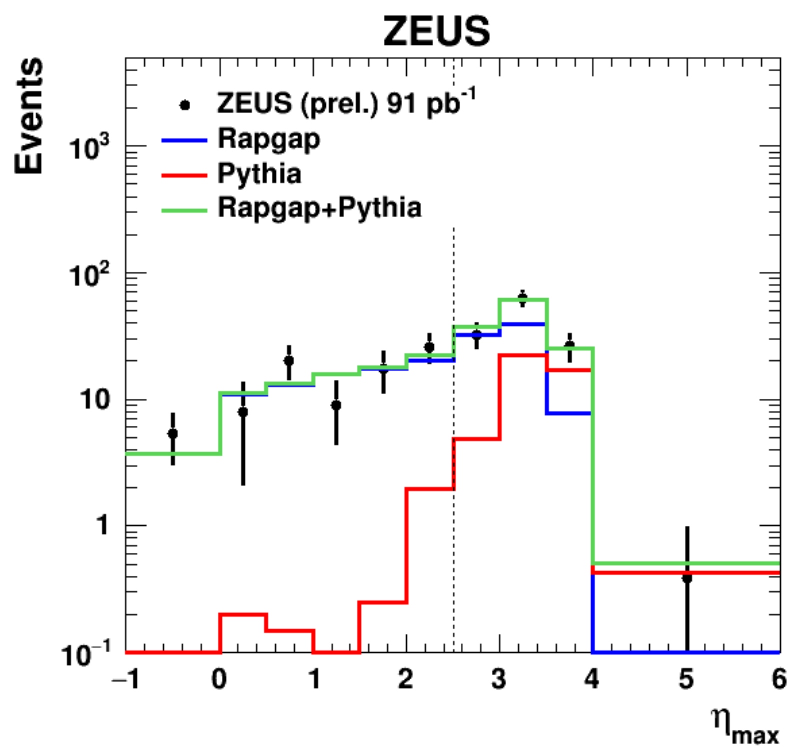
red – PYTHIA non-diffractive signal, 50/50 sum, normalized to the black data minus blue RAPGAP signal;

green – blue RAPGAP diffractive signal + red PYTHIA non-diffractive signal.

no diffractive cuts



Xp < 0.03



For HERAI data RAPGAP + PYTHIA mix gives reasonable description in whole η_{max} range

HERAII, η_{max} data (fitted photons) and MC distributions

γ+jet selection, no diffractive cuts

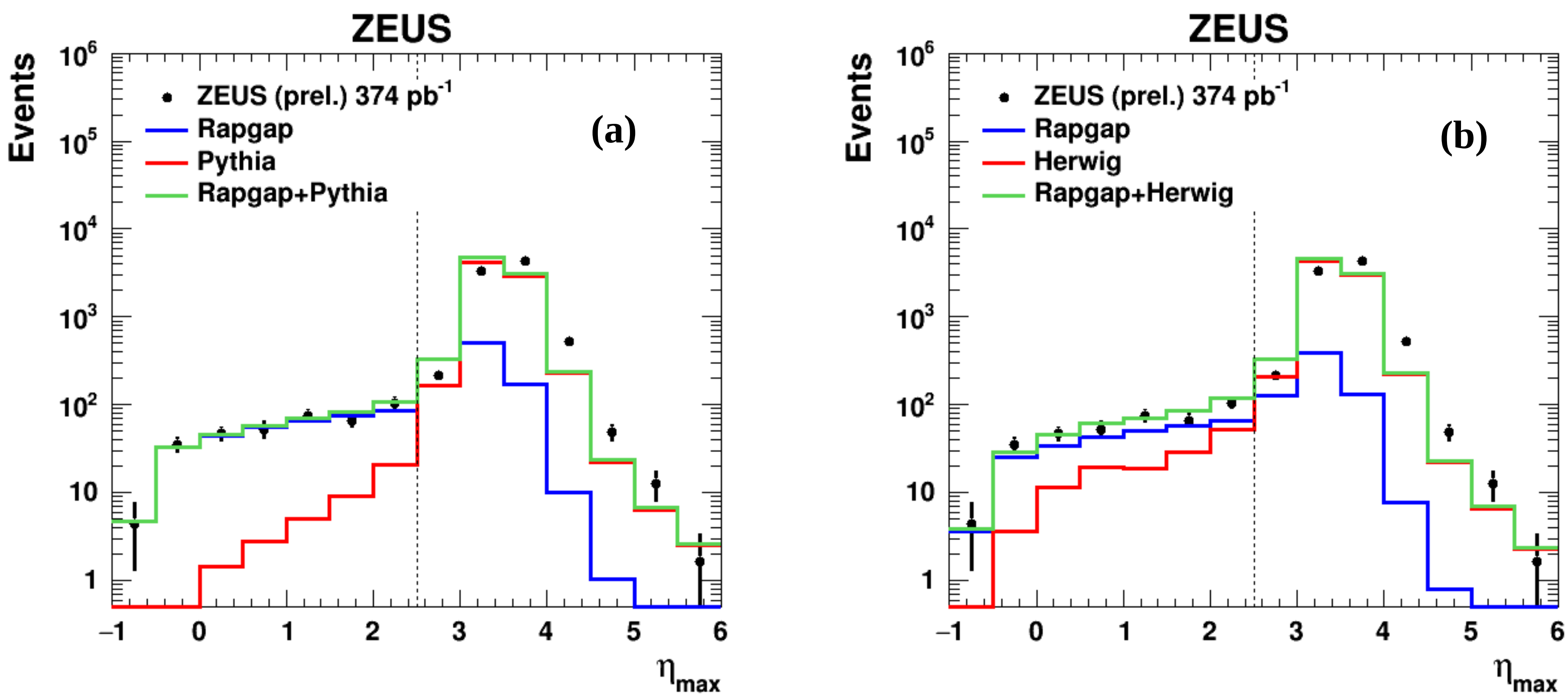
black dots – data (photoproduction photons);

blue – RAPGAP signal (reweighted), 80/20 sum, approximately normalized to fit the diffractive region of the η_{max} distribution;

red – PYTHIA(a)/HERWIG (b) non-diffractive signal, 50/50 sum, normalized to the black data minus blue Rapgap signal;

green – blue RAPGAP diffractive signal + red PYTHIA(a)/HERWIG(b) non-diffractive signal.

non-diffractive signal – PYTHIA **non-diffractive signal – HERWIG**



For diffractive region both PYTHIA and HERWIG gives reasonable description of data. HERWIG contains more events at low η_{max} than PYTHIA.

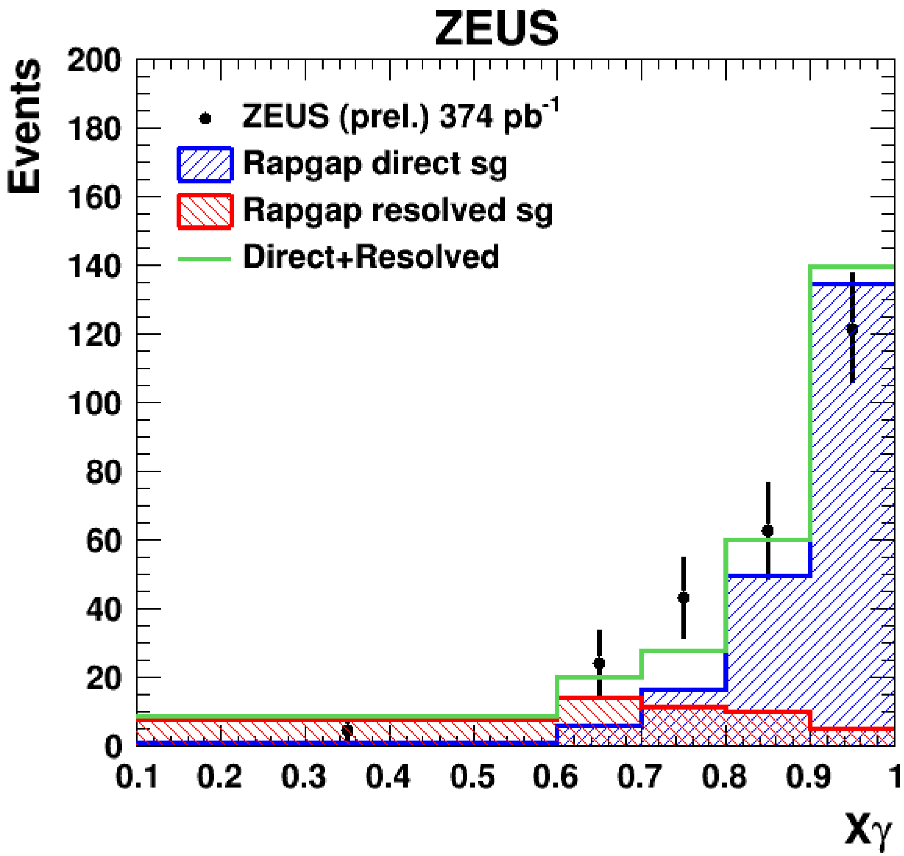
HERAII, the estimation of the fraction of direct and resolved events in data signal.

The fit of reweighted MC RAPGAP direct and resolved events to x_γ data signal distribution

HERAII, γ+jet selection, diffractive cuts are applied,

PYTHIA/HERWIG mean non-diffractive subtraction, Y axis - events per 0.1 bin interval

data is with non-diffractive events extracted



$$\mathbf{x_\gamma = \frac{E_\gamma + E_{jet} - p_{Z\gamma} - p_{Zjet}}{\sum_i (E_i - p_{Zi})}}$$ - sum over all EFOs

The fraction of direct/resolved events is: **81/19 ± 3%**

HERAII differential cross sections for photon E_T

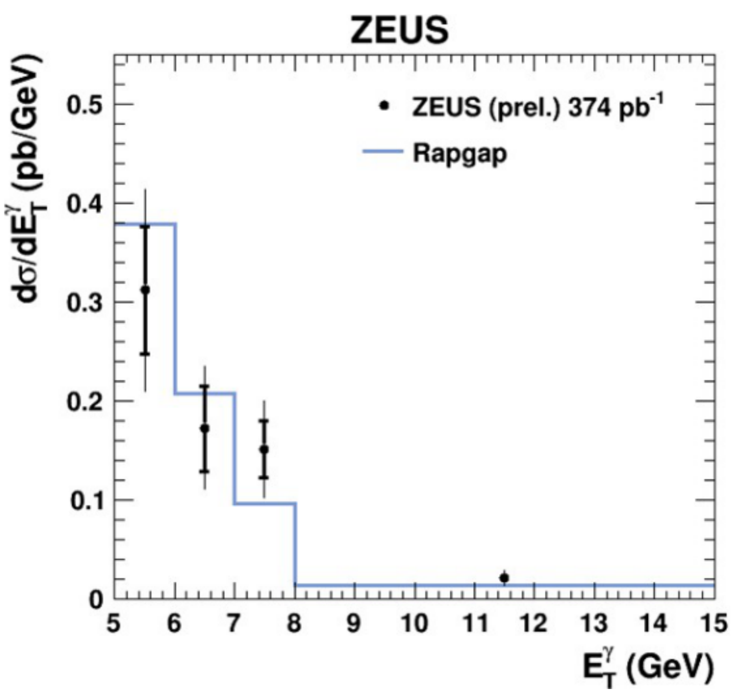
black – apply PYTHIA+HERWIG mean non-diffractive subtraction. Normalized to HERAI total cross section;

blue – RAPGAP prediction normalized to HERAII total cross section;

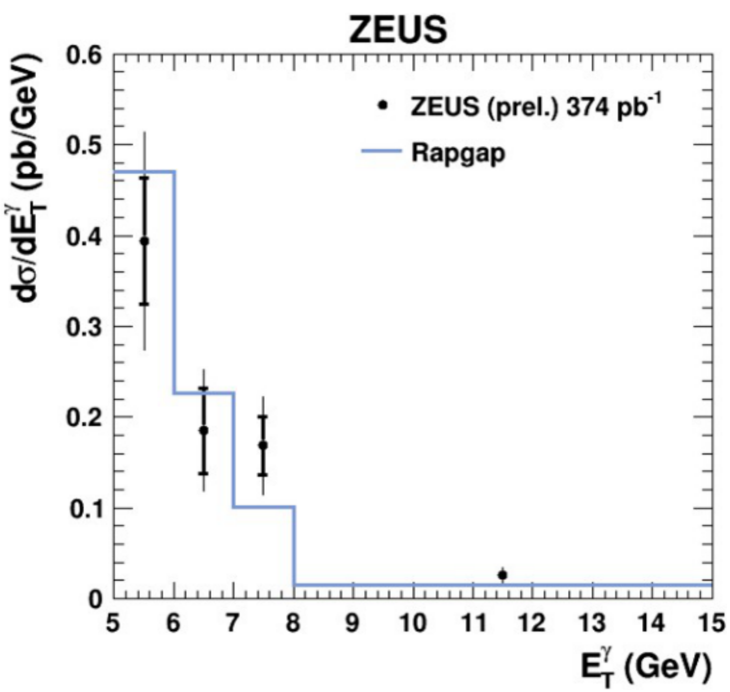
inner error bar is statistical.

outer (total) error bar + systematic + normalization + non-diffractive subtraction uncertainty.

γ+jet selection



inclusive selection



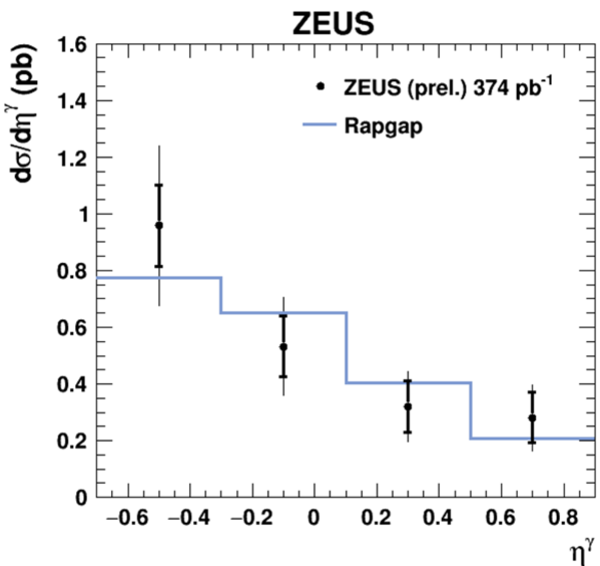
Shape of RAPGAP is fairly well described.
Most photons are accompanied by a jet.

HERAII differential cross sections for photon η

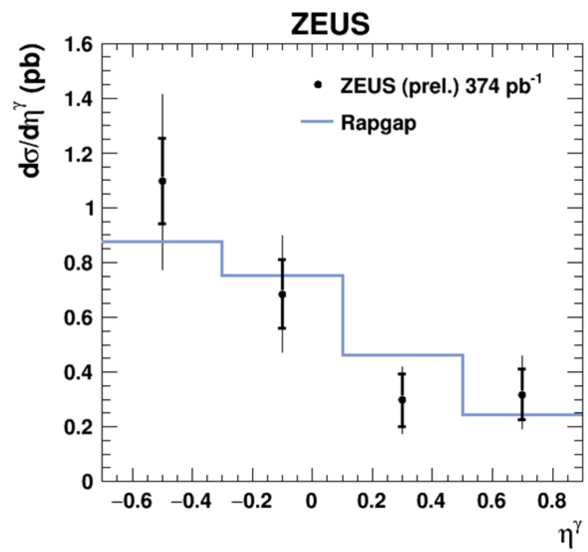
black – apply PYTHIA+HERWIG mean non-diffractive subtraction. Normalized to HERAI total cross section;

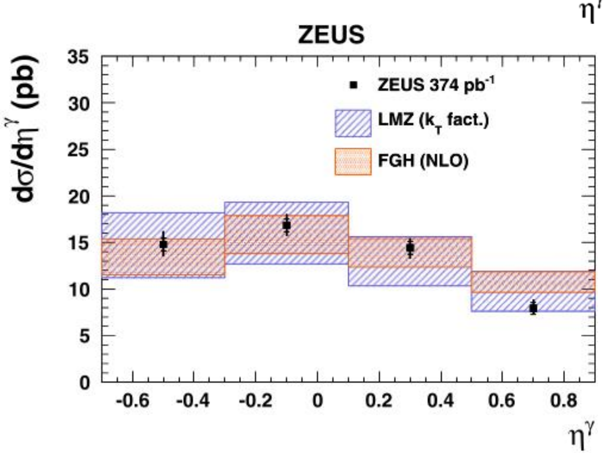
blue – RAPGAP prediction normalized to HERAII total cross section;

γ+jet selection

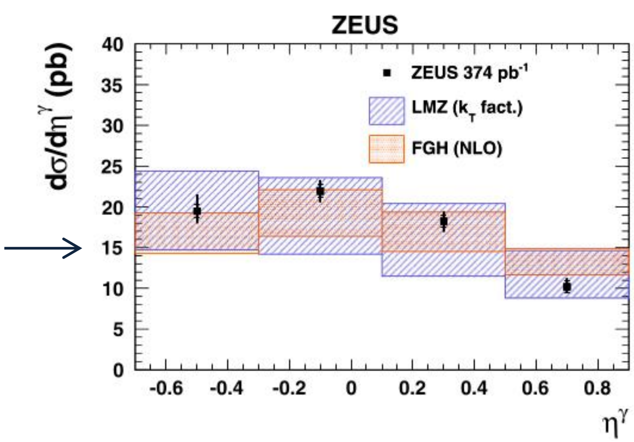


inclusive selection





Results from previous work on prompt photons in photoproduction (Phys. Lett. 730 (2014))

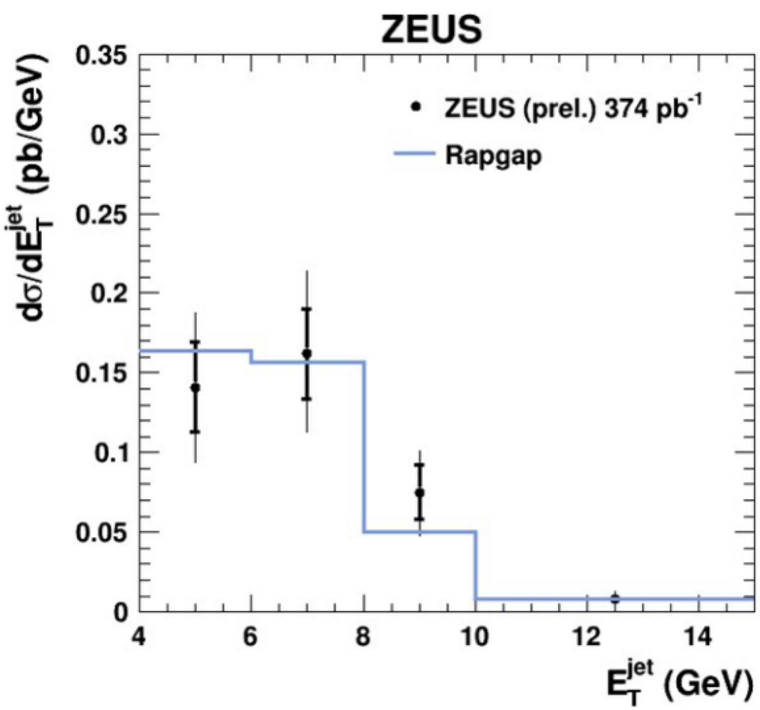


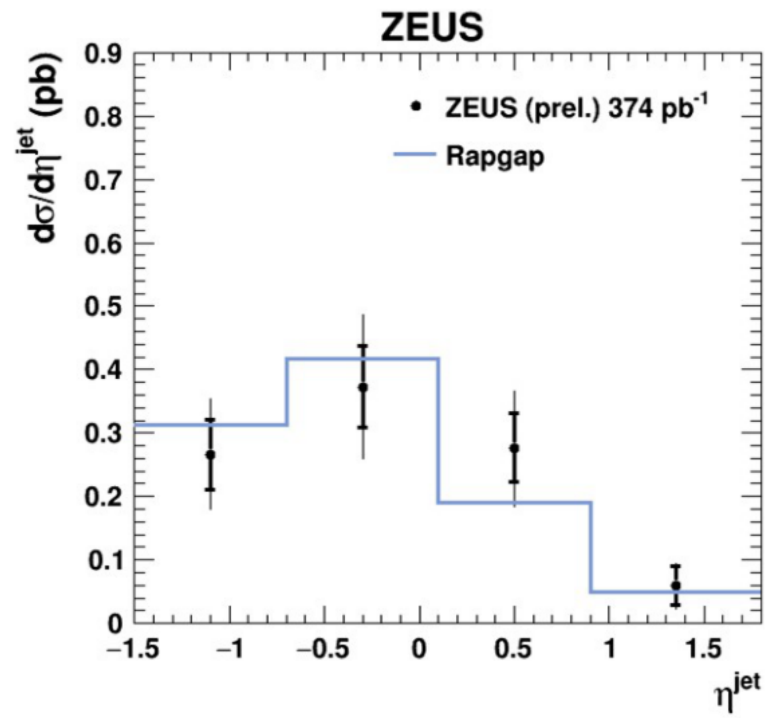
The RAPGAP prediction reproduces the behavior of data points and is consistent with them within errors.

HERAII differential cross sections for accompanying jet E_T and η

black – apply PYTHIA+HERWIG mean non-diffractive subtraction. Normalized to HERAI total cross section;

blue – RAPGAP prediction normalized to HERAII total cross section;



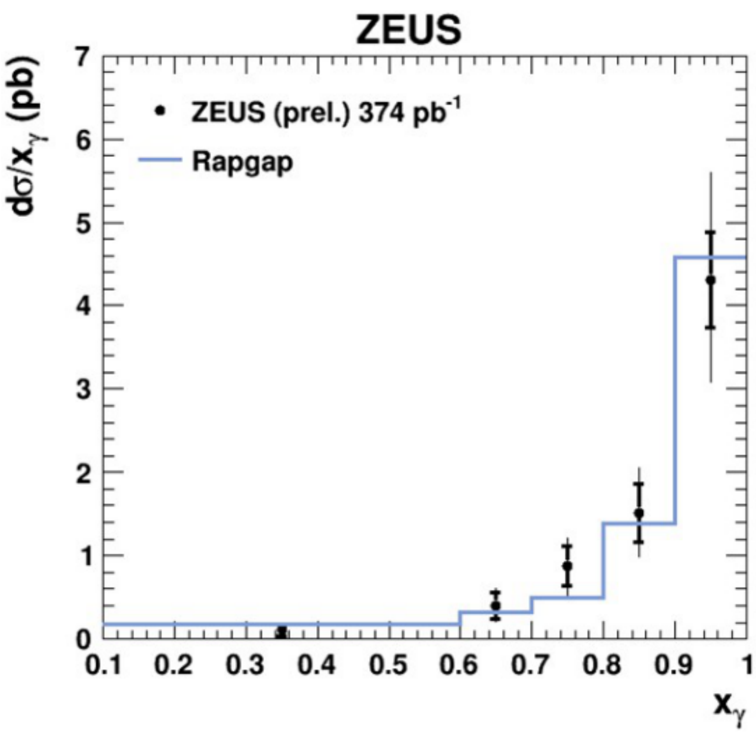


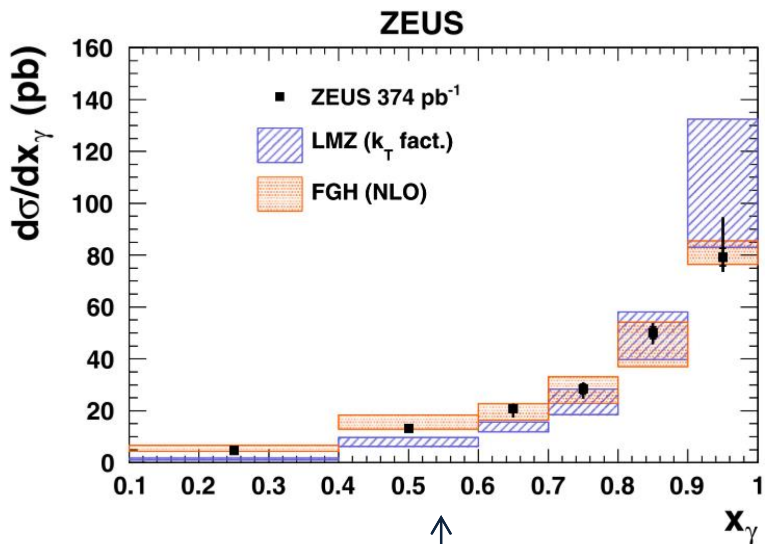
RAPGAP gives a good description of both variables.

HERAII differential cross sections for x_γ, γ+jet selection

black – apply PYTHIA+HERWIG mean non-diffractive subtraction. Normalized to HERAI total cross section;

blue – RAPGAP prediction normalized to HERAII total cross section;





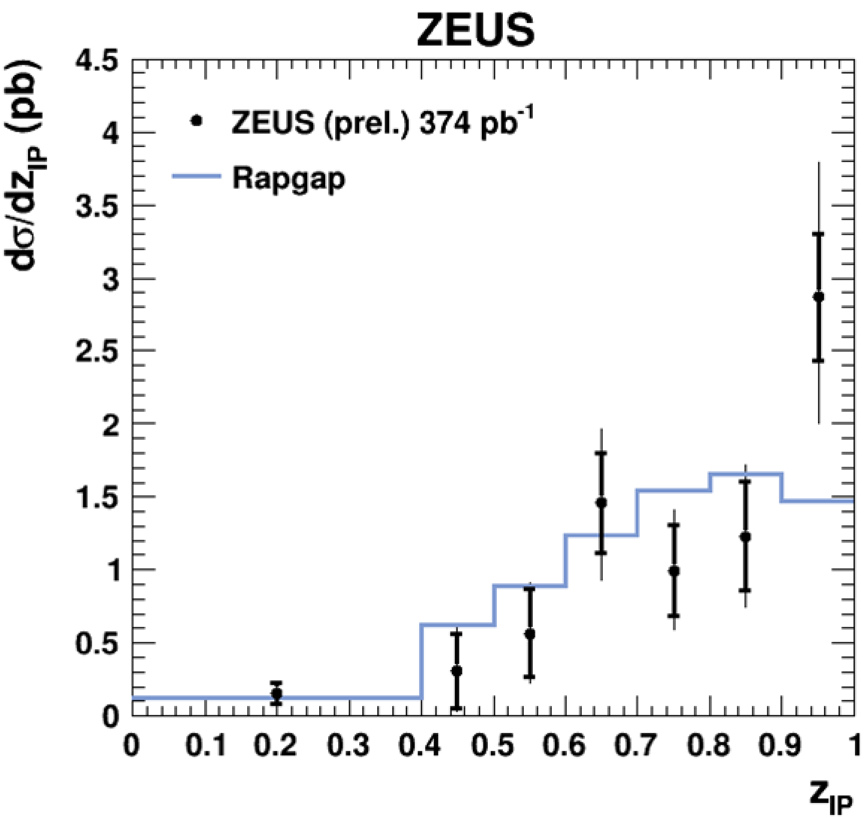
(Phys. Lett. 730 (2014))

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

HERAII differential cross sections for Zp, γ+jet selection

black – apply PYTHIA+HERWIG mean non-diffractive subtraction. Normalized to HERAI total cross section;

blue – RAPGAP prediction normalized to HERAII total cross section;



$$z_{IP} = \frac{E_\gamma + E_{jet} + p_{Z\gamma} + p_{Zjet}}{\sum_i (E_i - p_{Zi})}$$ - sum over all EFOs

The distribution in z_{IP} shows a feature that is not described by RAPGAP.

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.