Prompt photons at HERA

Future Physics with HERA Data Workshop
DESY, November 11-13, 2014

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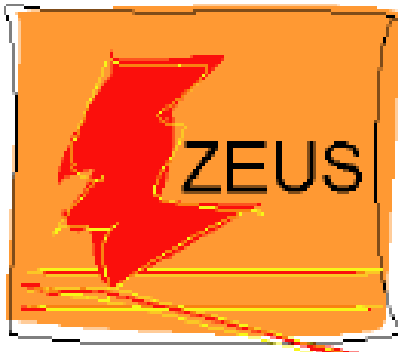


We discuss prompt-photon production at HERA in

- DIS

- photoproduction

- diffractive photoproduction

By “prompt photons” we mean photons that

- have high transverse momentum

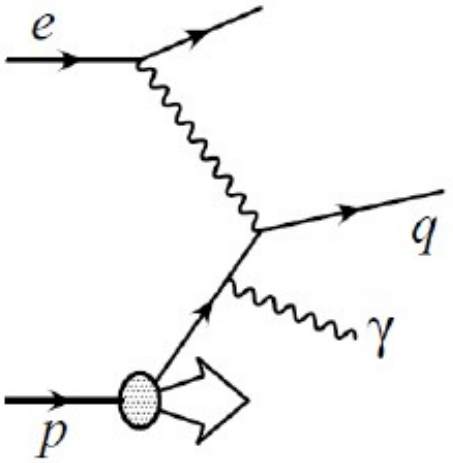
- satisfy an isolation criterion that serves to reduce the contributions from photons in jets and from decays of hadrons. This is applied both at detector level and at truth level (where photons from decays are also explicitly excluded).

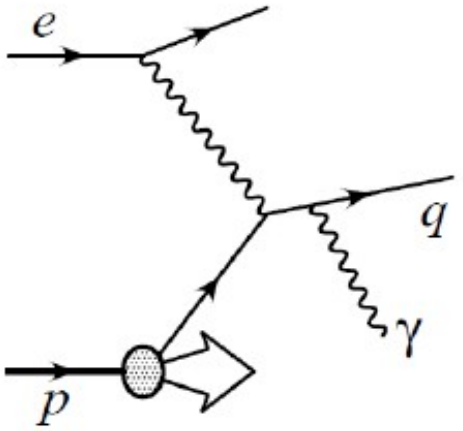
Some particular motivations for these measurements:

- Prompt photons emerge directly from the hard scattering process and give a particular view of this.
- Allows tests of specific QCD models.
- Prompt photons form a potential background to "new physics" processes, should be well understood.
- In diffraction, allows study of pomeron structure.

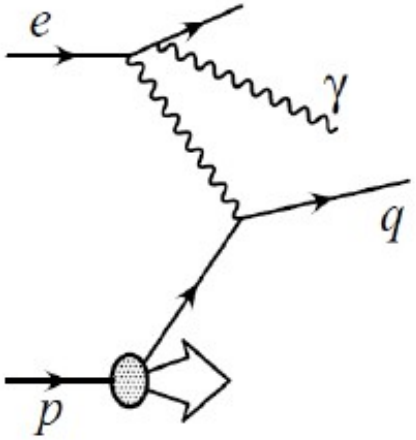
Deep Inelastic Scattering

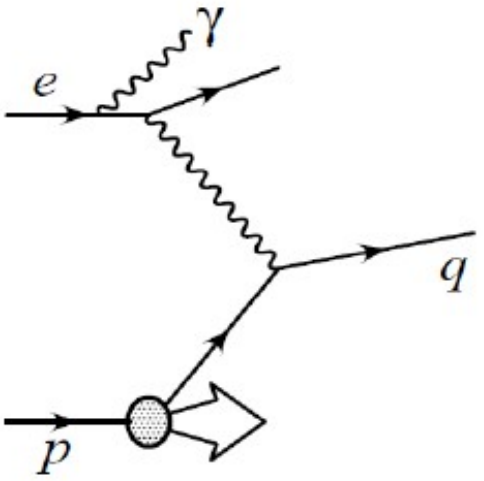
The main diagrams that contribute:





QQ diagrams

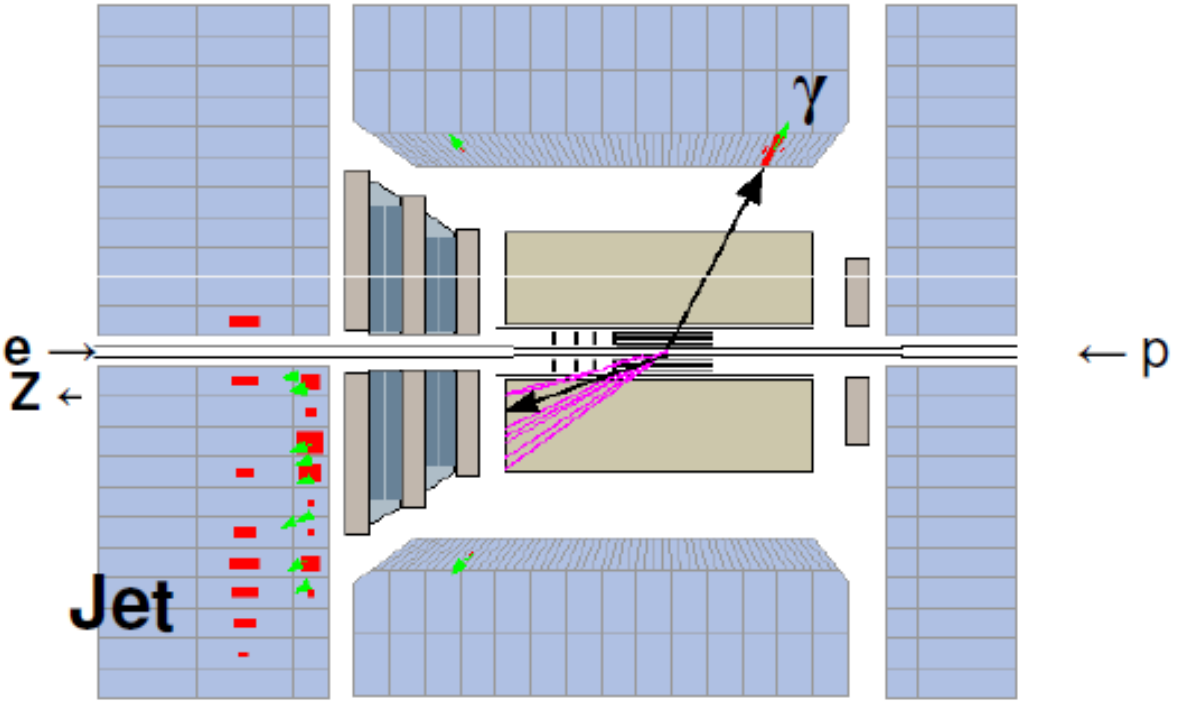


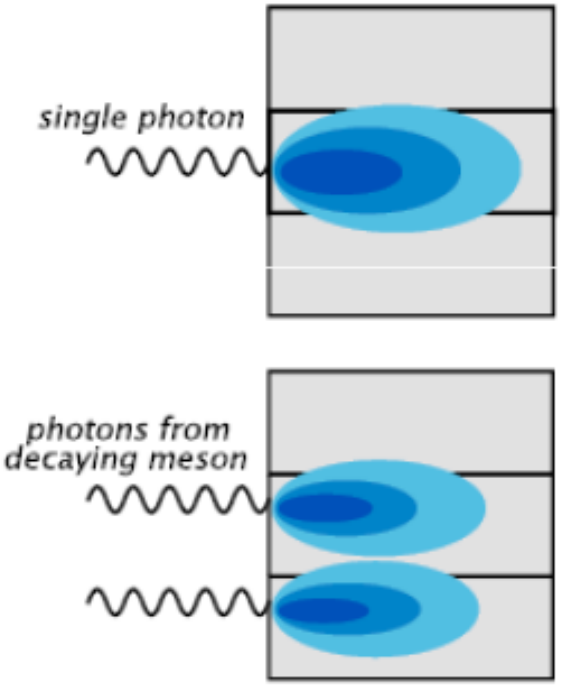


LL diagrams

(LL+QQ interference is small and neglected here)

Hard photons in finely segmented central ZEUS calorimeter

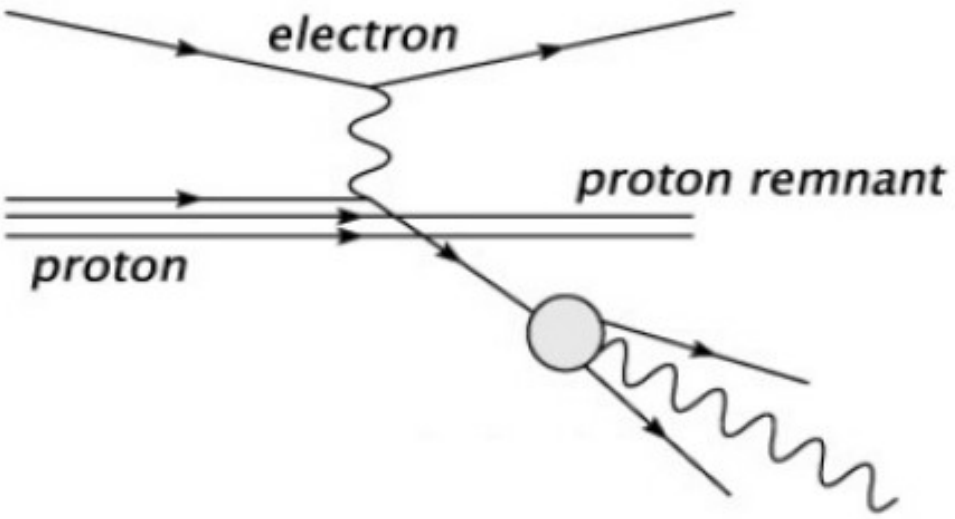




H1 analyses have used a discriminant based on a combined probability density using 6 shower-shape variables.

Measured over broader photon pseudorapidity range -1.2 – 1.8

Why we isolate the measured photon:



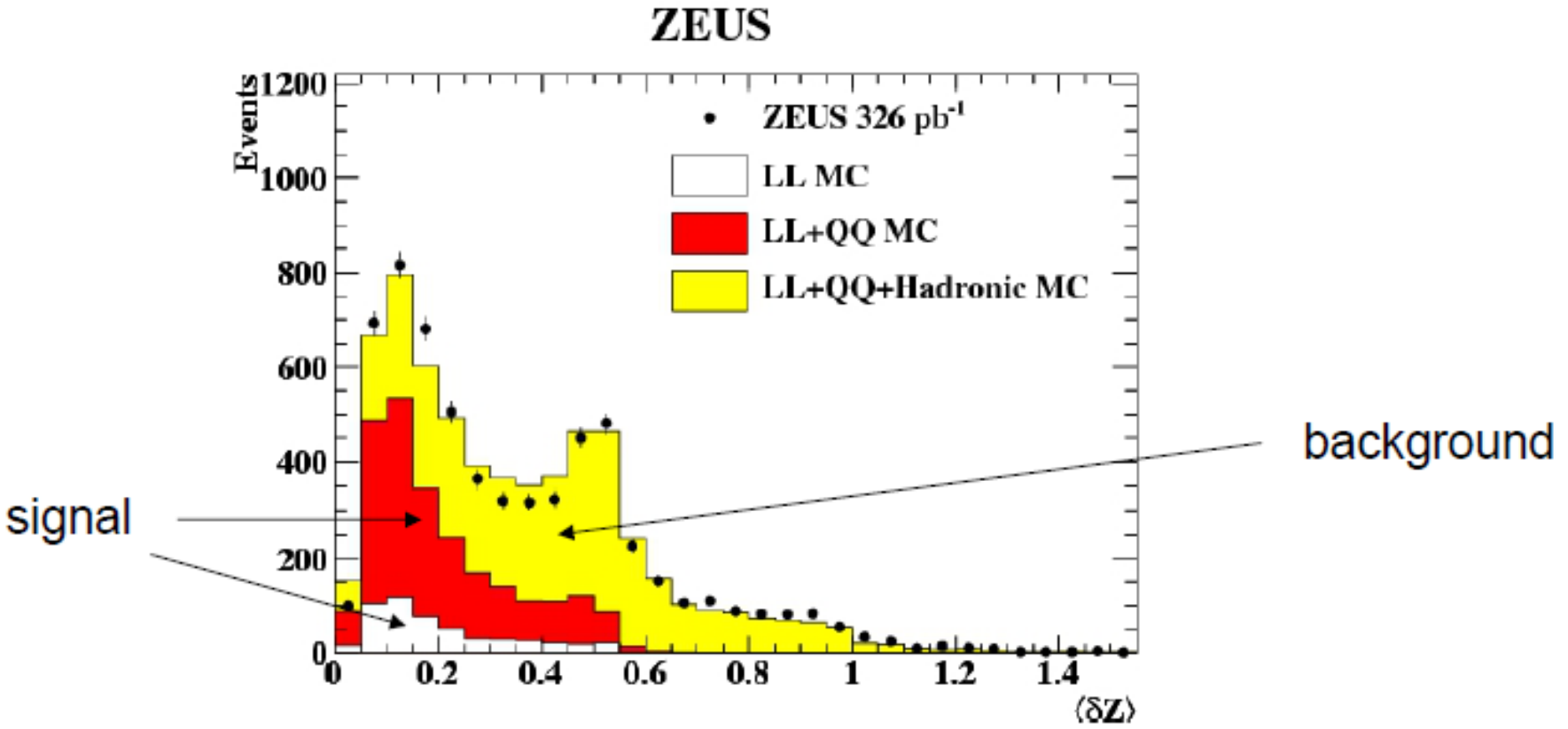
Photons in or near jets require a quark fragmentation function which is not easy to determine – requires non-perturbative input.

Also, the background from neutral mesons is large.

Typical isolation criterion is that the “jet” containing the photon should have at least 90% of its energy in the photon.

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}.

Challenge: 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 photoproduction analyses the LL component (radiation from beam) is absent.

Theoretical calculations

1) **GKS**

A. Gehrmann-de Ridder, G. Kramer, H Spiesberger,
Nucl. Phys. B 58 (2000) 56

A. Gehrmann-de Ridder, G. Kramer, E. Poulsen,
Phys. Rev. Lett. 96 (2006) 132002

A .Gehrmann-de Ridder, G. Kramer, E. Poulsen,
C47 (2006) 95

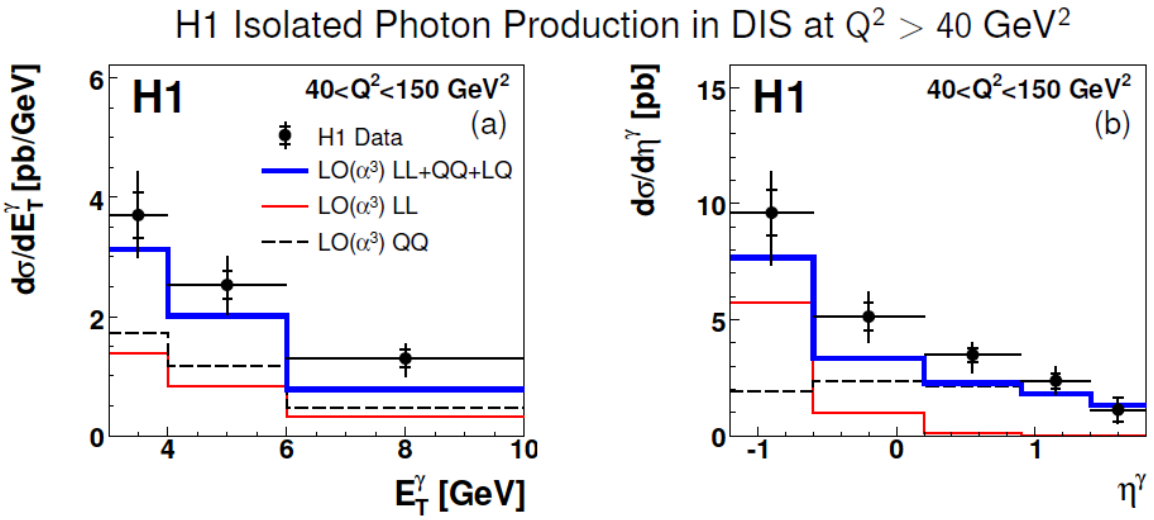
Calculations of the process $ep \rightarrow e\gamma X$ to orders α^3 and $\alpha^3 \alpha_s$
QQ and LL processes are included, interference is small and is neglected. HERAPDF 1.0 parton set is used.

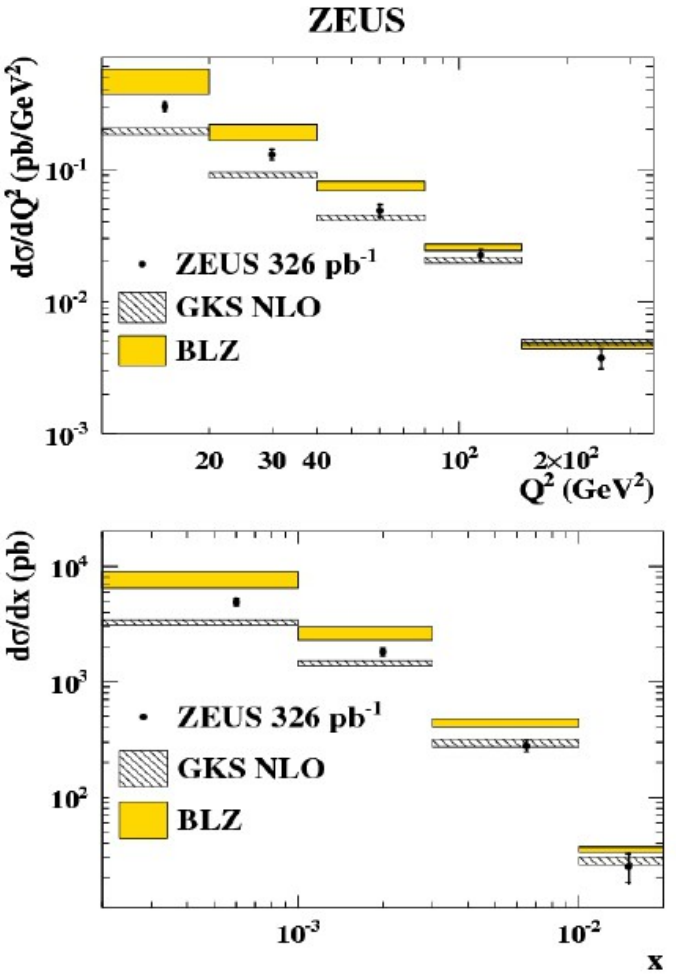
2) **BLZ**

S. Baranov, A. Lipatov, and N. Zotov,
Phys. Rev. D81 (2010) 094034

Calculation using unintegrated proton parton densities, to LO.
The calculation gives enhanced photon radiation from quarks.

What has been measured in DIS.



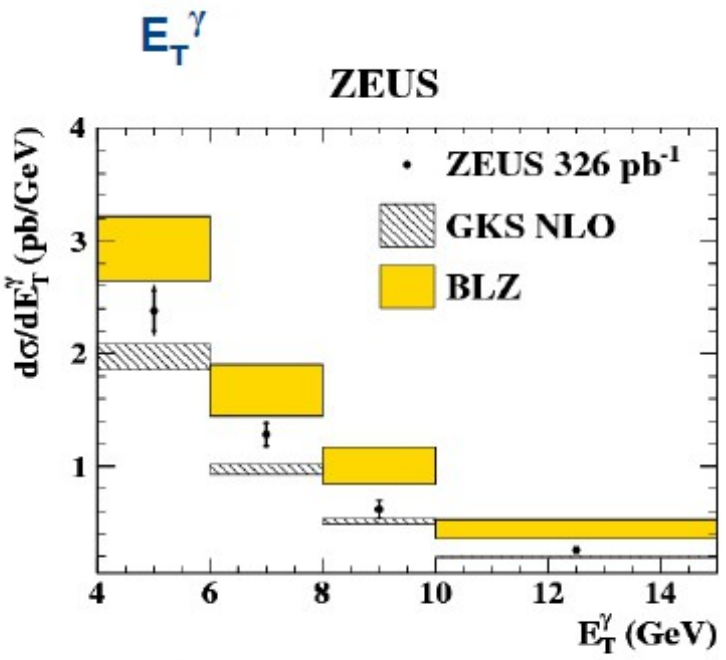


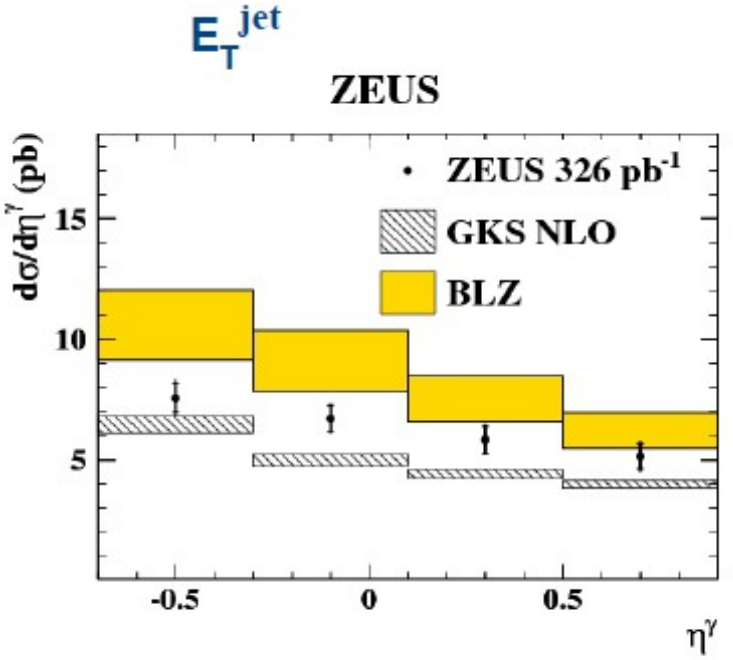
H1 inclusive photons compared to earlier version of theory.

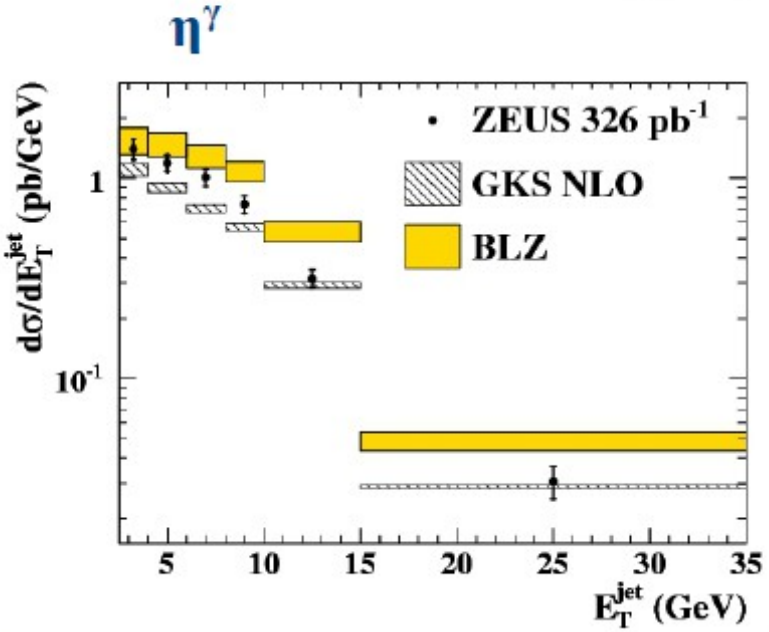
ZEUS photon + jet

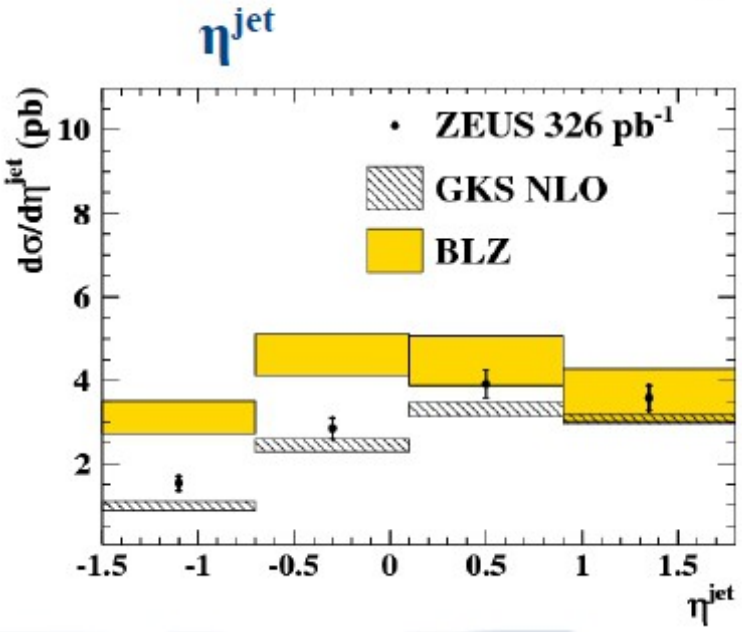
Data tend to lie above GKS theory and its earlier version.

Most recent publications:
H1: Eur.Phys.J.C54 (2008) 371-387
ZEUS: Phys Lett B 715 (2012) 88-97


E_T^γ
ZEUS
ZEUS 326 pb^{-1}
GKS NLO
BLZ
$d\sigma/dE_T^\gamma$ (pb/GeV)
E_T^γ (GeV)


E_T^{jet}
ZEUS
ZEUS 326 pb^{-1}
GKS NLO
BLZ
$d\sigma/d\eta^\gamma$ (pb)
η^γ


η^γ
ZEUS 326 pb^{-1}
GKS NLO
BLZ
$d\sigma/dE_T^{jet}$ (pb/GeV)
E_T^{jet} (GeV)


η^{jet}
ZEUS 326 pb^{-1}
GKS NLO
BLZ
$d\sigma/d\eta^{jet}$ (pb)
η^{jet}

What could be measured next in DIS.

Further parameters and variables:

1) Azimuthal structure of the events: angles between the photon, jet and recoil electron

   Sensitive to higher-order effects.

2) Fraction of final state entering the photon and jet system

Make use of $x_\gamma^{meas} = \Sigma_{photon+jet}(E - p_z) / \Sigma_{all\ final\text{-}state\ hadrons}(E - p_z)$

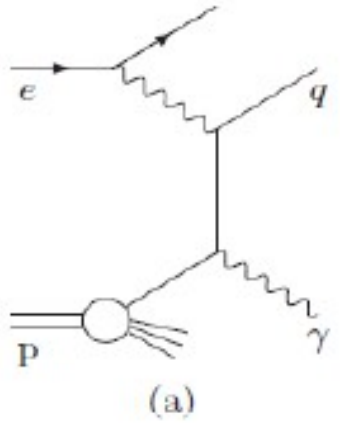
which can be used similarly to photoproduction.

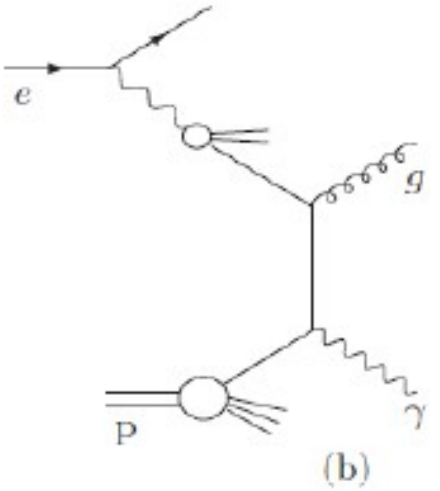
Expectation is for a distribution that is dominated by a direct (lowest-order) peak, but with an extension to lower values governed by higher-order processes (would merge into the resolved photon contribution if very low Q^2 could be measured).

Photoproduction.

Lowest-order diagrams:

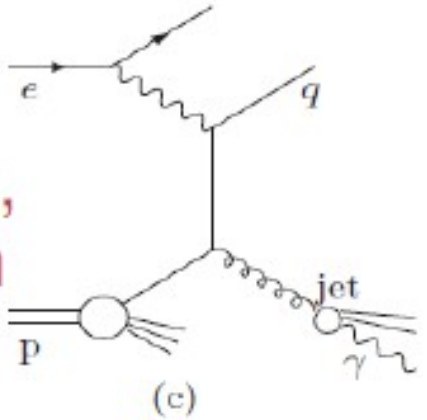
direct

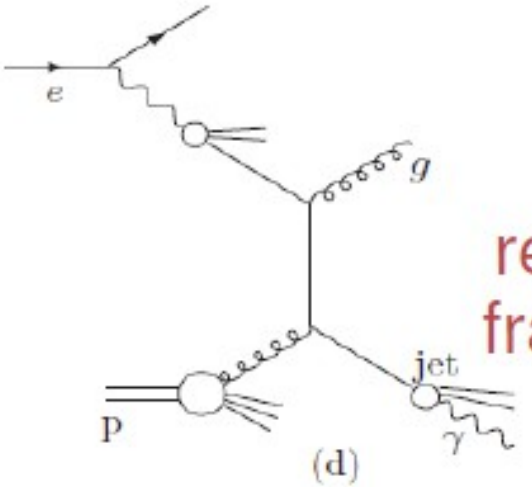




resolved

direct,
fragmentation





resolved,
fragmentation

Theoretical models

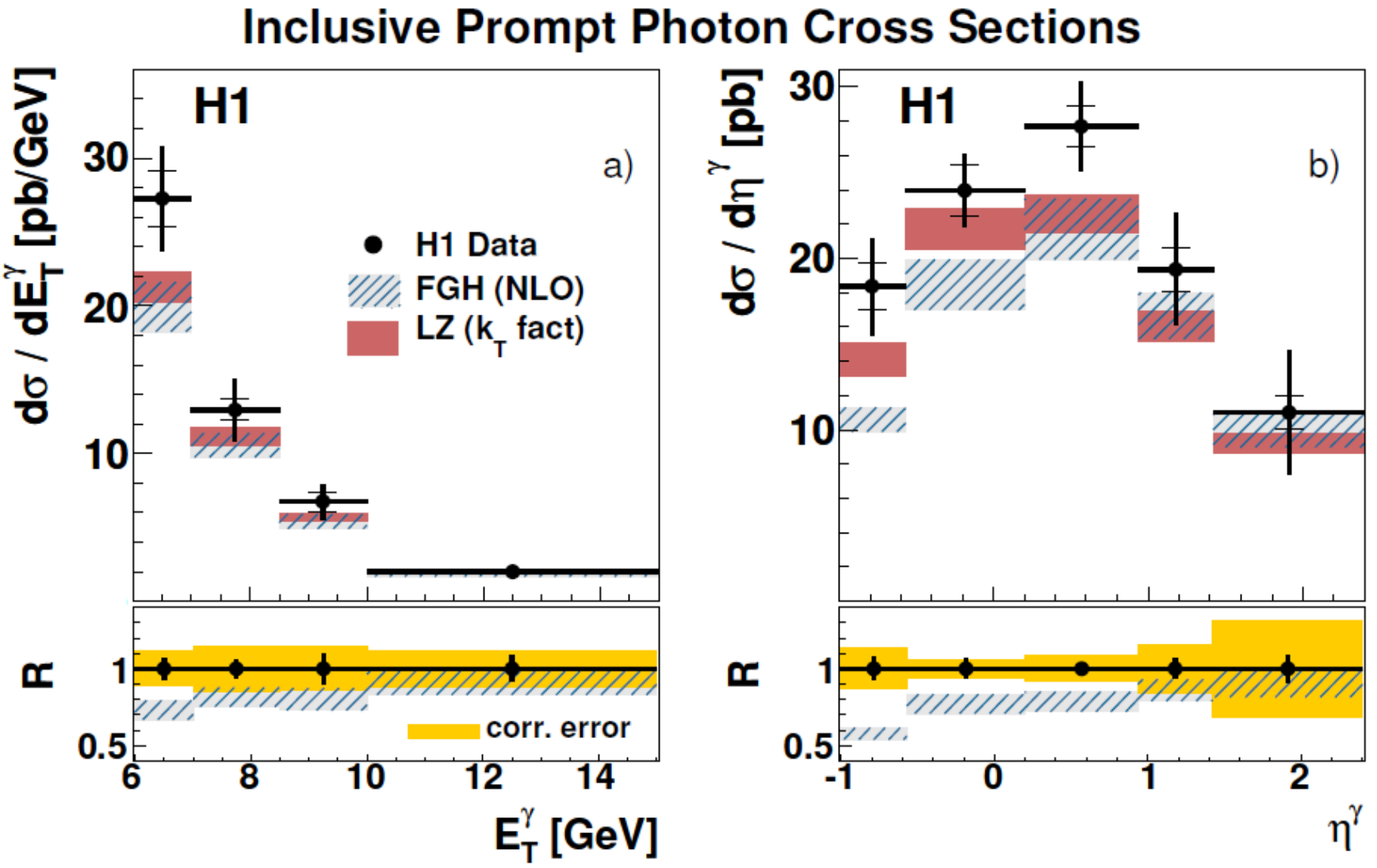
Fontannaz, Guillet and Heinrich (FGH, EPHOX):

NLO + box diagram and a contribution from fragmentation.

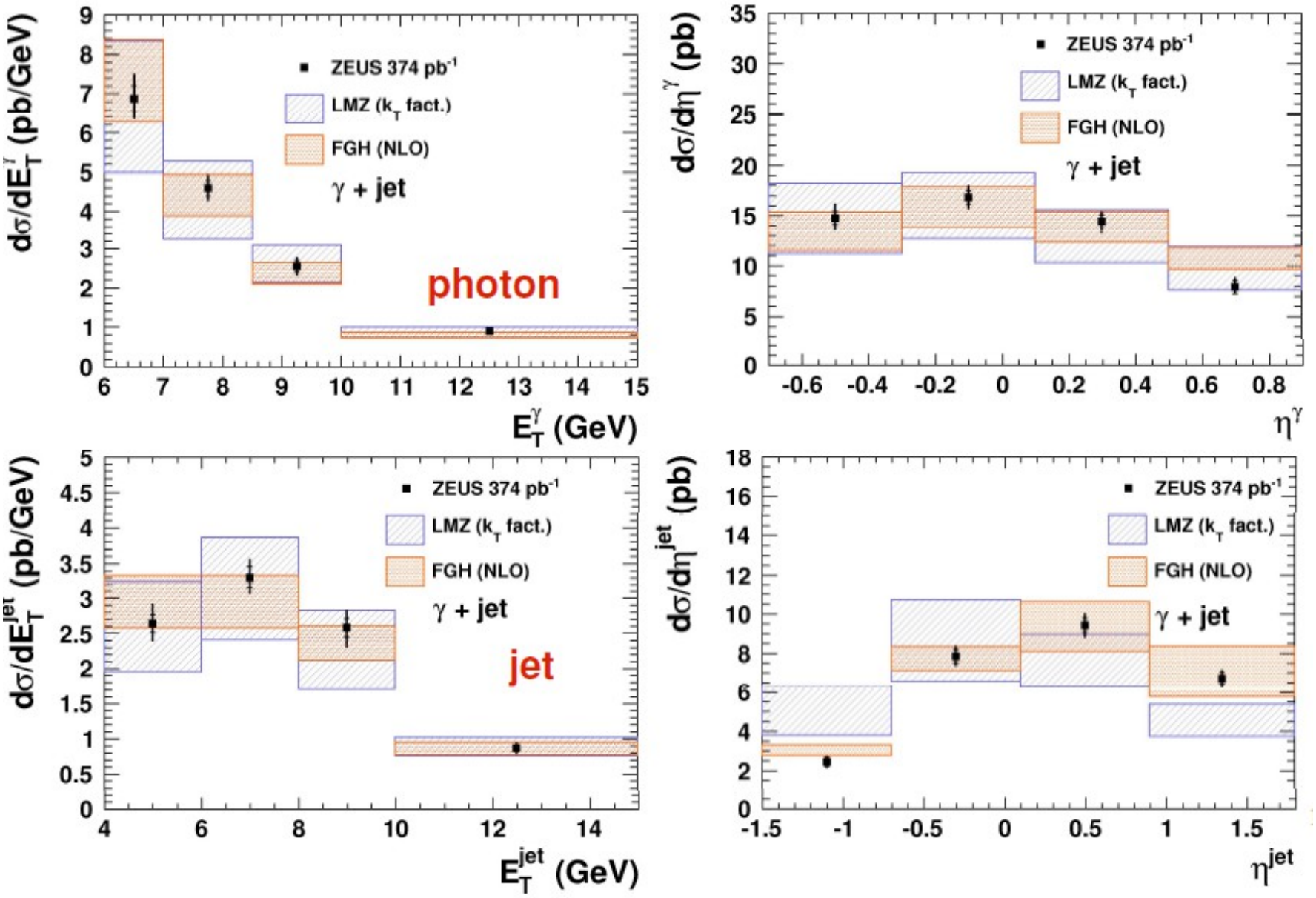
Lipatov, Malyshev, Zotov (LMZ): k_T-factorisation with unintegrated parton distributions and initial-state parton cascade. Upgraded for second ZEUS analysis.

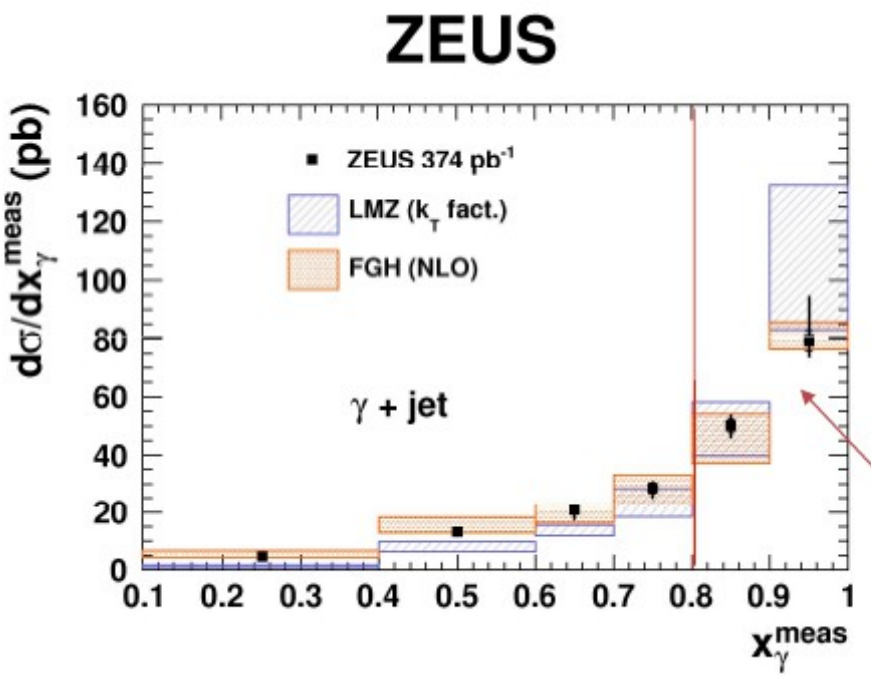
Experimental publications:

H1: Eur.Phys.J. C66 (2010) 17
ZEUS: Physics Letters B 730C (2014) 293-301
JHEP08 (2014) 023


Inclusive Prompt Photon Cross Sections
H1
a)
H1 Data
FGH (NLO)
LZ (k_T fact)
dσ / dE_T^γ [pb/GeV]
R
corr. error
E_T^γ [GeV]
H1
b)
dσ / dη^γ [pb]
R
η^γ

Cross sections for photon plus jet



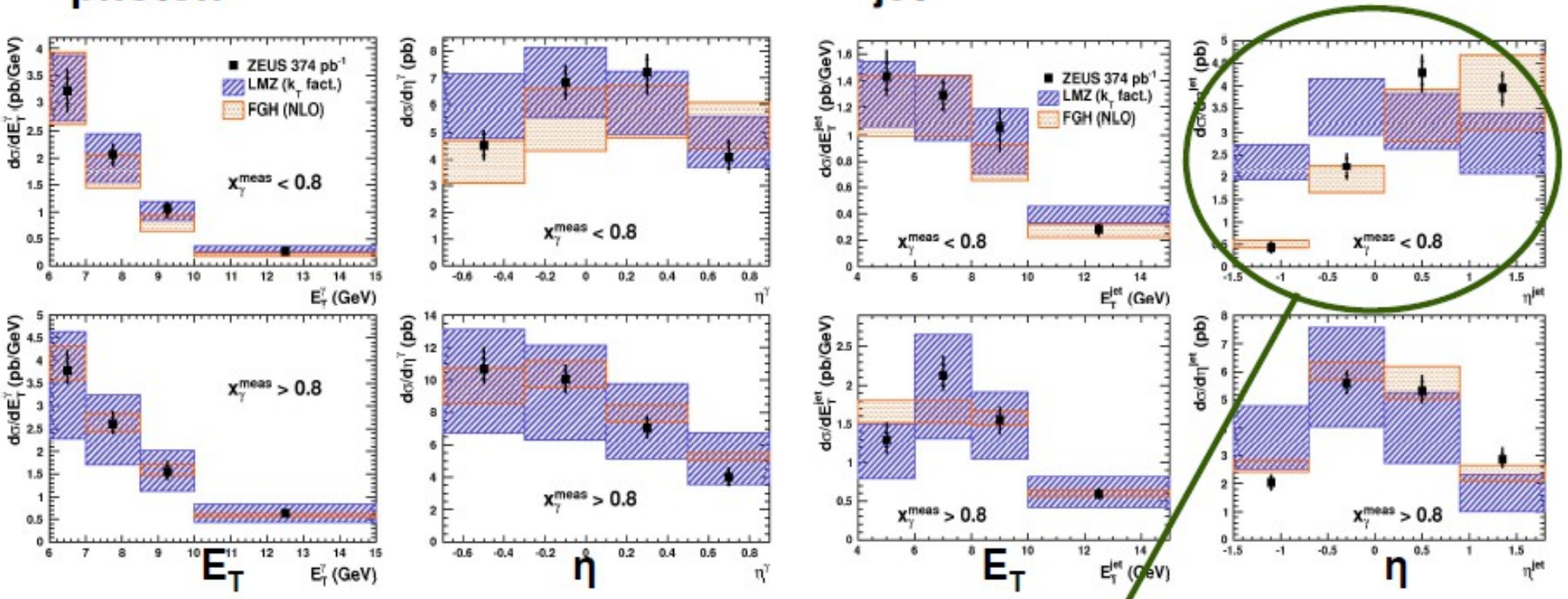


The x_γ^{meas} distribution shows a peak near unity corresponding to the direct process.

To investigate resolved-enhanced and direct-enhanced regions further,
apply selections $x_\gamma^{meas} < 0.8$ **and** $x_\gamma^{meas} > 0.8$

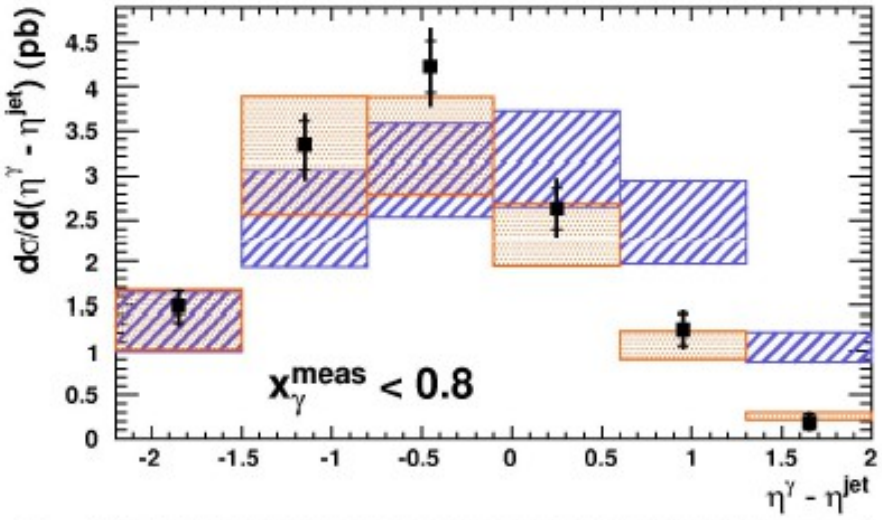
$x_\gamma^{meas} < 0.8$ **(upper)** $x_\gamma^{meas} > 0.8$ **(lower)**

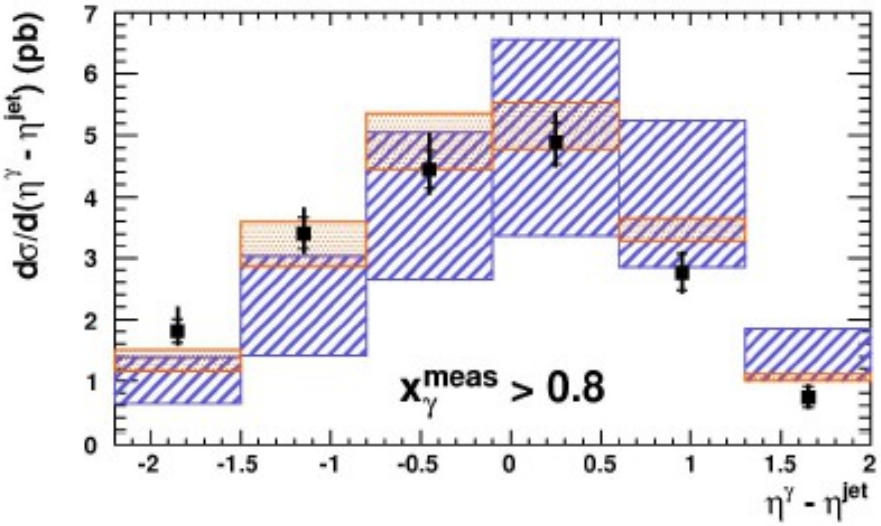
photon **jet**

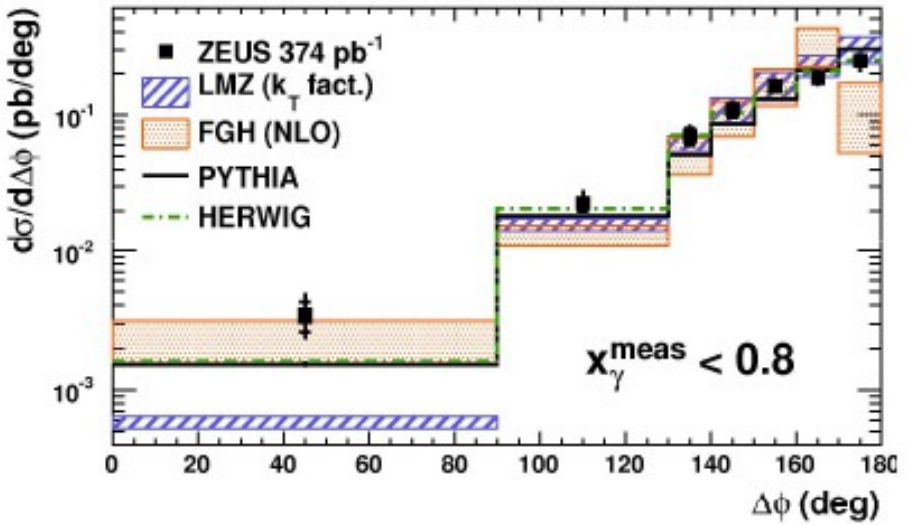


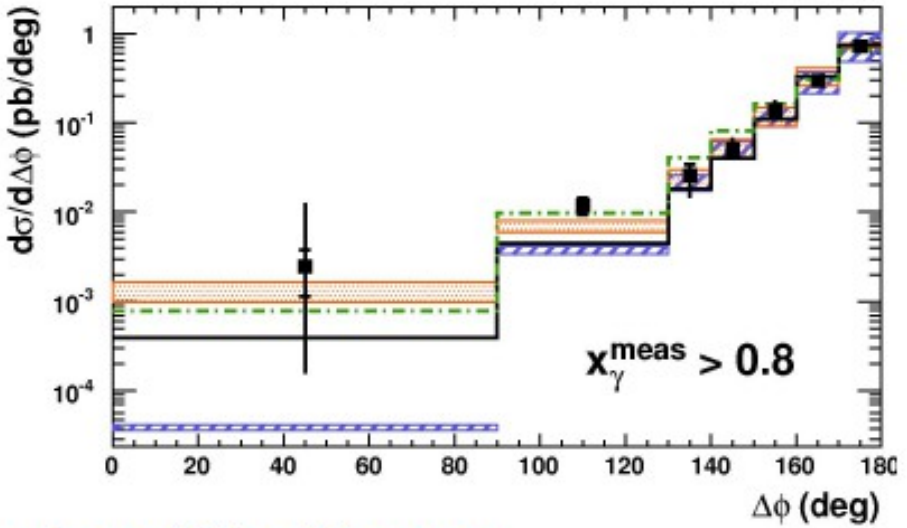
All distributions good for both models, except η(jet) for LMZ, $x_\gamma^{meas} < 0.8$.
Perhaps due to mismodelling of initial-state cascade.

Further variables: $\eta^{\gamma} - \eta^{jet}$ and $|\varphi^{\gamma} - \varphi^{jet}|$









FGH is again fine, LMZ poorer on pseudorapidity difference.

PYTHIA and HERWIG also do well in the azimuth difference.

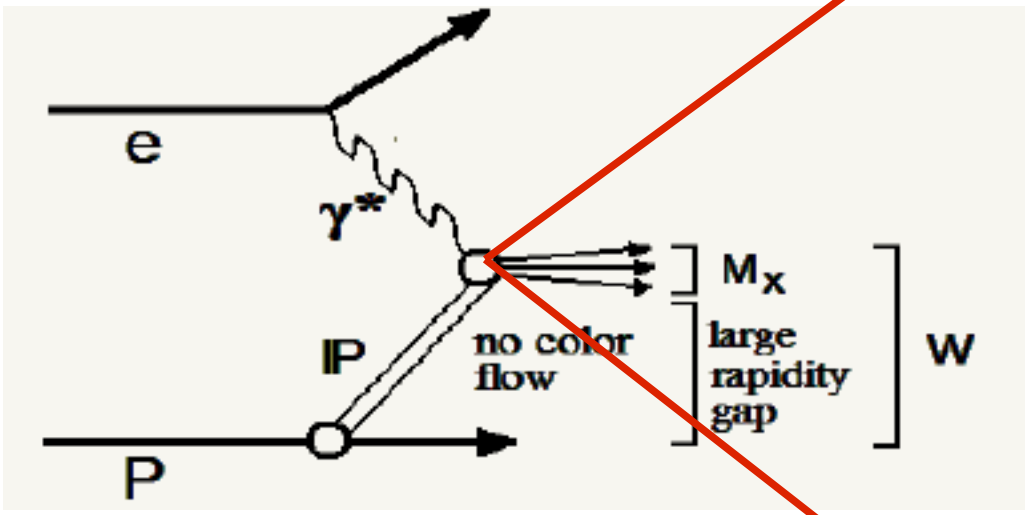
Future possibilities:

Extend the measurements to lower photon transverse energies to test the theory more strenuously.

Try to look at cosθ* distributions to study dynamics of resolved and direct processes in more detail.

Incorporate into photon and proton structure fits.

Diffractive processes



photon

jet or other final state.

Only photoproduction is feasible to study with HERA statistics

Some more diagrams:

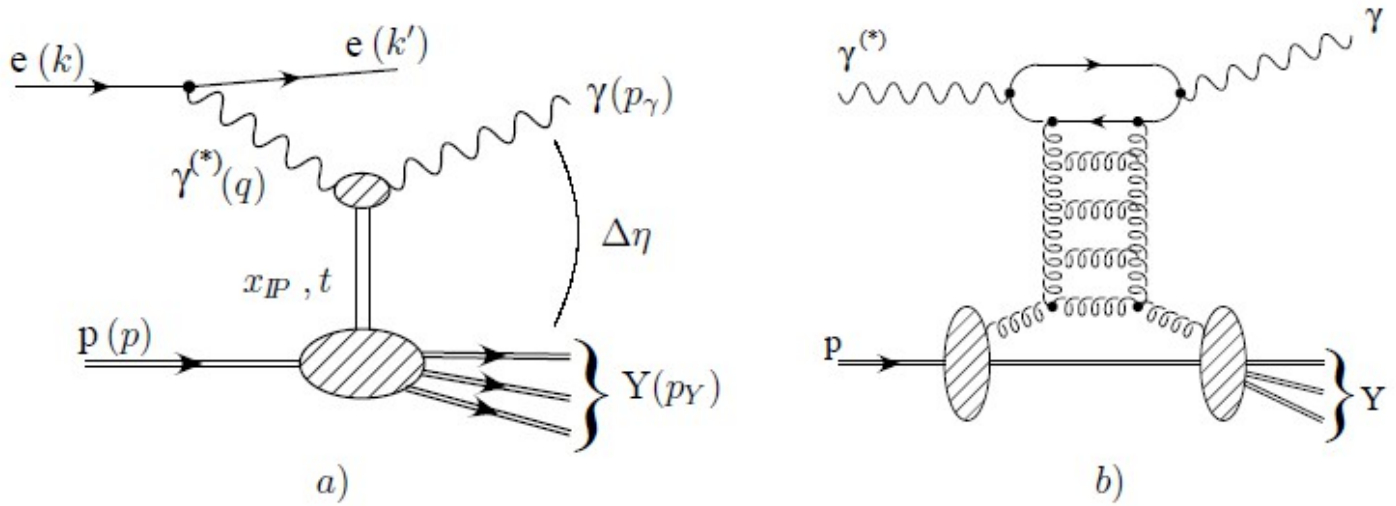
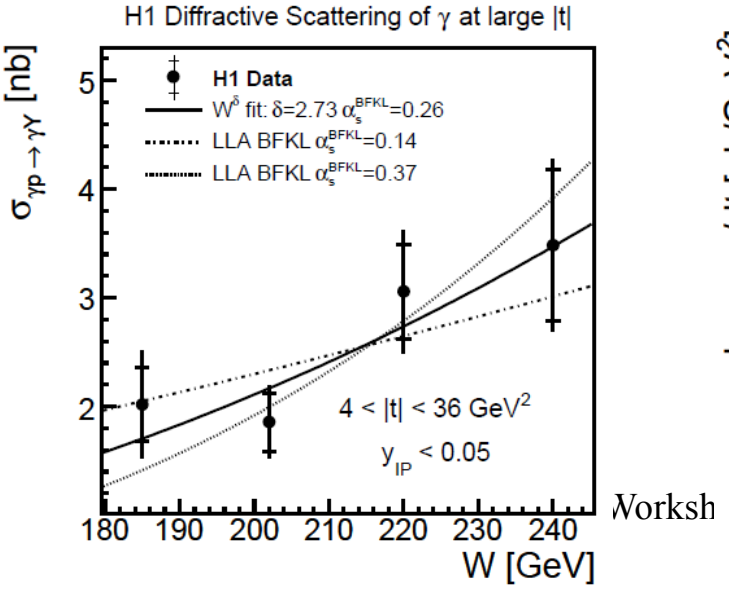
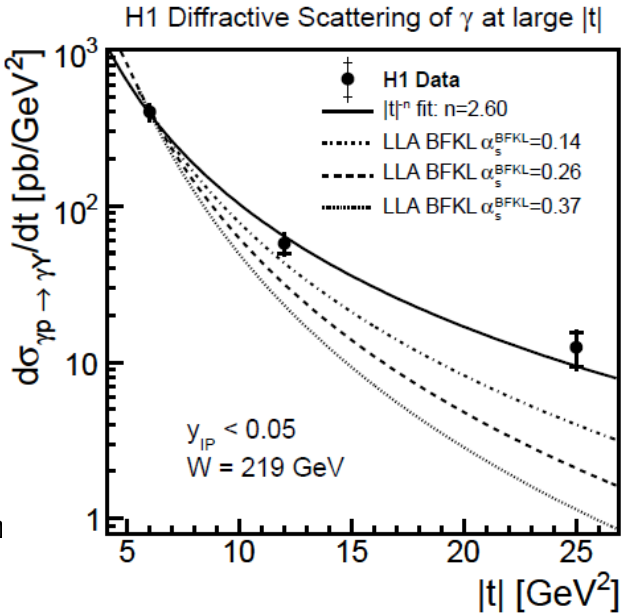


Figure 1: a) Schematic illustration of the $ep \to e\gamma Y$ process. b) Illustration of the $\gamma^{(*)}p \to \gamma Y$ process in a LLA BFKL approach.

From H1: Phys. Lett. B672 (2009) 219-226





Work in progress now.

ZEUS are investigating the diffractive production of prompt photons in HERA-2 data.

Study all feasible variables, and compare with the rather sparse predictions.

RAPGAP has been used so far for the MC calculation.

Summary and comments.

There are still measurements in the prompt photon area that are worth making, extending the parameters that are measured in photoproduction and DIS, and in diffraction.

Especially in collaboration with the theorists.

The limited statistics are the main obstacle to measuring new channels.