DIFFRACTIVE PRODUCTION OF ISOLATED PHOTONS WITH THE ZEUS DETECTOR AT HERA

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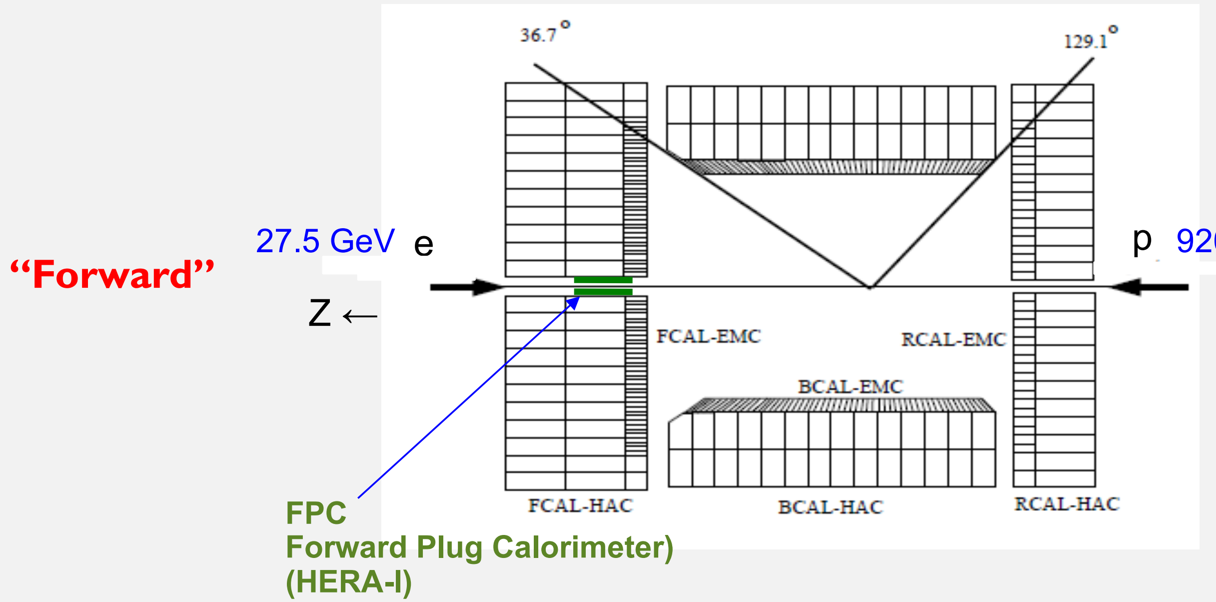
HERA-I data: 1998-2000
HERA-II data: 2004-2007

The ZEUS detector



Replaced by a beam focussing Magnet In HERA-II

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

EMC = electromagnetic section

Photoproduction: No scattered electron Observed, $0.2<y_{JB}<0.7$, usual cut

Diffraction: No energy in the forward region, $\eta_{max}^{EFO}<2.5$ - **Large Rapidity Gap (LRG)**

THE REACTION

$e^{\pm} + p \rightarrow (e^{\pm}) + \gamma + X + {}_{[LRG]} + (p \text{ or } pdiss)$

$\gamma^* + p \rightarrow \gamma + X + {}_{[LRG]} + (p \text{ or } pdiss)$

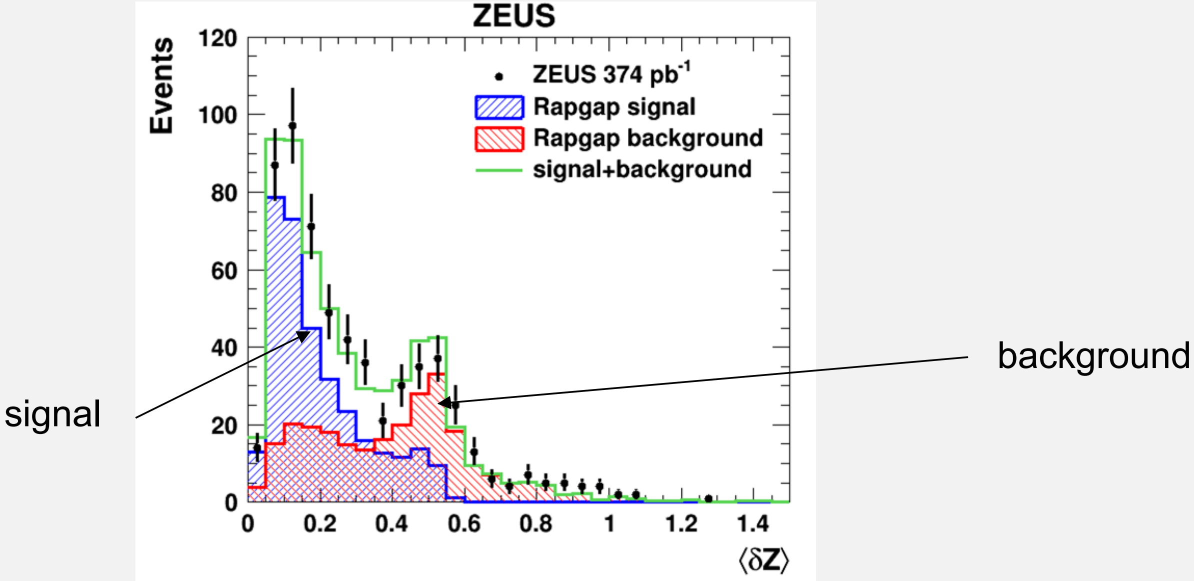
{ γ^* - quasi-real ($Q^2<1$ GeV^2, $\langle Q^2\rangle \sim 10^{-5}$GeV^2), no scattered electron observed}

γ – isolated high E_T (> 5 GeV), X – hadrons or jets

The outgoing Photon

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 **signal** photons from **background** coming from photon decays of neutral mesons.



<dZ> = E-weighted mean of $|Z_{CELL} - Z_{Mean}|$.

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.

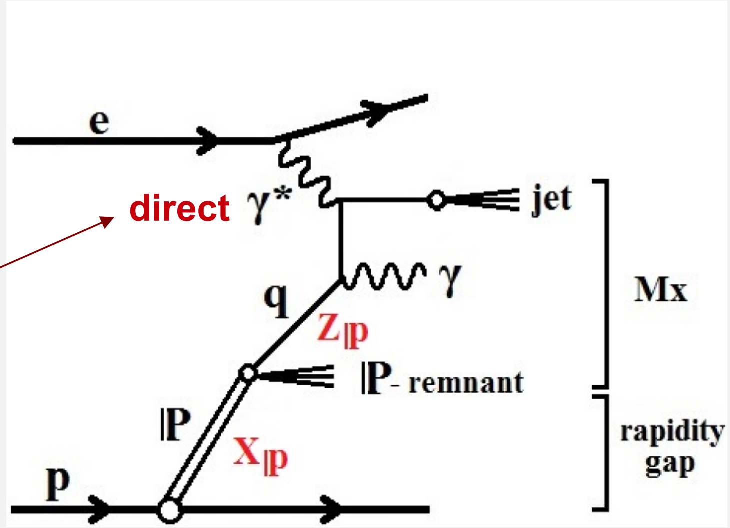
Fragmentation uses the Lund string model as implemented in PYTHIA.

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.

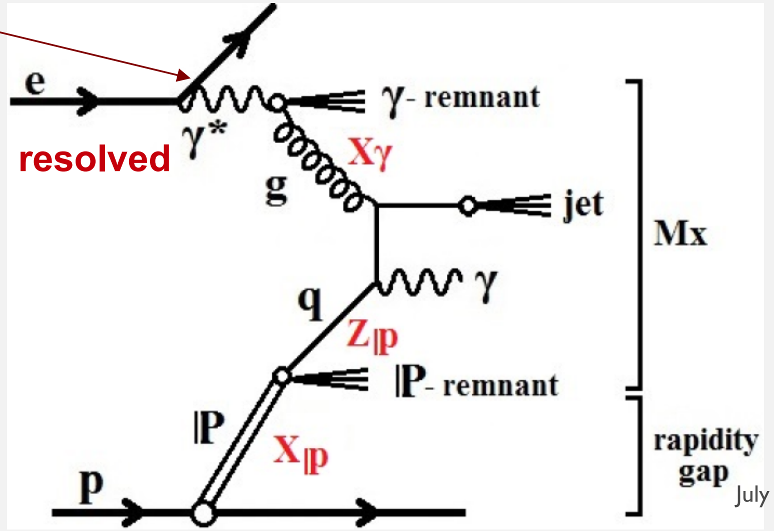
Examples of lowest-order "resolved–Pomeron" diagrams by which diffractive processes may generate a prompt photon

Direct incoming photon gives all its energy to the hard scatter (x_γ = 1).

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



Resolved incoming photon gives fraction x_γ of its energy.



Some kinematics:

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

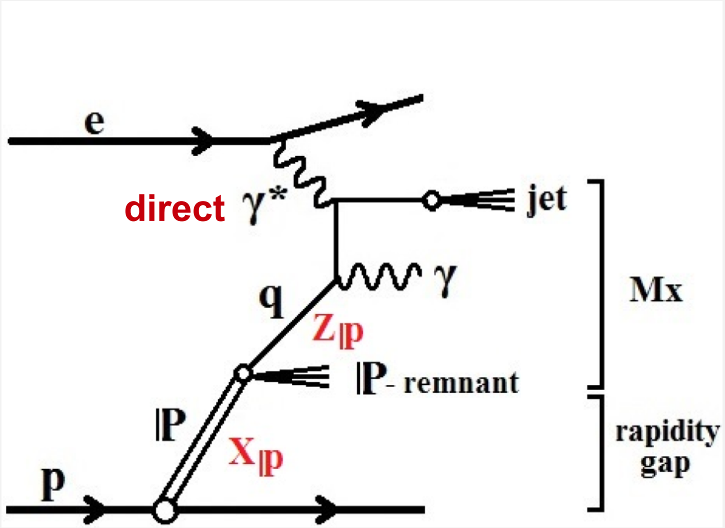
$$\Sigma_{\text{all EFOs}} (E + p_z) / 2 E_p$$

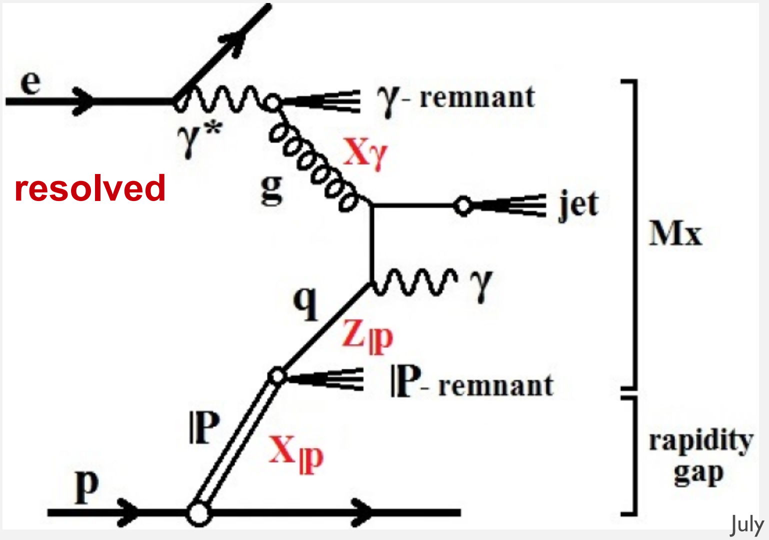
z_{IP} = fraction of Pomeron **E+p$_z$** taken by photon + jet measured as

$$\Sigma_{\gamma + \text{jet}}(E + p_z) / \Sigma_{\text{all EFOs}}(E + p_z)$$

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

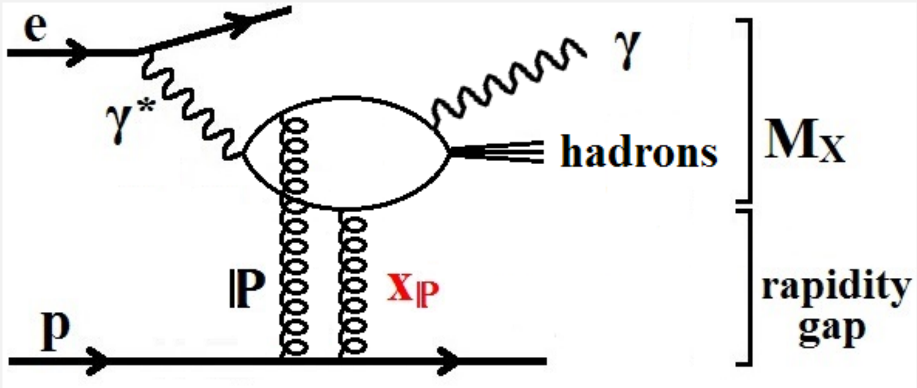
Diffractive processes are characterised by a low value of η_{max} and/or low x_{IP}.





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

THE DATA

1) The forward scattered proton is not measured in these analyses.

2) Remove non-diffractive events: $\eta_{max} < 2.5$ and $x_{IP} < 0.03$

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

3) Remove remaining DIS events and Bethe-Heitler and DVCS events.
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}

THE DATA

Hard photon candidate:

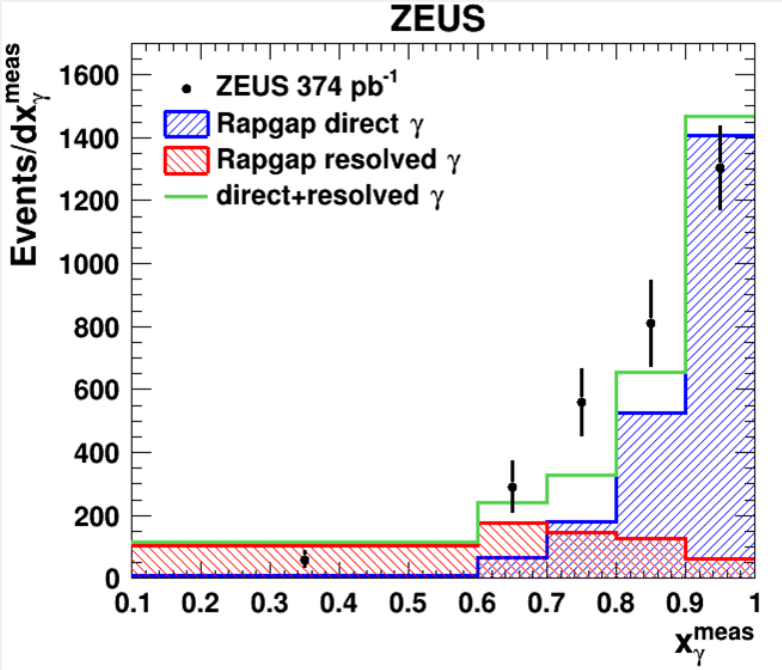
- found with energy-clustering algorithm in BCAL: $E_{EMC}/(E_{EMC}+E_{HAD}) > 0.9$
- $E_T^{\gamma} > 5$ GeV
- $-0.7 < \eta^{\gamma} < 0.9$ where $\eta \equiv$ pseudorapidity. (i.e. in ZEUS barrel calorimeter)
- **Isolated.** In the "jet" containing the photon candidate, the photon must contain at least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

Jets

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

x_γ

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



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

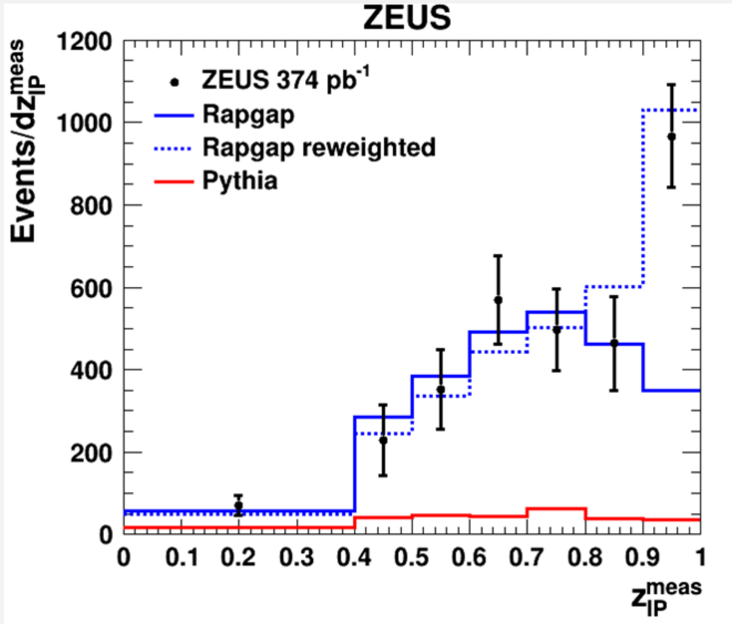
Plot z_{IP}^{meas} and compare with RAPGAP

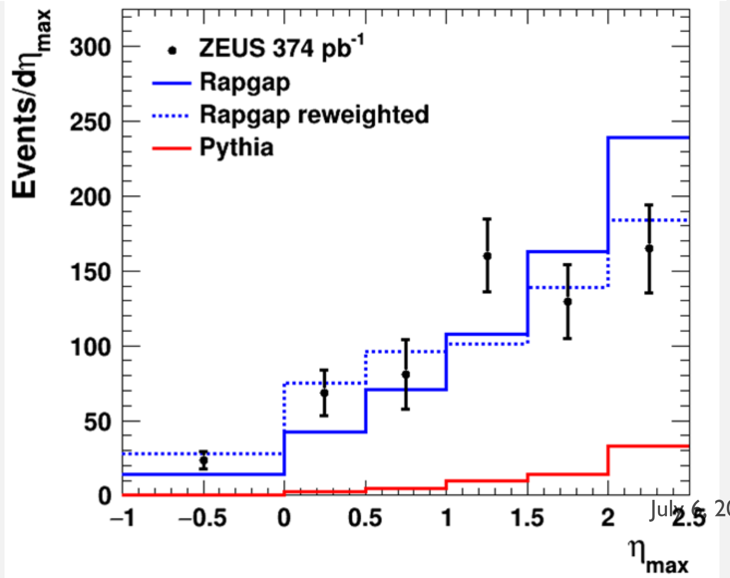
Shape does not agree.
An excess is seen in the top bin.
Can reweight Rapgap to describe the shape.

Unreweighted 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.)

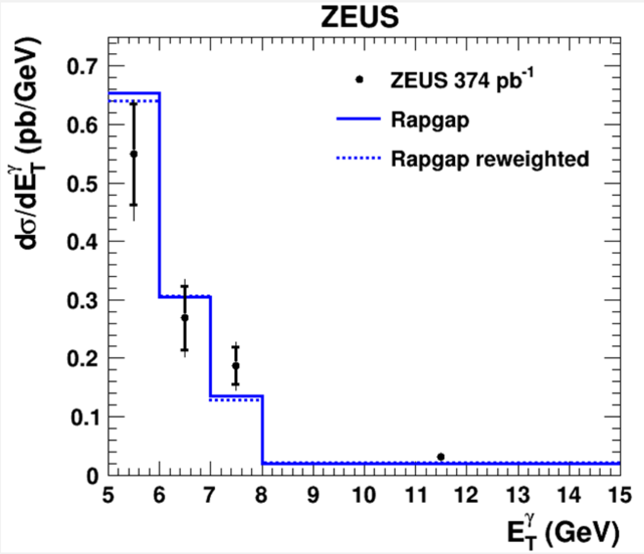




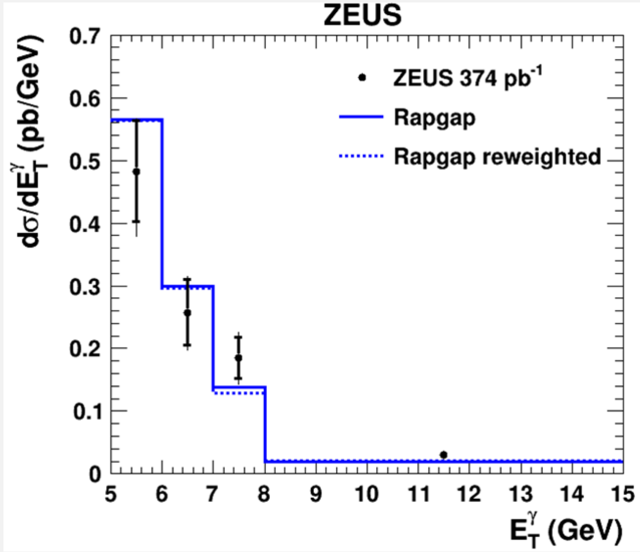
Results

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.



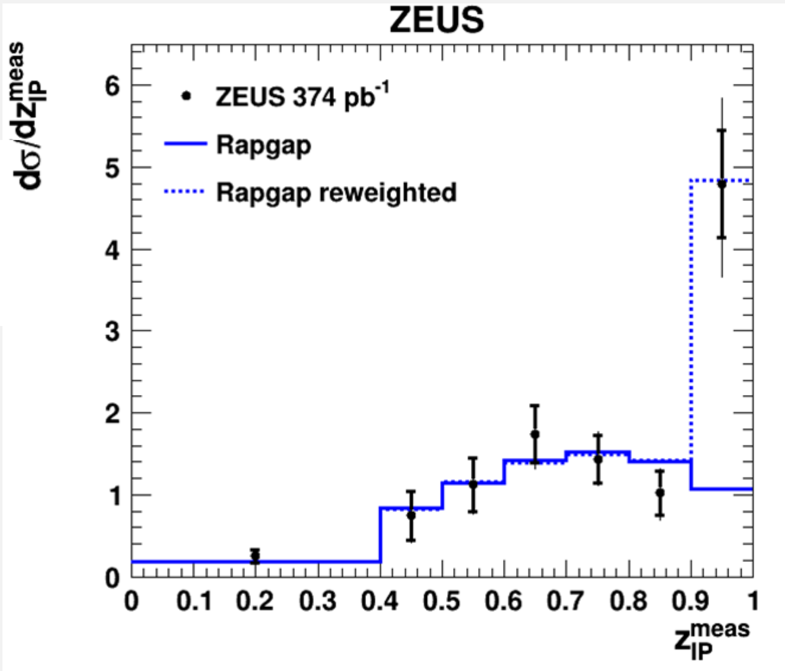
Inclusive photon



Photon + jet

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

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

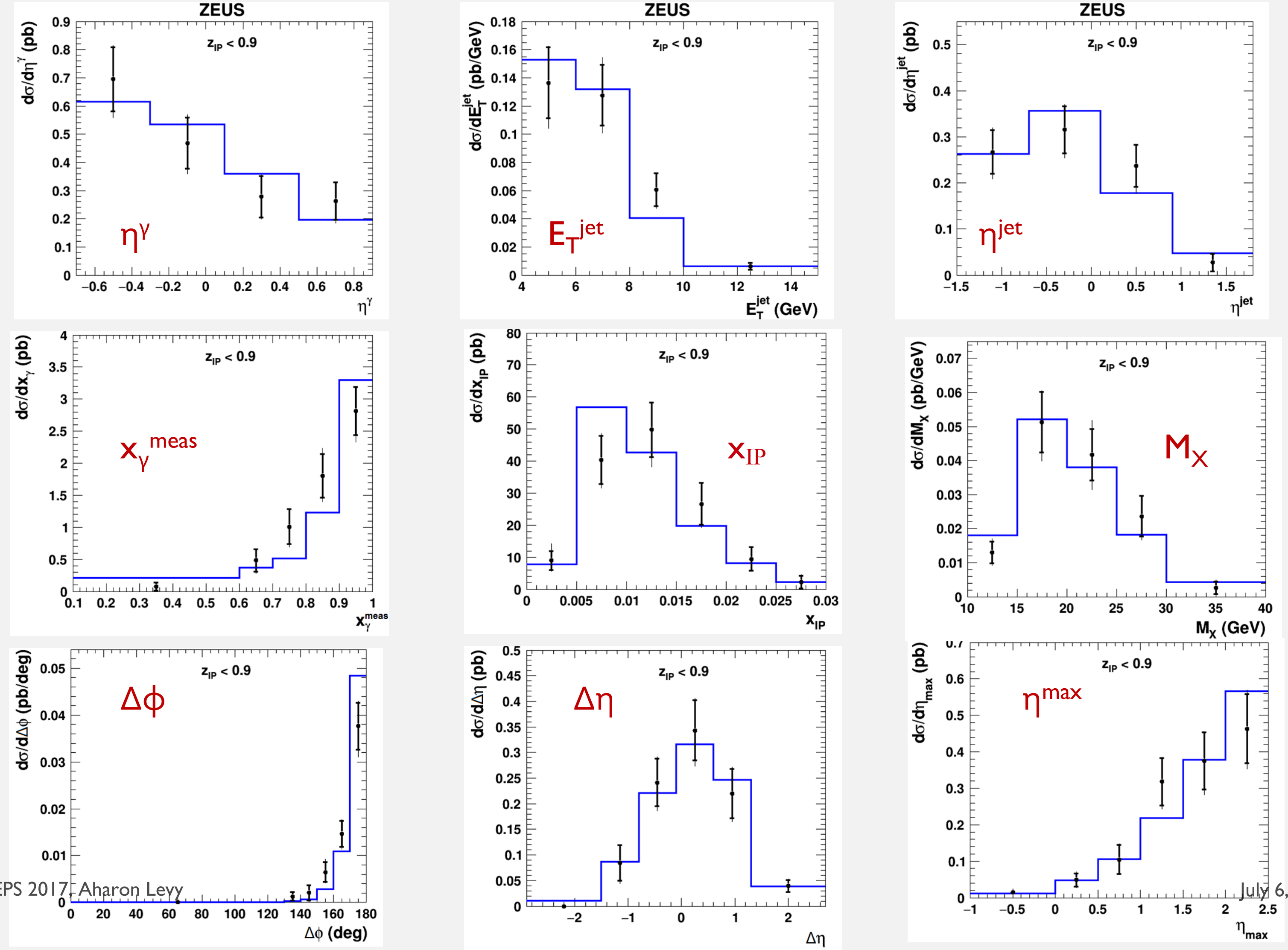


Evidence for "direct" Pomeron interactions

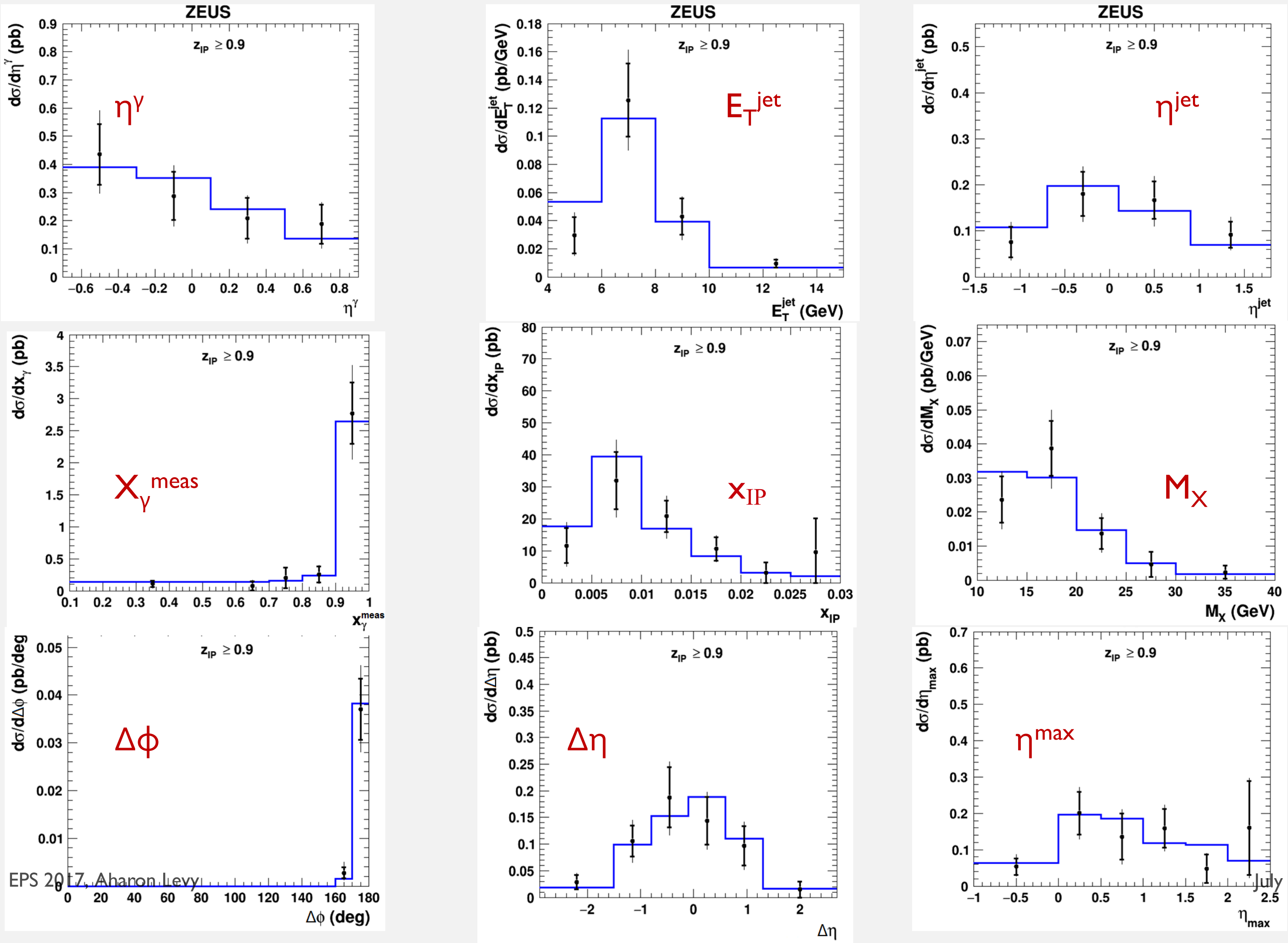
Using HERA-I data, integrated cross section for $\mathbf{z_{IP}^{meas} < 0.9}$ = $0.68 \pm 0.14 ^{+0.06}_{-0.07}$ pb

RAPGAP gives 0.68 pb. No allowance for proton dissociation which is ~ 16 ± 4%.

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



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



Summary

ZEUS have measured **isolated ("prompt") photons in diffractive photoproduction**, 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_{IP}^{meas} shows a peak at high values that implies the presence of processes not currently modelled in RAPGAP.

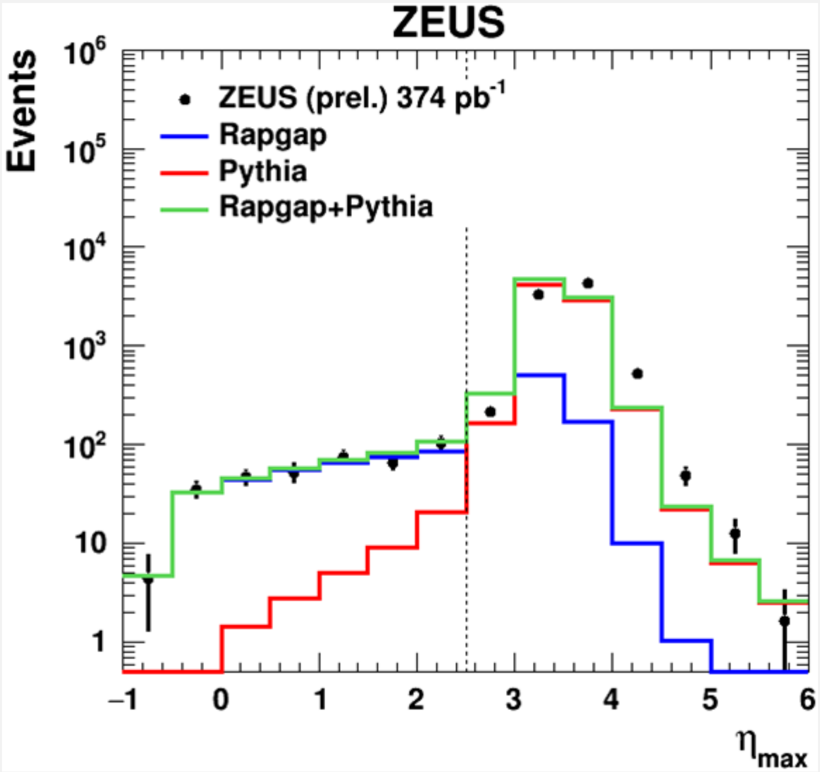
This gives evidence for a **"direct-Pomeron"** process

Dominantly in the direct-photon channel.

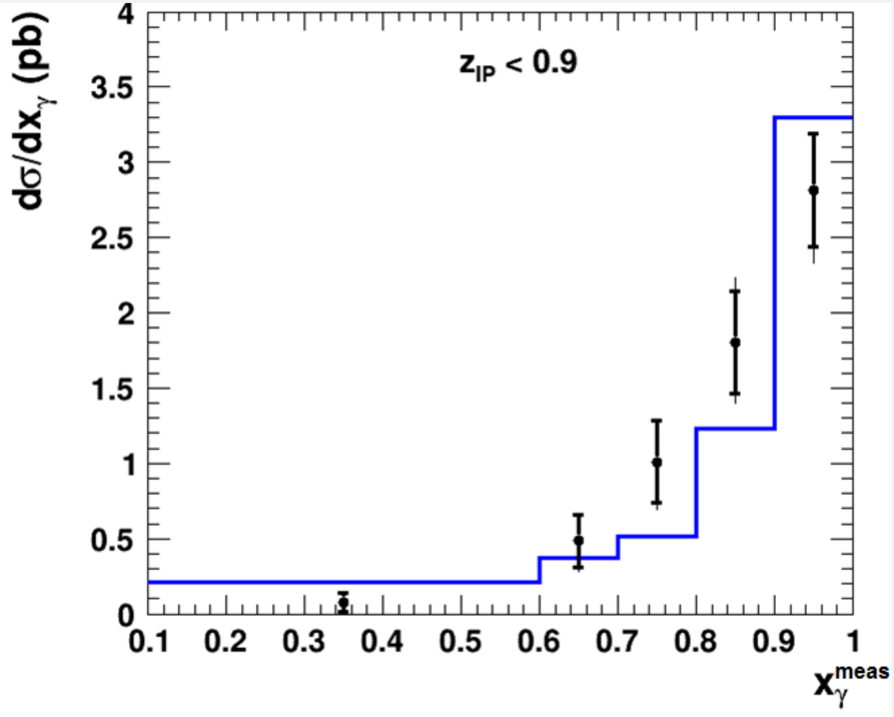
In both regions of z_{IP}^{meas} the cross sections of the kinematic variables are well described in shape by RAPGAP.

Backups

η_{max} distribution for HERA II.

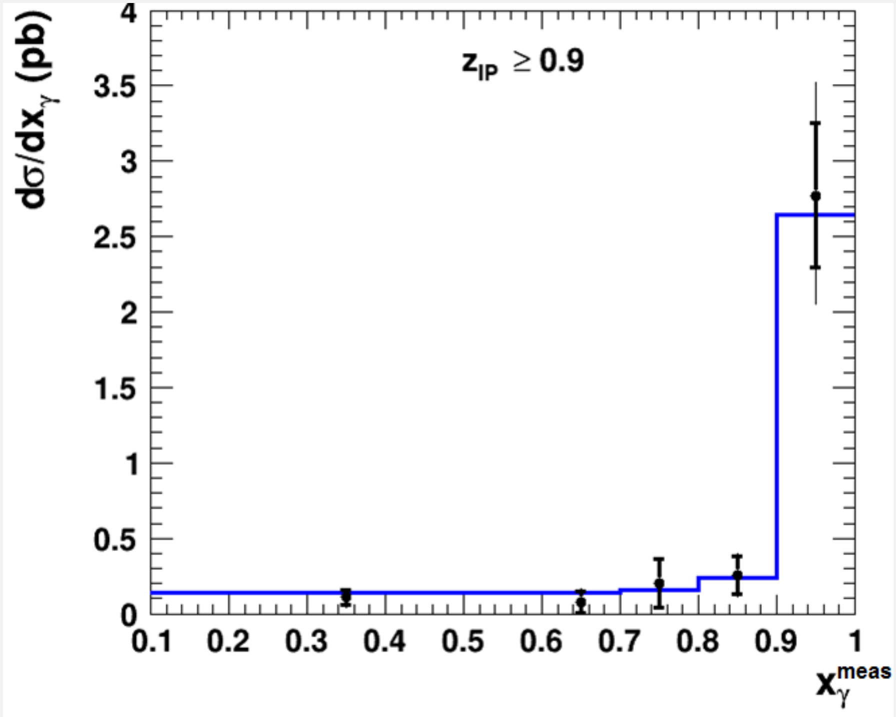


ZEUS

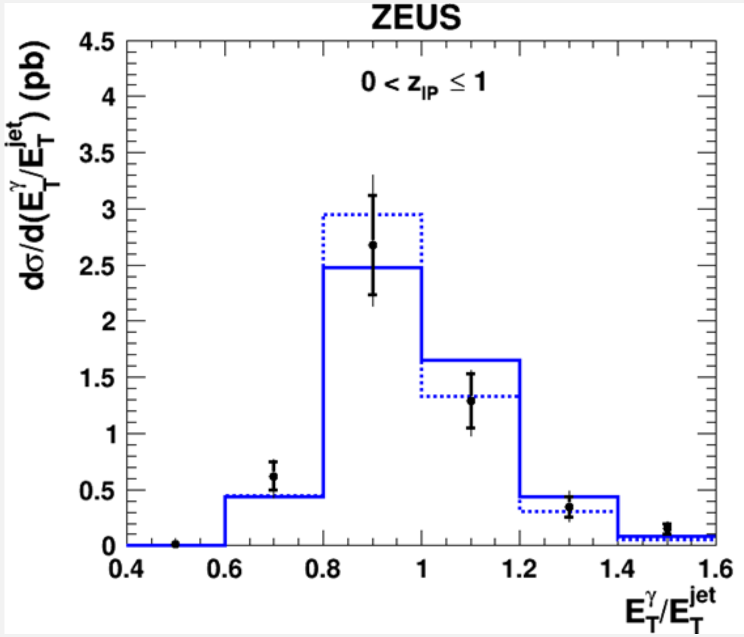


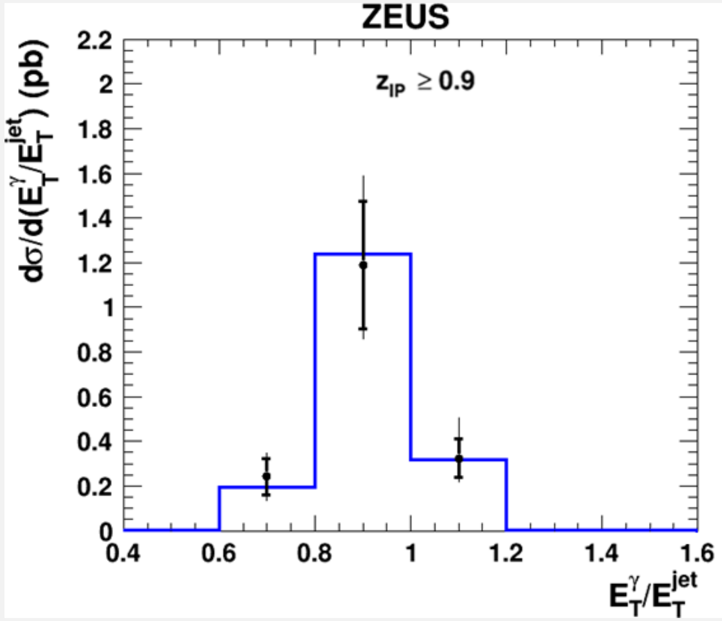
z_{IP} < 0.9
$d\sigma/dx_\gamma$ (pb)
0
0.5
1
1.5
2
2.5
3
3.5
4
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
x_γ^{meas}

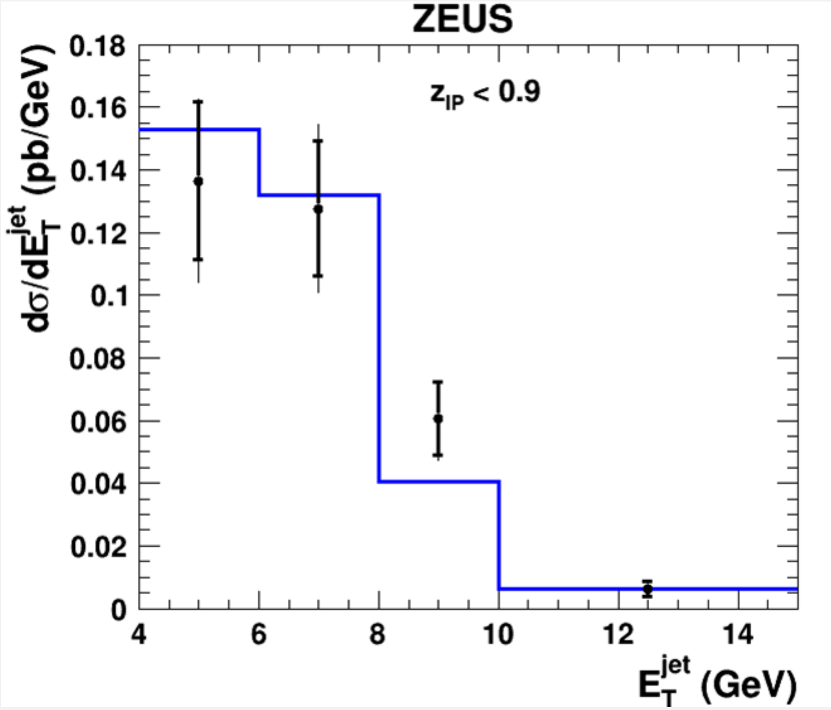
ZEUS

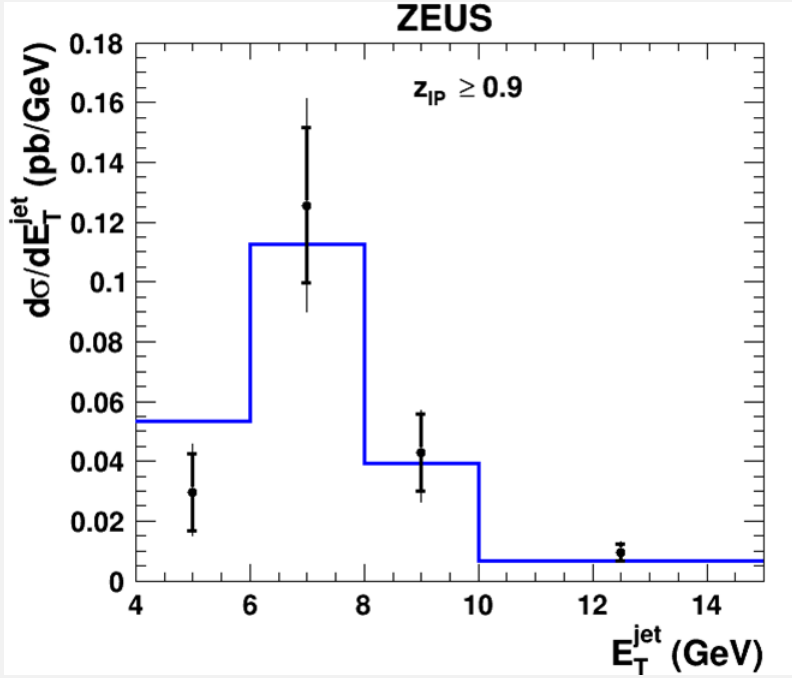


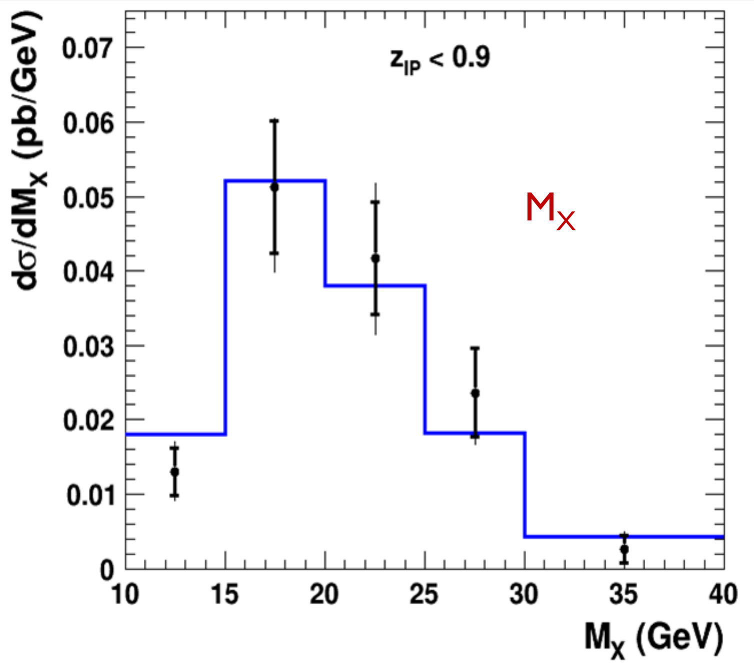
$z_{IP} \geq 0.9$
$d\sigma/dx_\gamma$ (pb)
0
0.5
1
1.5
2
2.5
3
3.5
4
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
x_γ^{meas}


ZEUS
$0 < z_{IP} \leq 1$
$d\sigma/d(E_T^{\gamma}/E_T^{jet})$ (pb)
E_T^{γ}/E_T^{jet}

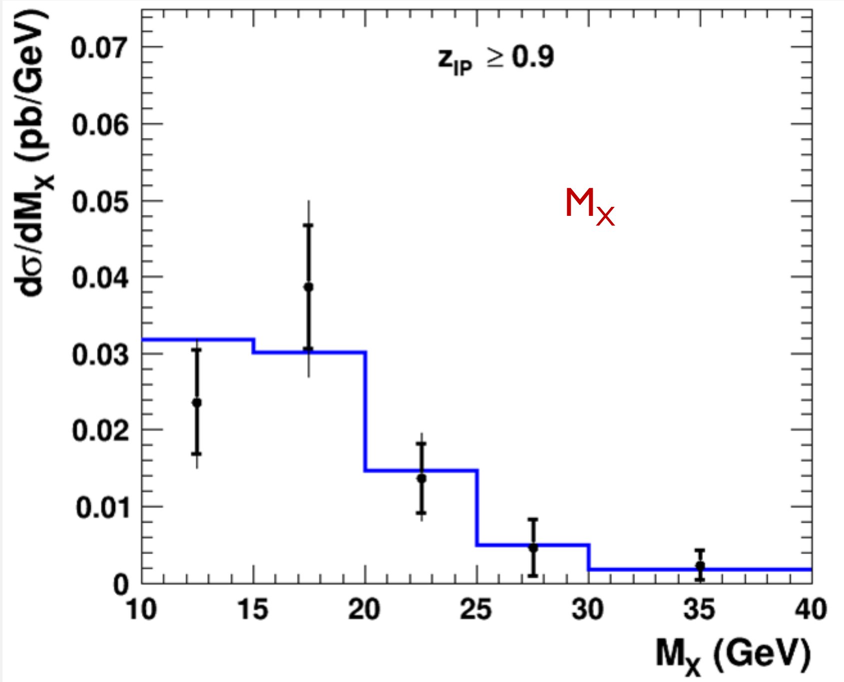

ZEUS
$z_{IP} \geq 0.9$
$d\sigma/d(E_T^{\gamma}/E_T^{jet})$ (pb)
E_T^{γ}/E_T^{jet}


ZEUS
$z_{IP} < 0.9$
$d\sigma/dE_T^{jet}$ (pb/GeV)
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
4
6
8
10
12
14
E_T^{jet} (GeV)


ZEUS
$z_{IP} \geq 0.9$
$d\sigma/dE_T^{jet}$ (pb/GeV)
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
4
6
8
10
12
14
E_T^{jet} (GeV)



$z_{IP} < 0.9$
M_X
$d\sigma/dM_X$ (pb/GeV)
M_X (GeV)



$z_{IP} \geq 0.9$
M_X
$d\sigma/dM_X$ (pb/GeV)
M_X (GeV)