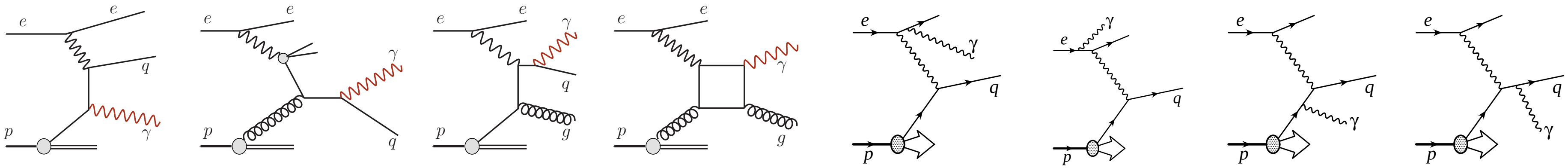
Isolated Photons at HERA

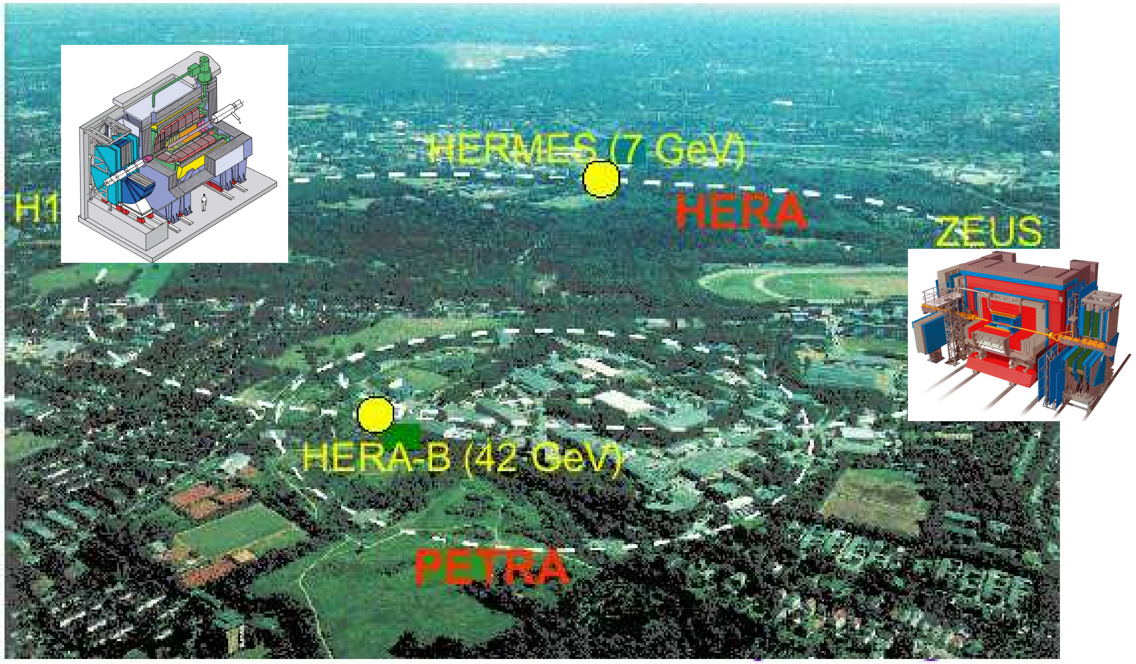
S. Levonian (DESY)

representing

H1 and ZEUS



HERA: The World's Only ep Collider

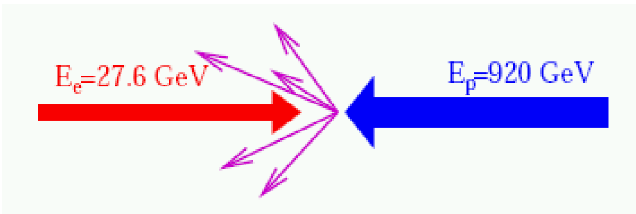


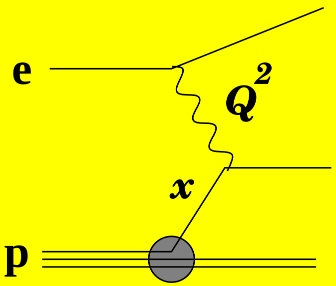
HERA-1 (1993-2000) $\simeq 120$ pb^{-1}

HERA-2 (2003-2007) $\simeq 380$ pb^{-1}

Final Data samples

H1+ZEUS: 2×0.5 fb^{-1}



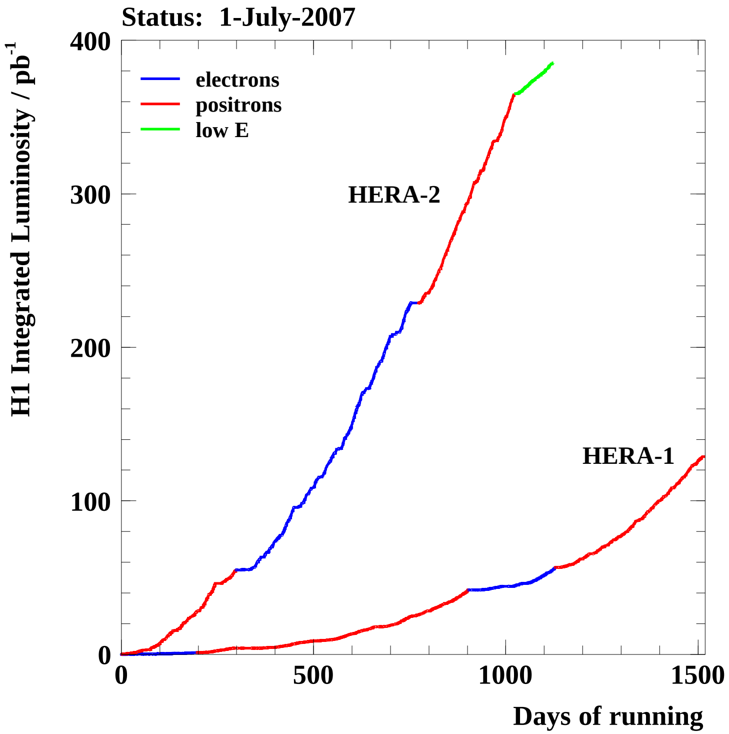


$Q^2 > 1$ GeV^2

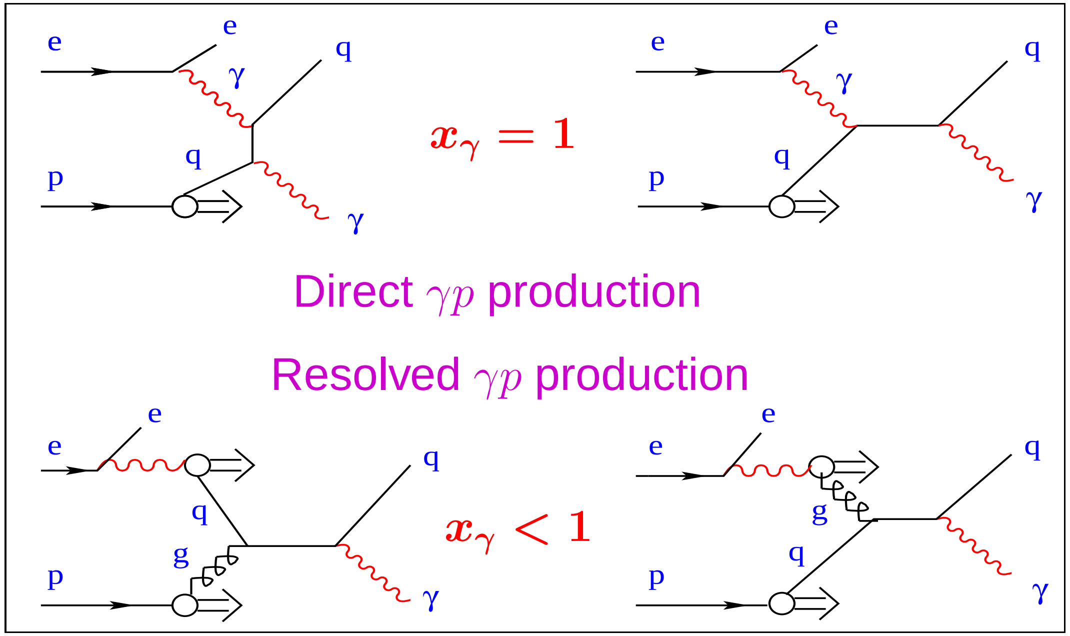
Deep Inelastic Scattering (DIS)

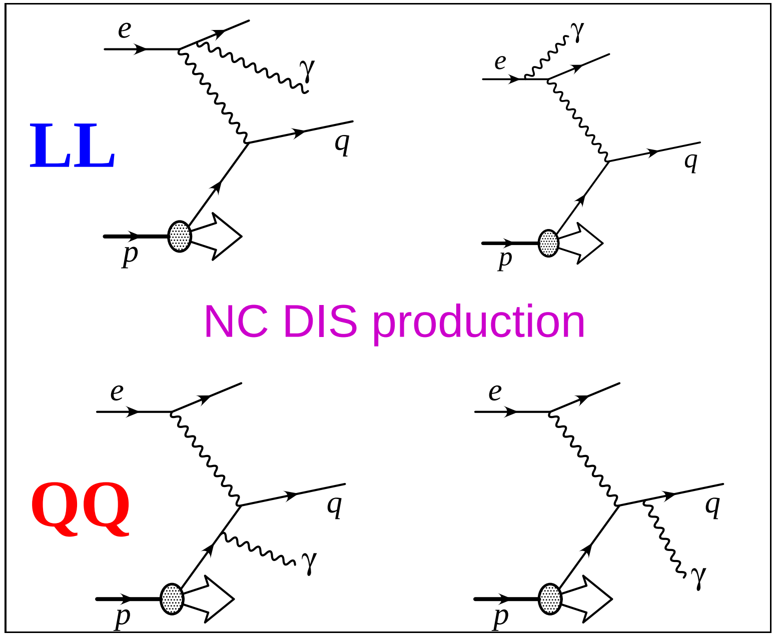
$Q^2 \approx 0$ GeV^2

Photoproduction (PhP)



Prompt photons at HERA





Lowest-order diagrams for isolated photon production in ep scattering

- Free of hadronisation corrections for photon $\Rightarrow$ direct link to parton level 
- Sensitivity to proton and photon PDFs (u-quarks radiate γ four times more than d-quarks)
- Important SM background to possible New physics

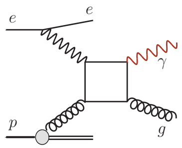
- Low statistics as compared to jets (but somewhat smaller E-scale uncertainty) 
- Difficult background from $\pi^0/\eta/\ldots$ decays (dominant systematics, $\approx 5-10\%$)

MC models and QCD calculations

MC models (LO + PS + fragmentation)

- ▷ PYTHIA: for QQ channels in DIS
- ▷ RAPGAP(H1), DGANGOH(ZEUS): for LL radiation in DIS
- ▷ PYTHIA (Lund string), HERWIG (cluster hadronisation): for photoproduction

pQCD (Photoproduction)

- Fontannaz, Guillet, Heinrich (FGH) (2001,2004)
  collinear factorisation, DGLAP evolution (includes also box diagram $\gamma g \to \gamma g$: 

)
- Lipatov, Zotov (LZ) (2005, 2010)
  k_t factorisation approach, using unintegrated parton densities (box diagram neglected so far)

pQCD (DIS)

- German-De Ridder, Kramer, Spiesberger (GKS) (2000)
- German-De Ridder, German, Poulsen (GGP) (2006)
  collinear factorisation, DGLAP evolution ($\mathcal{O}(\alpha^3\alpha_s^0)$ for inclusive γ, $\mathcal{O}(\alpha^3\alpha_s)$ for $\gamma + jet$)
- Baranov, Lipatov, Zotov (BLZ) (2010)
  k_t factorisation approach, using unintegrated parton densities (according to KMR prescription)

HERA data and publications on Isolated Photons

HERA-1

Year	Publication	$\mathcal{L}/pb^{-1}$	Experiment	Photoproduction	D.I.S.
1997	*PL B413*	(6)	ZEUS	γ+jet	
2000	*PL B472*	(38)	ZEUS	incl. γ	
2001	*PL B511*	(38)	ZEUS	<k_t>	
2004	*PL B595*	(121)	ZEUS		incl. γ ; γ+jet
2005	*EPJ C38*	(105)	H1	incl. γ ; γ+jet	
2007	*EPJ C49*	(77)	ZEUS	γ+jet	

HERA-2

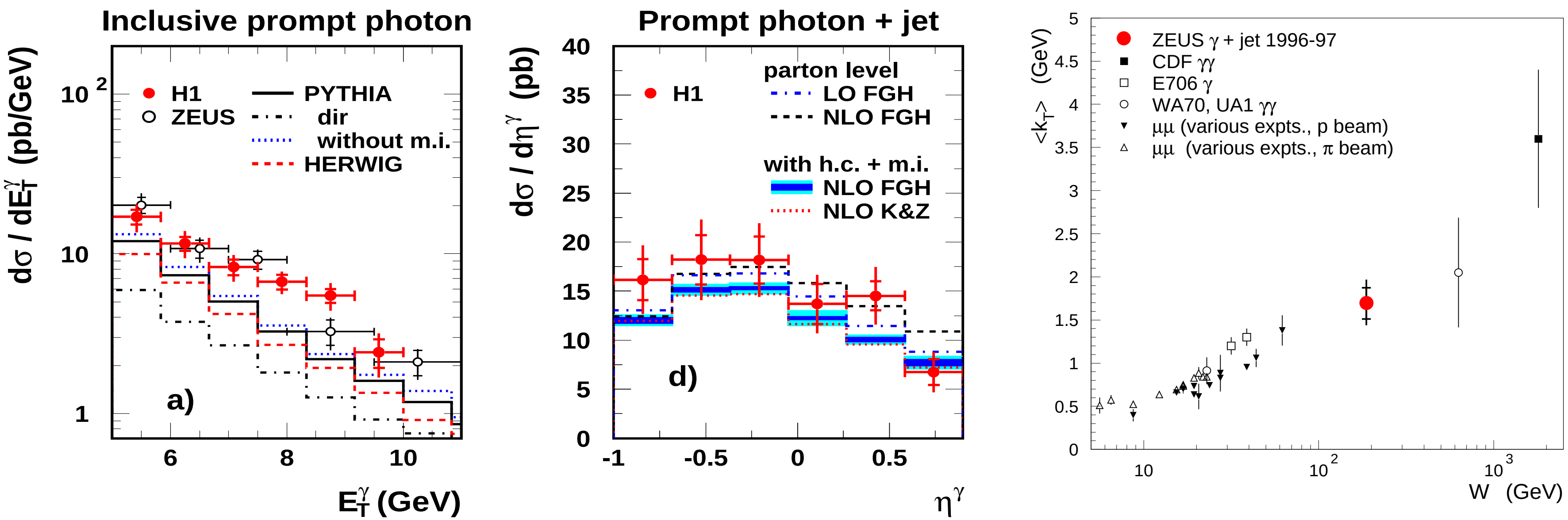
Year	Publication	$\mathcal{L}/pb^{-1}$	Experiment	Photoproduction	D.I.S.
2008	*EPJ C54*	(227)	H1		incl. γ ; γ+jet
2010	*EPJ C66*	(340)	H1	incl. γ ; γ+jet	
2010	*PL B687*	(320)	ZEUS		incl. γ
2012	*=> PLB*	(326)	ZEUS		γ+jet

Messages from HERA-1 results

★ LO MC: shapes are well described, but overall cross sections fall below data by $\sim 50\%$

★ NLO/LO corrections are substantial, but still NLO rate is low by $25 - 30\%$
(note however limited experimental precision) $\Rightarrow$ Need for HO corrections?

★ Intrinsic transverse momentum of the partons in the proton may explain $\gamma + jet$ data
$\langle k_T \rangle = 1.7$ GeV is required (inferred from tuned Pythia) $\Rightarrow$ Non-collinear approach?



HERA-2: (3-4) fold statistics, improved systematics

Isolated Photon Event selection

PhP sample ($\mathcal{L} = 340$ pb^{-1})

- **Inclusive phase space**
  - ▷ $6 < E_T^\gamma < 15$ GeV
  - ▷ $-1.0 < \eta^\gamma < 2.43$
  - ▷ $z = E_T^\gamma / E_T^{\gamma\, jet} > 0.9$
  - ▷ $Q^2 < 1$ GeV^2, $0.1 < y < 0.7$
- **Photon + jet phase space**
  - ▷ $p_T^{jet} > 4.5$ GeV (inclusive k_T algorithm)
  - ▷ $-1.3 < \eta^{jet} < 2.3$

DIS sample ($\mathcal{L} = 326$ pb^{-1})

- **Inclusive phase space**
  - ▷ $4 < E_T^\gamma < 15$ GeV
  - ▷ $-0.7 < \eta^\gamma < 0.9$
  - ▷ $z = E_T^\gamma / E_T^{\gamma\, jet} > 0.9$
  - ▷ $10 < Q^2 < 350$ GeV^2, $W_X > 5$ GeV
- **Photon + jet phase space**
  - ▷ $p_T^{jet} > 2.5$ GeV (inclusive k_T algorithm)
  - ▷ $-1.5 < \eta^{jet} < 1.8$

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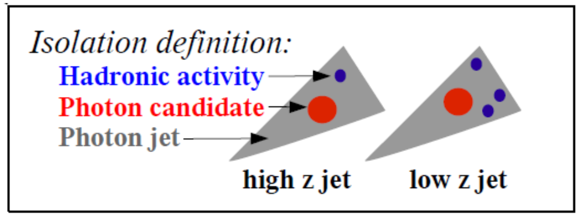
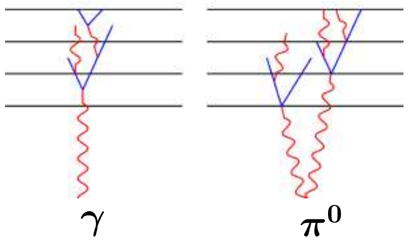
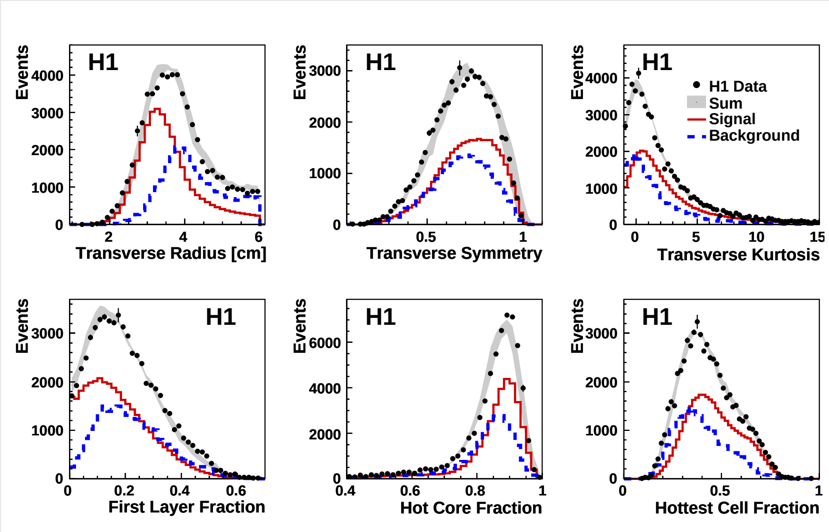


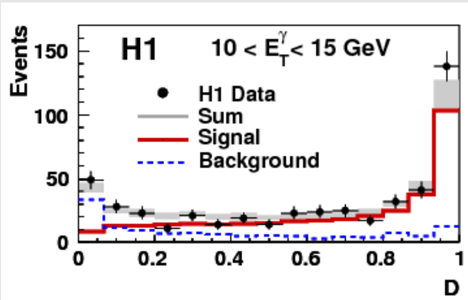


shower shape analysis

Signal extraction

H1 (photoproduction)

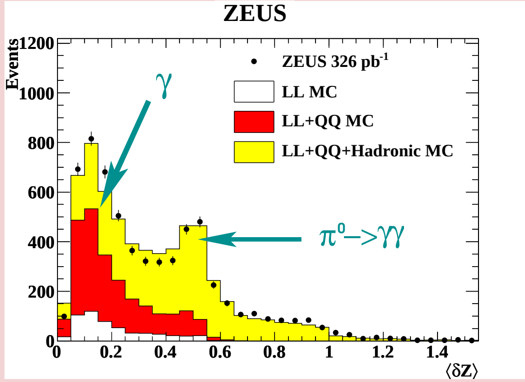


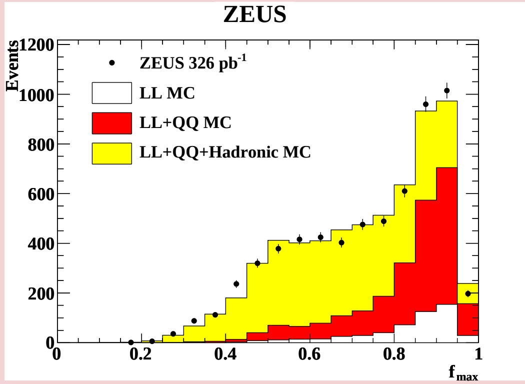


Discriminant distribution in a typical $(E_T^\gamma, \eta^\gamma)$ bin

- Use combined discriminant $D = P_\gamma/(P_\gamma + P_{bgr})$ based on *em* shower shape parameters, then unfold to extract signal
- Signal purity is in average $\sim 60\%$

ZEUS (NC DIS)





- Use lateral e.m. cluster width $\langle \delta z \rangle$, and energy fraction in most energetic cell, f_{max}
- Remaining bgr is subtracted statistically
- Signal purity is 30% (γ) and 40% ($\gamma + jet$)

Prompt Photons in PhP: Cross sections

- **Inclusive cross sections**

FGH: underestimate cross section by $\sim 20\%$,
problems at low η^γ

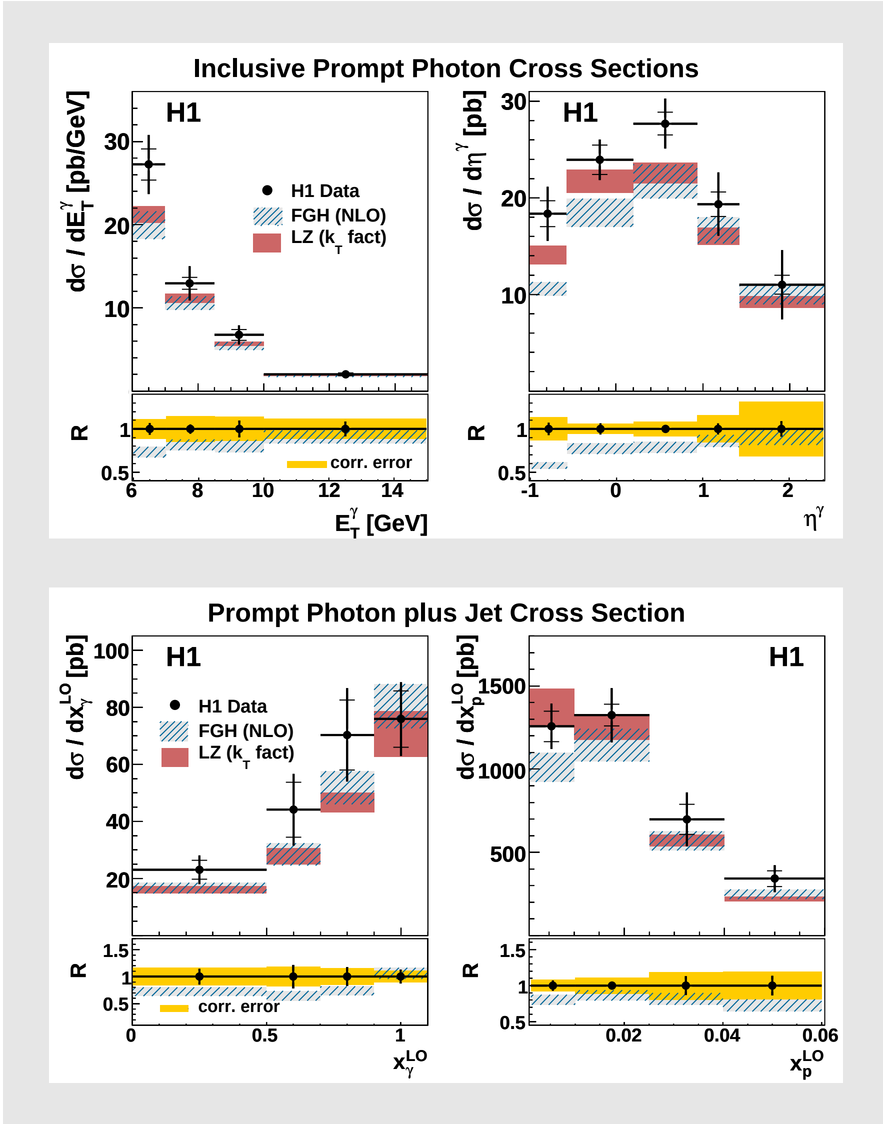
LZ: comes closer to the data

- **$\gamma + jet$ cross sections**

both calculations provide fair description,

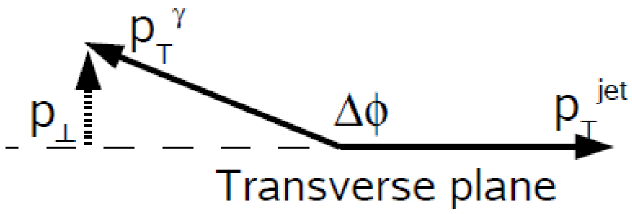
k_T-fact. (LZ) improves agreement at low x_p^{LO}

$$x_\gamma^{LO} = E_T^\gamma \frac{e^{-\eta^{jet}} + e^{-\eta^\gamma}}{2yE_e}; \qquad x_p^{LO} = E_T^\gamma \frac{e^{\eta^{jet}} + e^{\eta^\gamma}}{2E_p}$$

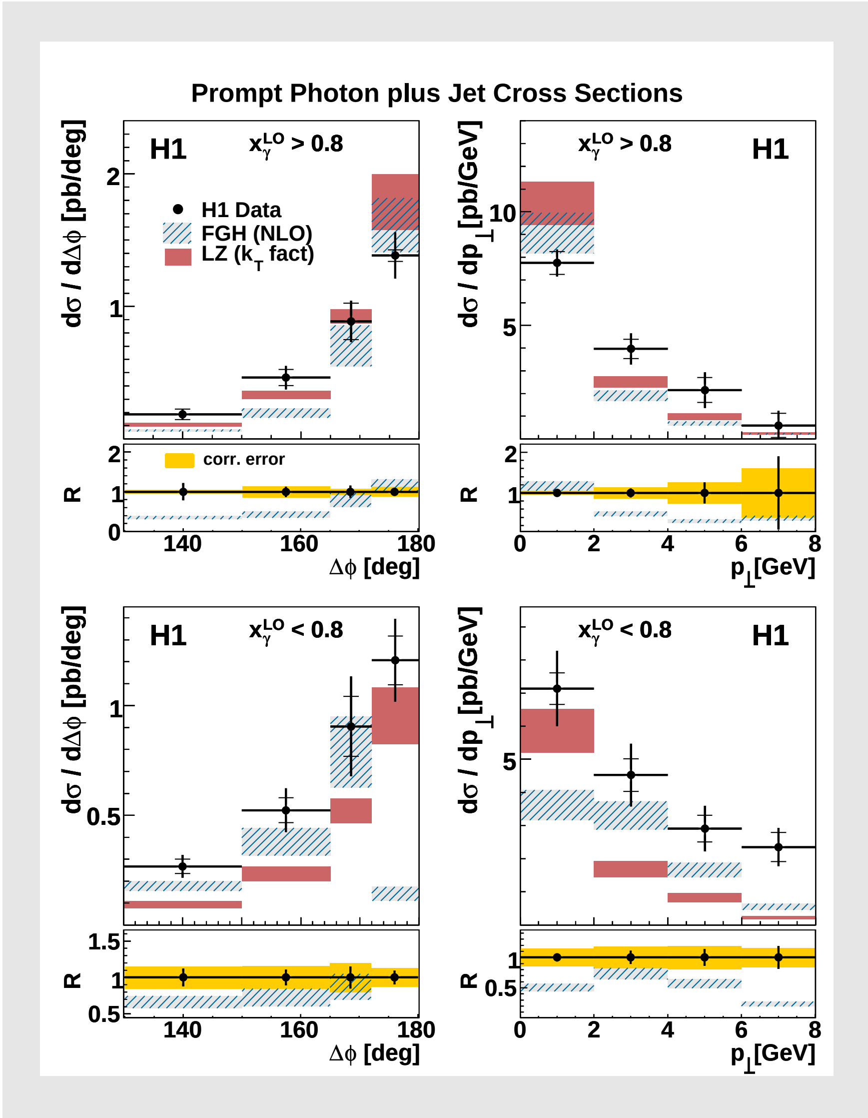


★ k_T-factorisation at LO performs better than collinear pQCD at NLO

Prompt Photons in PhP: γ-jet correlations

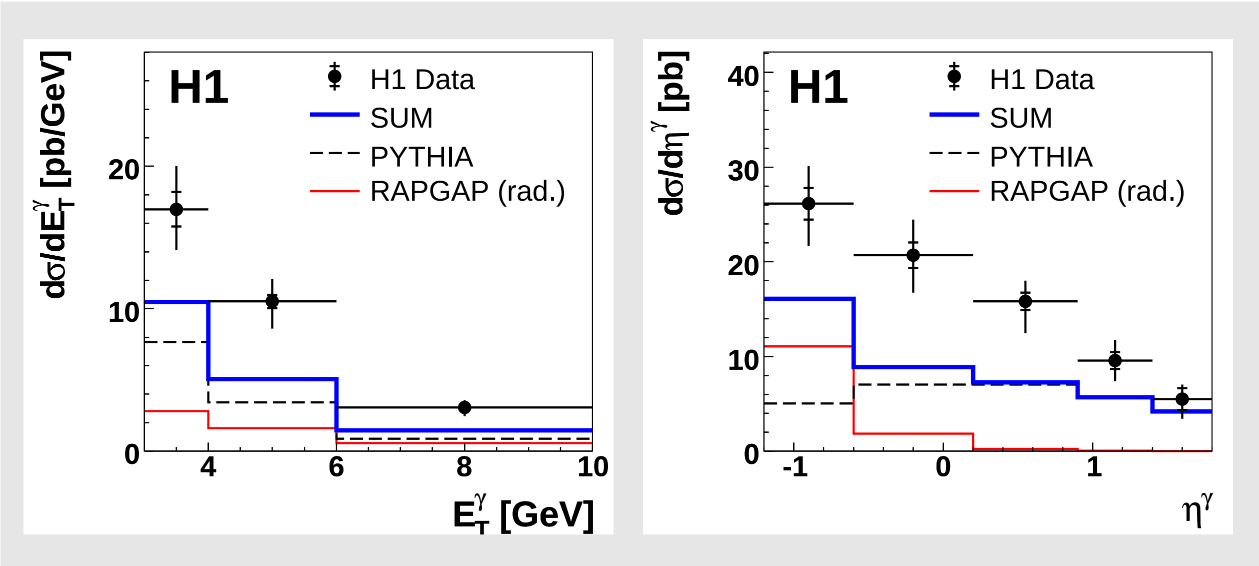


- Study photon-jet correlations in direct (resolved) enhanced phase space
- Direct process is more back-to-back
- Sensitive to soft gluon emission in the highest $\Delta\Phi$ bin
- LZ missing diagrams are expected to contribute in tails of resolved cross sections



★ More work to be done from theory side...

Prompt Photons in DIS: Inclusive cross sections

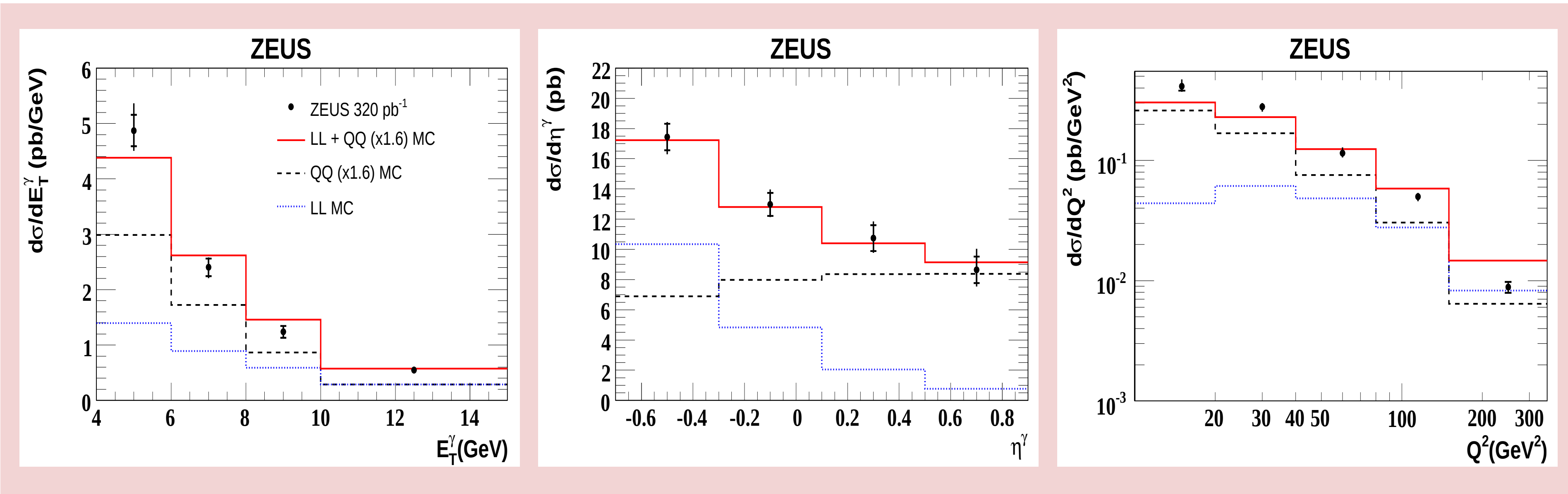


Both measurements are consistent:

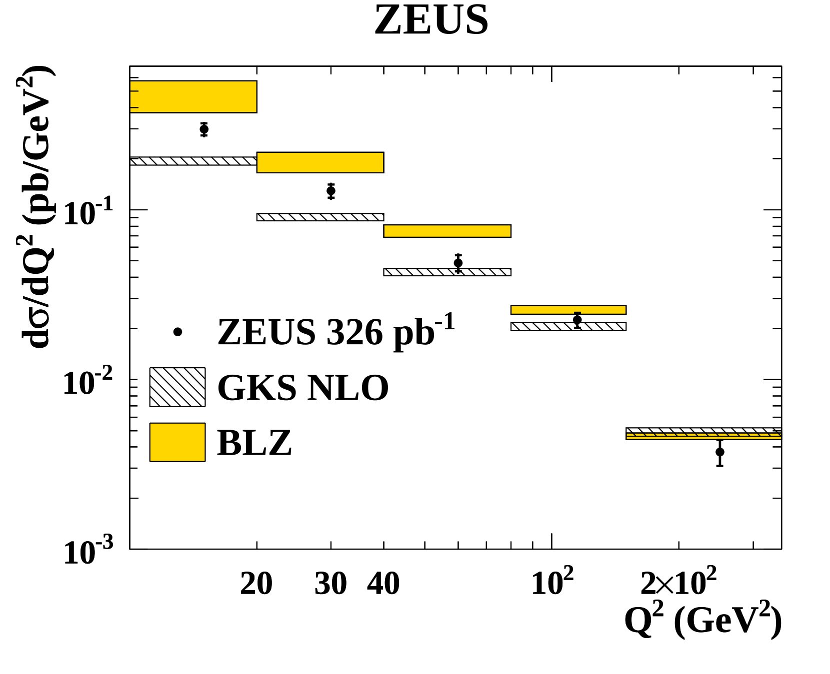
LO MC needs significant scaling: QQ(PYTHIA)$\times 1.6$

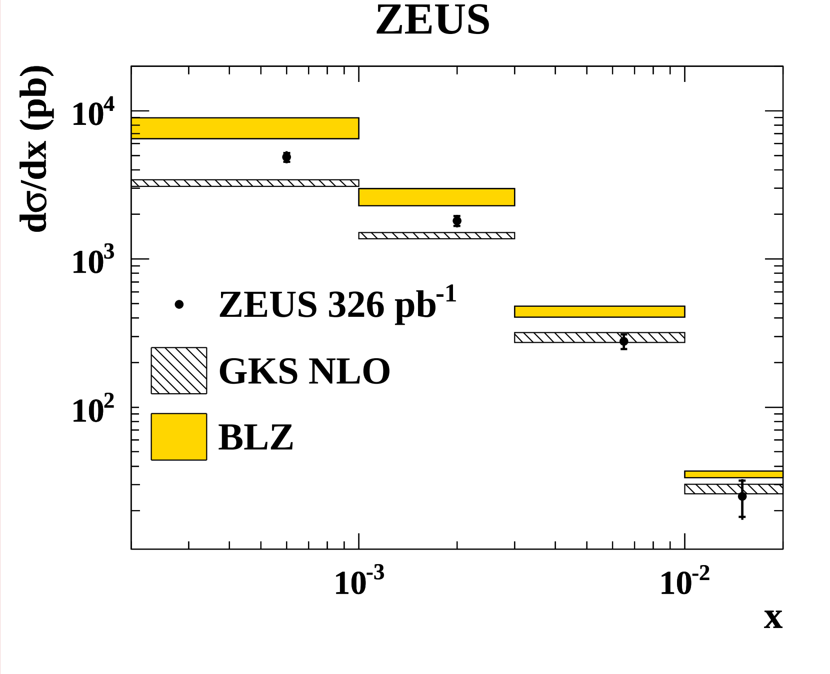
Same for $\mathcal{O}(\alpha^3\alpha_s^0)$ QCD calculations (not shown)

Go to NLO pQCD



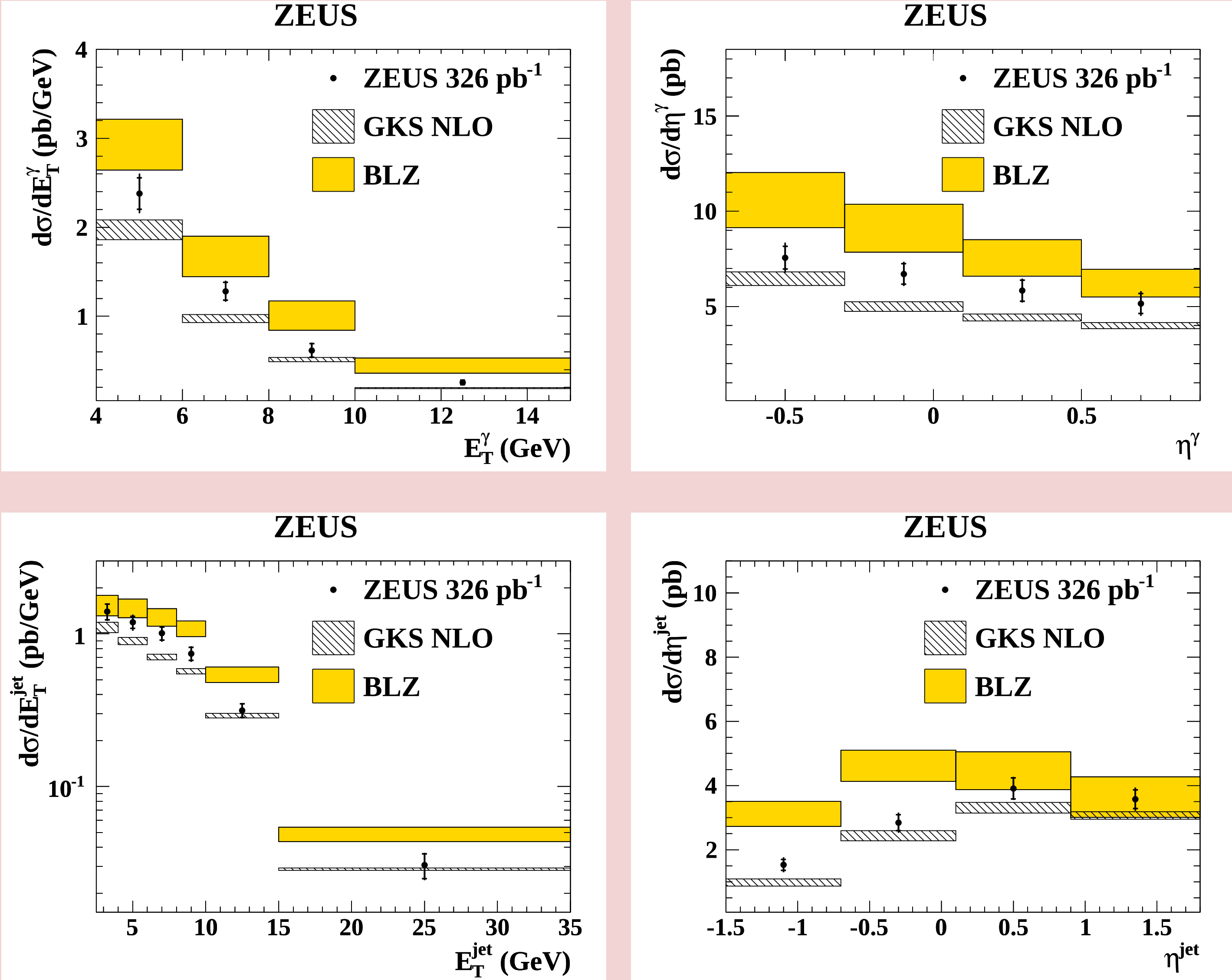
Prompt Photons in DIS: $\gamma + jet$





- Significantly improved precision as compared to HERA-1 data
- NLO calculations improves LO ones by 35%
- Problems are mainly observed at low Q^2 and low x:
  GKS NLO still underestimate cross sections by $\sim 20\%$
  while BLZ (k_T-factorisation) predicts now too high rate. Why? $\Rightarrow$

Prompt Photons in DIS: $\gamma + jet$



Photon

Shapes are fairly well described

Jet

GKS NLO describes shapes

BLZ comes too high at backward $\eta^{jet} \Rightarrow$ not optimal procedure constructing jet from evolution chain?

Summary

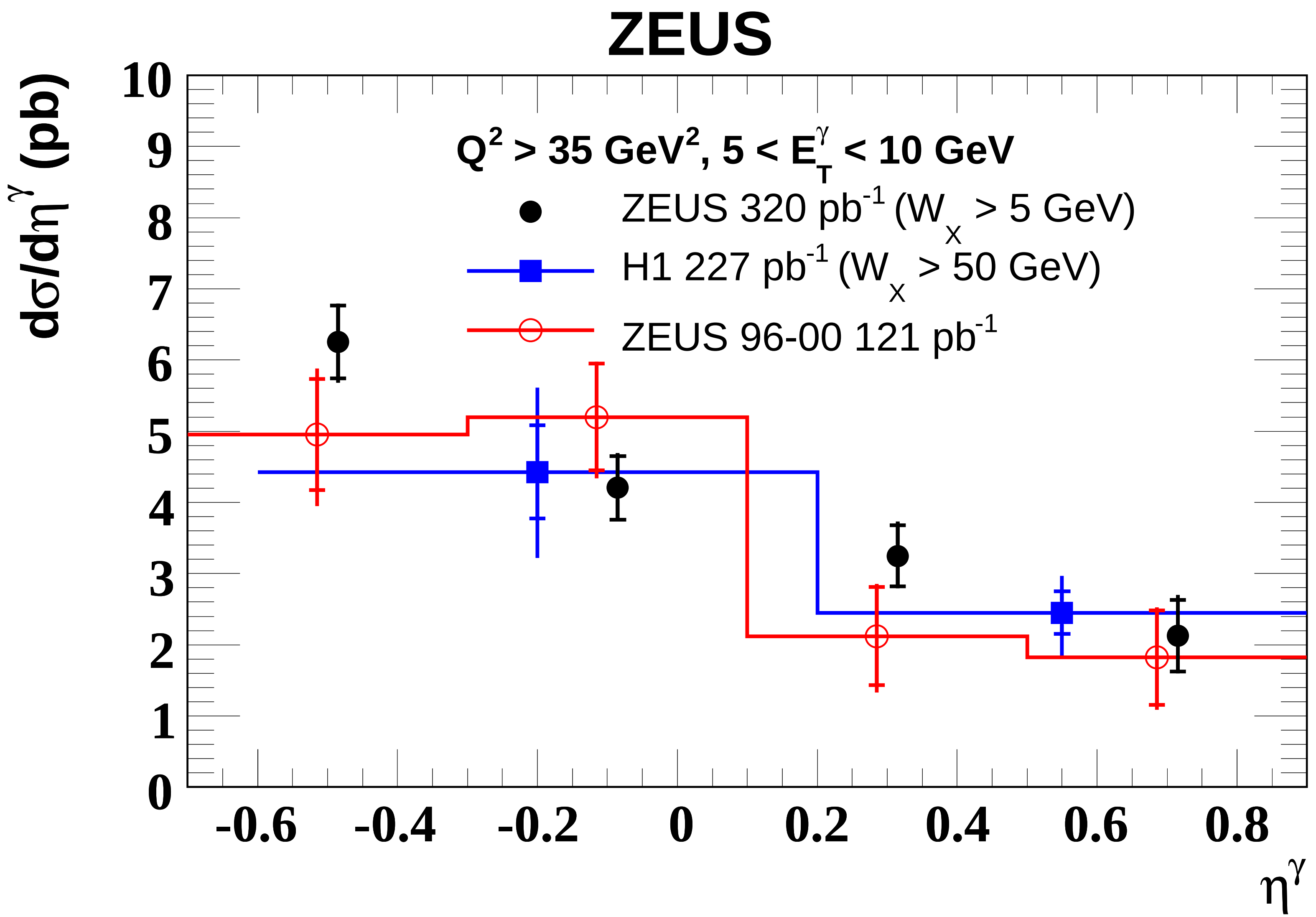
- HERA collider experiments completed measurements of high E_t isolated photons both in photoproduction and DIS regimes, using full HERA-2 data samples.
  Compared to previous publications based on HERA-1 data experimental precision is improved by factor of two (from $25-30\%$ to $10-15\%$)

- Prompt photons production still remains a challenge for theory: NLO QCD calculations in collinear approximation underestimate cross sections.
  k_T-factorisation approach in several aspects comes closer to the data, yet it fails to describe them in all details.

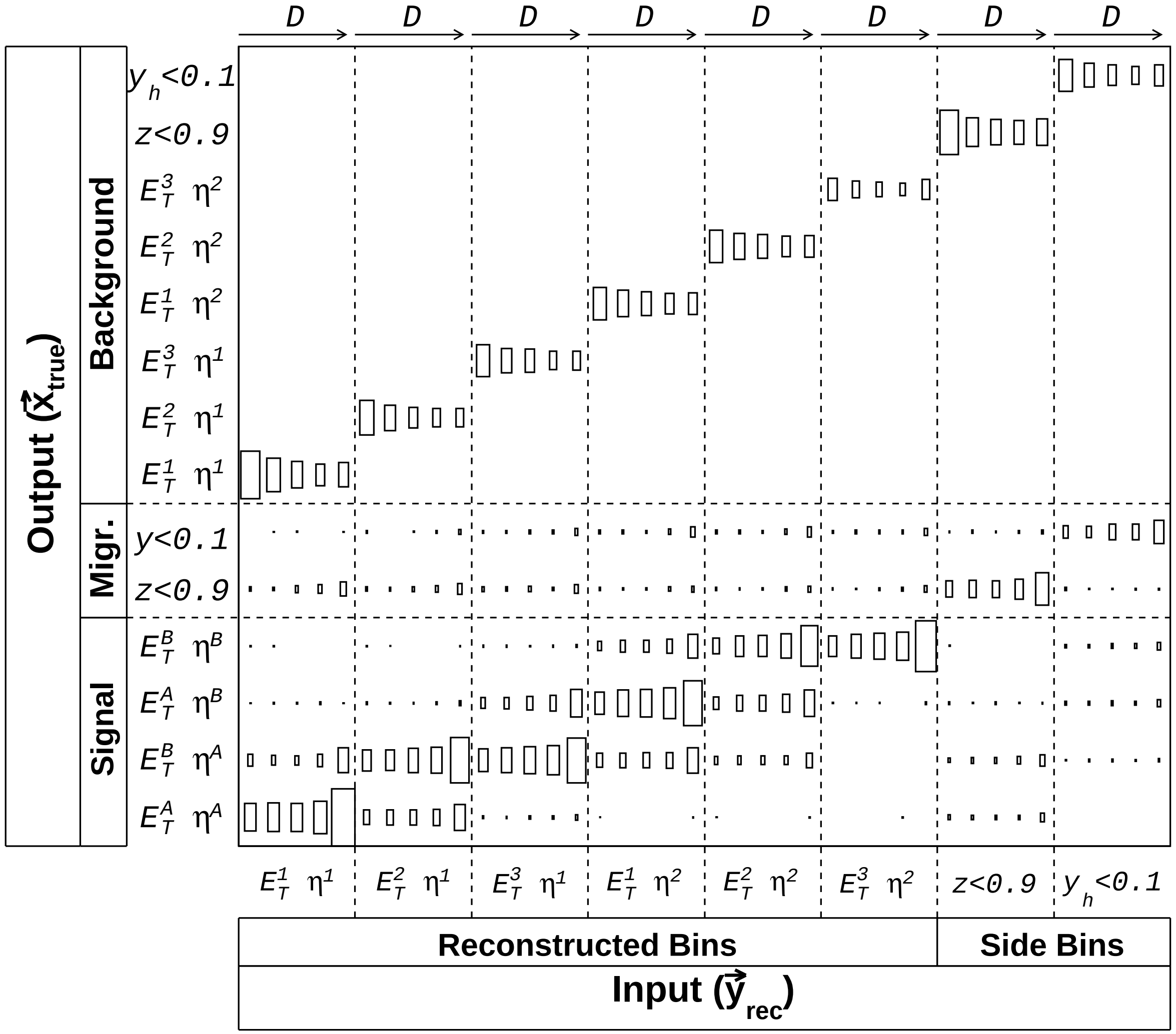
- Recently published H1 and ZEUS results can be used to gain deeper insight into underlying QCD dynamics of this reaction.

Backup Slides

Prompt photons: H1 vs ZEUS in a common phase space



Prompt photons: Unfolding Matrix



$$A\vec{x}_{\mathrm{true}} = \vec{y}_{\mathrm{rec}}$$

(A is computed using PYTHIA simulation for sig + bgr in extended phase space)