Prompt photon production with associated jets at HERA

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Deep inelastic scattering:

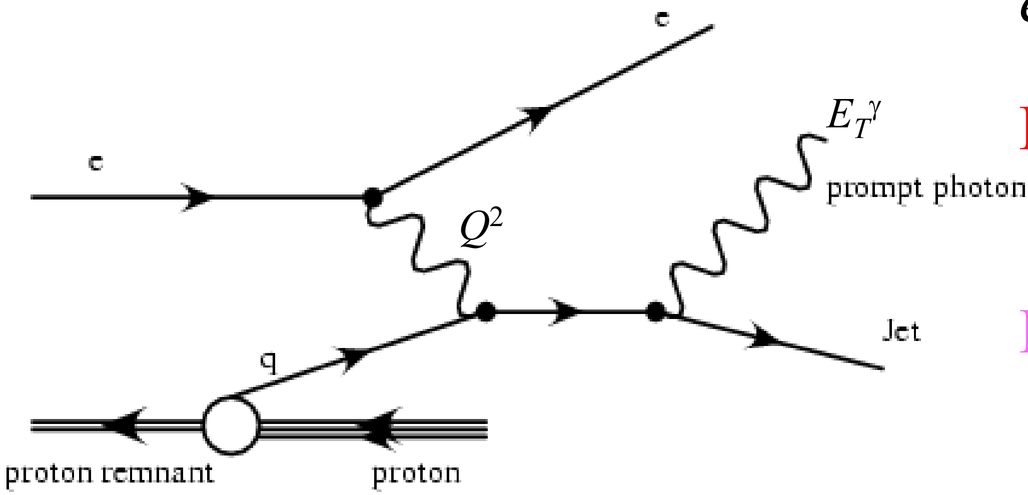
first observation by ZEUS (inclusive, γ + jet) with comparison to MC and to NLO calculations

Photoproduction:

new results from H1 (inclusive, γ + jet) with comparison to NLO calculations

Both based on full data set 1996-2000 **> 100 pb^{-1}**

Prompt photon production: γ radiation from quark line



$eq \rightarrow eq\gamma$

DIS: isolated e,γ (incl.)
isolated e,γ,jet

Photoprod'n (Q^2<1 GeV^2)
e unobserved
isolated γ,
jet balancing p_T

Backgrounds: γ radiation from initial state, final state e (DIS)
γ from jet fragmentation
γ from π^0, η^0 decay

Kinematic region

H1 photoproduction	ZEUS photoprod'n (old)	ZEUS DIS
96-00 data (105 pb^{-1})	96-97 data (38 pb^{-1})	96-00 data (121 pb^{-1})
$Q^2 < 1$ GeV^2		$Q^2 > 35$ GeV^2
$5 < E_T^\gamma < 10$ GeV (15 GeV for ZEUS photo $d\sigma/d\,E_T^\gamma$)		
$-1.0 < \eta^\gamma < 0.9$	$-0.7 < \eta^\gamma < 0.9$	
$122 < W < 266$ GeV	$134 < W < 285$ GeV	31(69)%@300(318)GeV
Isolation: $E_t^\gamma / E_t^{total} > 0.9$ in cone of $\Delta R = (\Delta\Phi^2 + \Delta\eta^2)^{1/2} = 1$		
Prompt photon + jet		
Inclusive k_T		Cone $\Delta R = 0.7$
$E_t^{jet} > 4.5$ GeV	$E_t^{jet} > 5$ GeV	$E_t^{jet} > 6$ GeV
$-1.0 < \eta^{jet} < 2.3$	$-1.5 < \eta^{jet} < 1.8$	

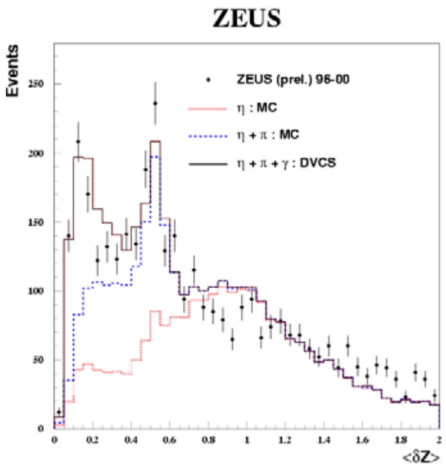
Table after Lemrani

γ signal – π^0 and η^0 backgrounds

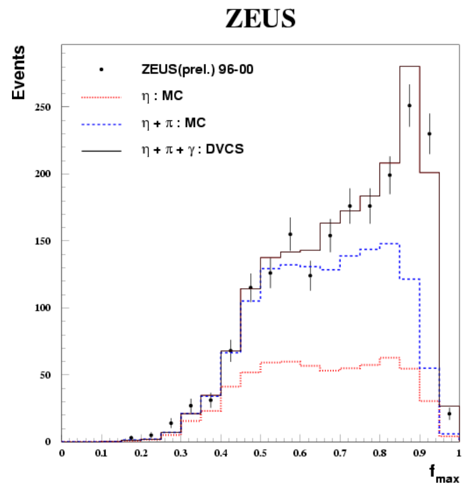
Use e.m. calorimeter shower shape

ZEUS DIS

Shower width



Hot core fraction



ZEUS z-strips

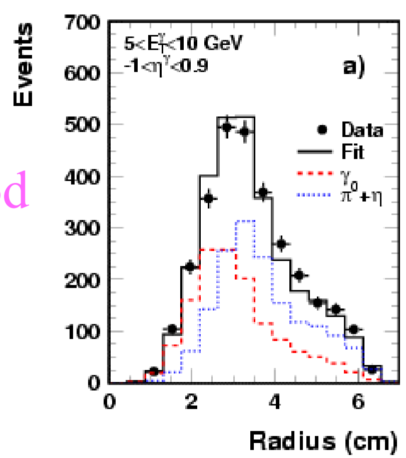
γ shape from DVCS data

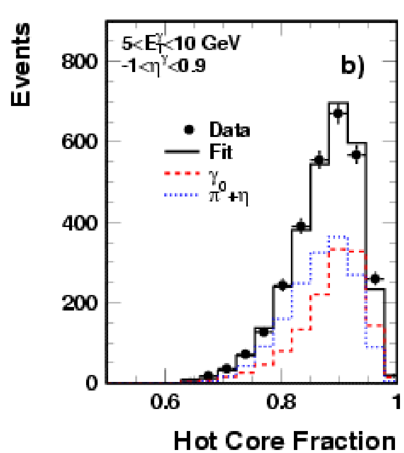
π^0,η^0 shapes from MC

Fit for γ,π^0,η^0 fractions

Background subtraction is rather stable against errors in γ shape.

H1 photoprod



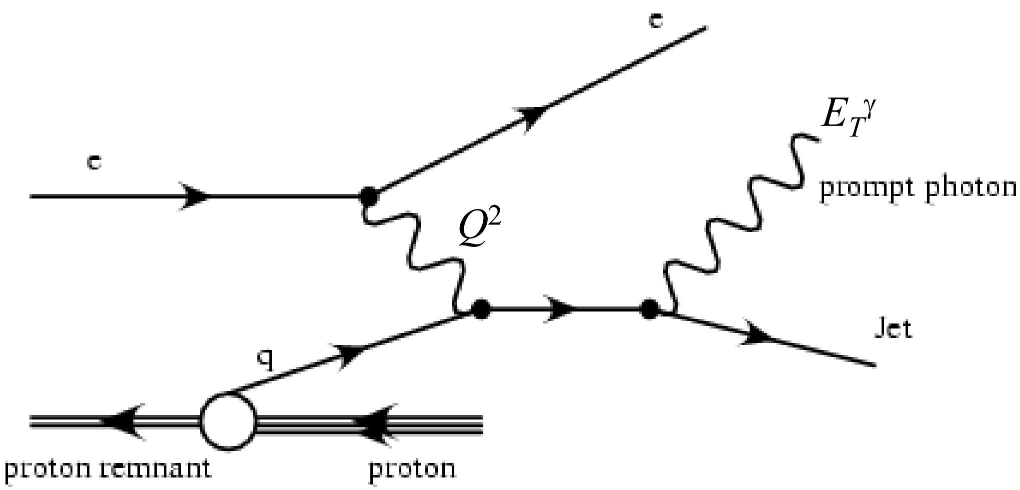


H1 cells

$\gamma,(\pi^0+\eta^0)$ shapes from MC

Likelihood discriminator in (E_T,η) bins

$eq \rightarrow eq\gamma$ in Deep Inelastic Scattering



Minimise ISR, FSR

(139.8° < θ_e < 171.9°) far from γ

Two hard scales:

(Q^2, E_T^{γ}) hard for MC to simulate

PYTHIA v6.206 (new)

HERWIG v6.1

Comparisons available for $e\gamma X$, $e\gamma$jet

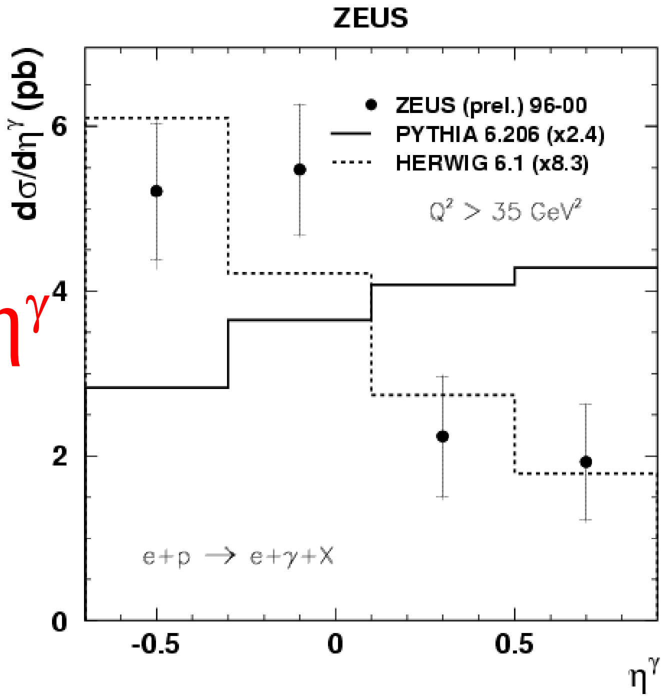
NLO calculations $O(\alpha^3\alpha_s)$ by Kramer and Spiesberger

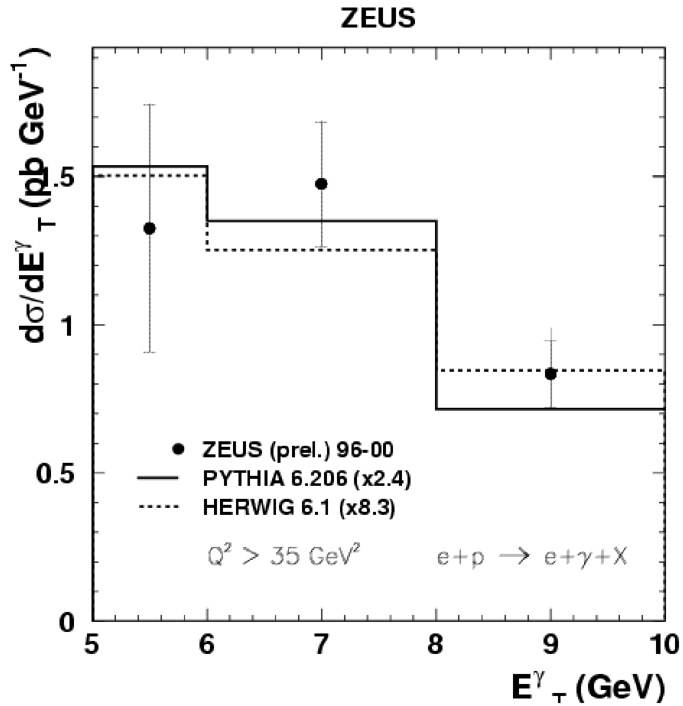
Based on A. Gehrmann-de Ridder,K,S Nucl. Phys. **B578** (2000) 326

- includes ISR, FSR, vertex diagrams, all interferences,
- predictions for (e+γ+one jet) including renorm. scale uncertainty

DIS: $eq \rightarrow e\gamma X$ (inclusive)

η^{γ}



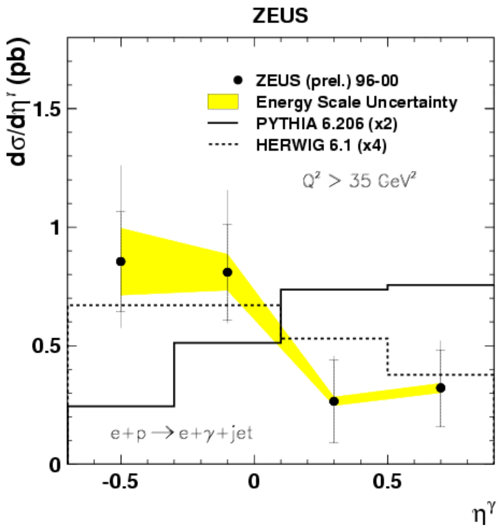


E_T^{γ}

	$<Q^2>$(GeV^2)	$<x_{Bj}>$	η^{γ} shape	E_T^{γ} shape	normalisation factor needed
Data	87	0.0049			
PYTHIA	87	0.0047	BAD	OK	2.4
HERWIG	62	0.0017	OK	OK	8.3

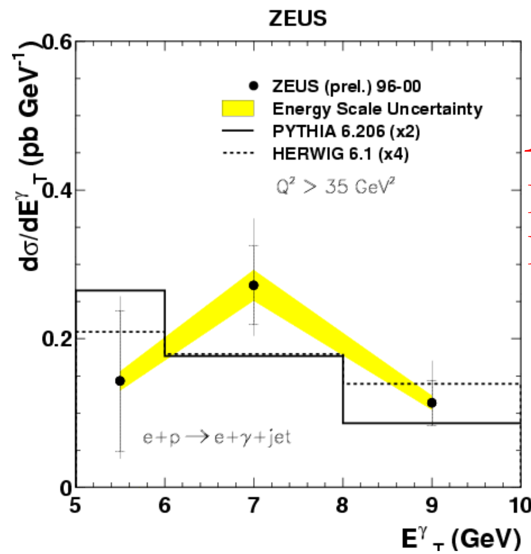
NEITHER IS A GOOD DESCRIPTION OF THE DATA.

DIS: *eq* → *eγ* + one jet



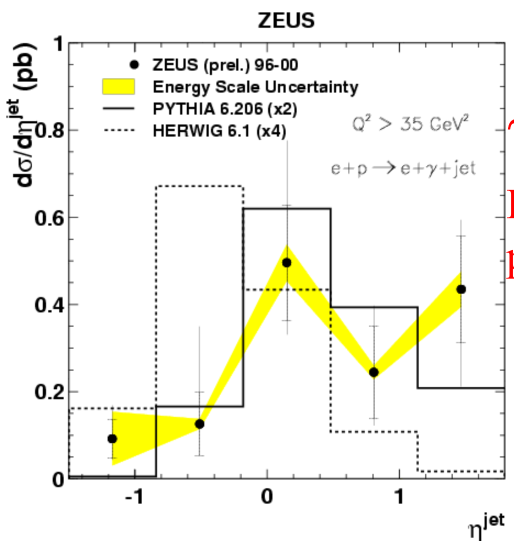
η^γ

HERWIG preferred



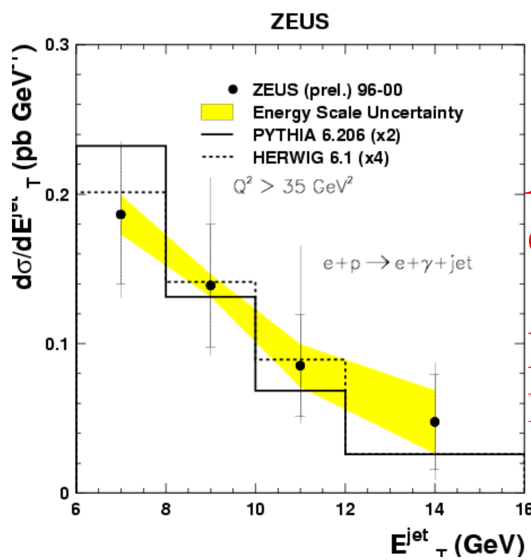
E_T^γ

Data uneven.
MC's similar



η^{jet}

PYTHIA preferred



E_T^{jet}

OK

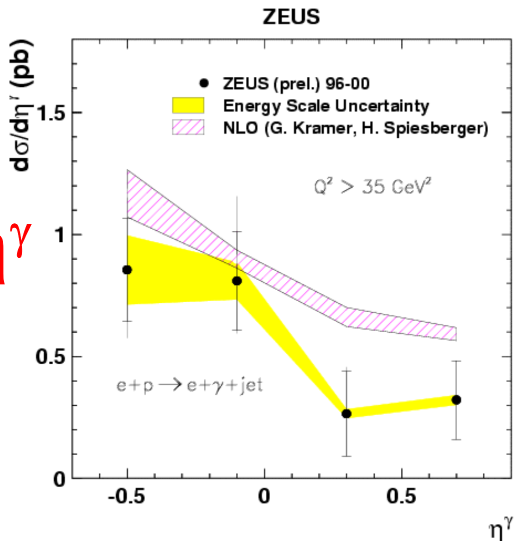
Normalisation:
Both poor

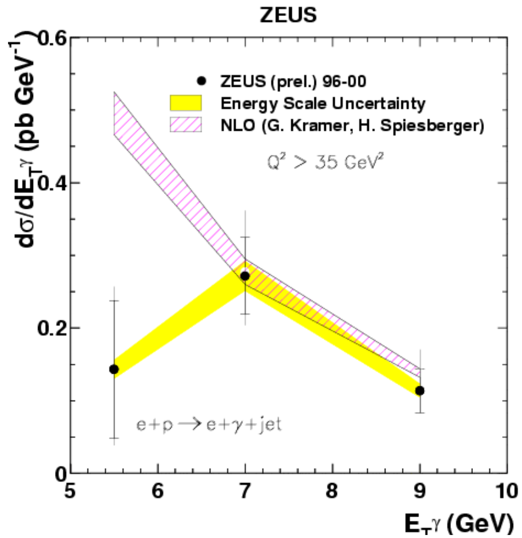
DIS: $eq \rightarrow e\gamma$ + one jet

Comparison to NLO calculations

(Kramer & Spiesberger)

η^{γ}

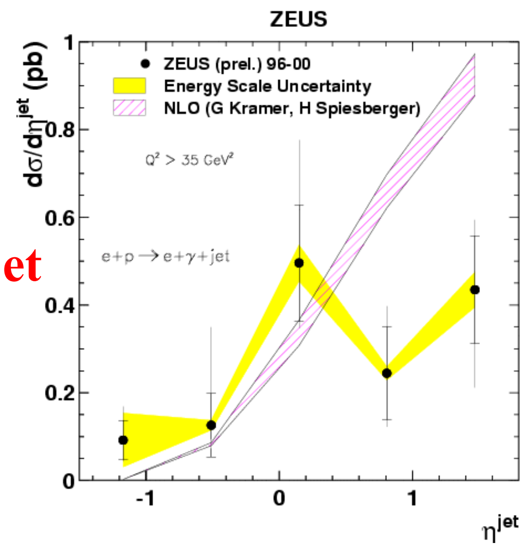


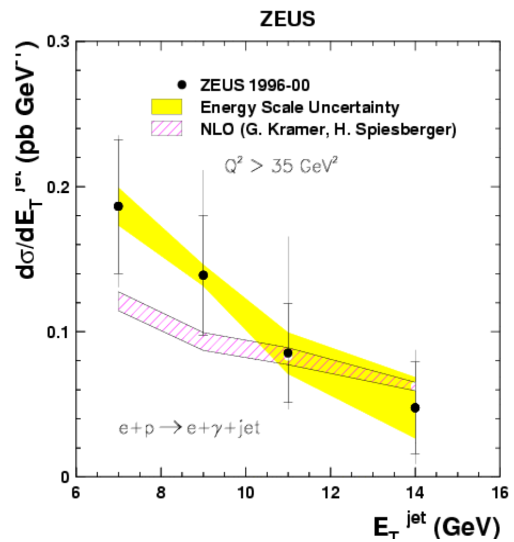


E_T^{γ}

Total cross section:
Data slightly below theory (1.7 S.D.)

η^{jet}



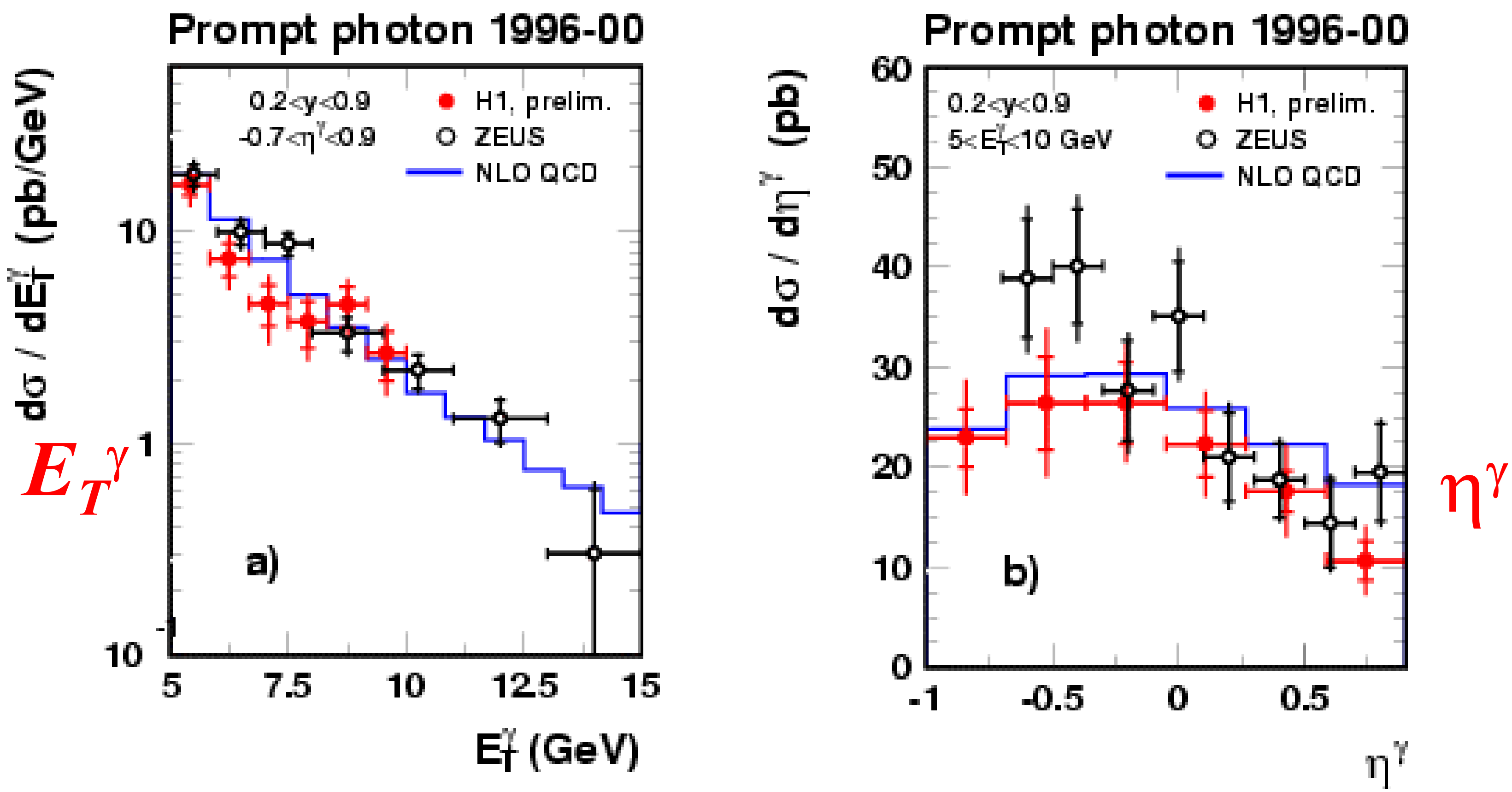


E_T^{jet}

Overall: 'fair' agreement rates well predicted

Photoproduction:

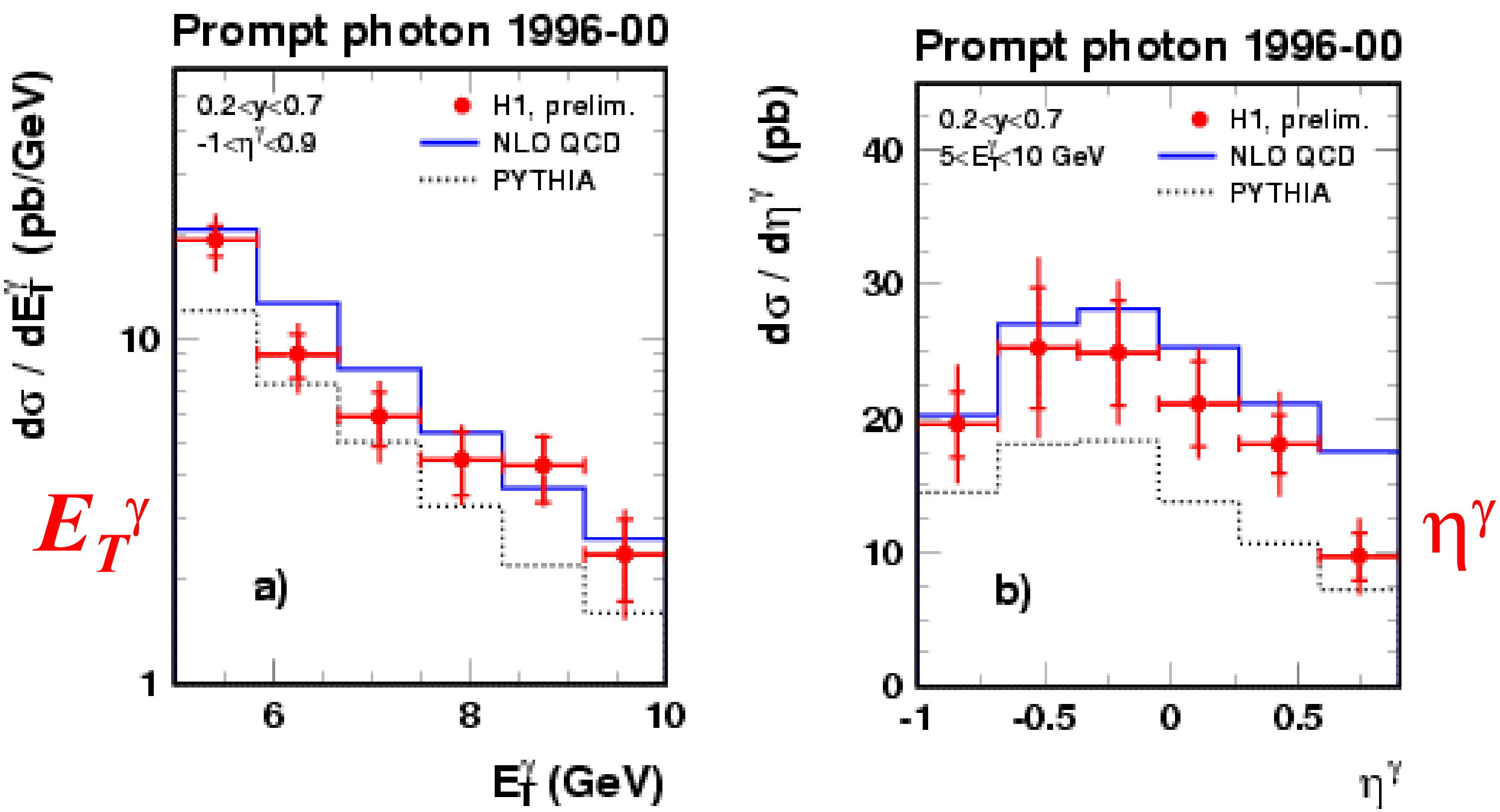
Inclusive prompt photon cross section



Data consistent within errors.

Photoprodution:

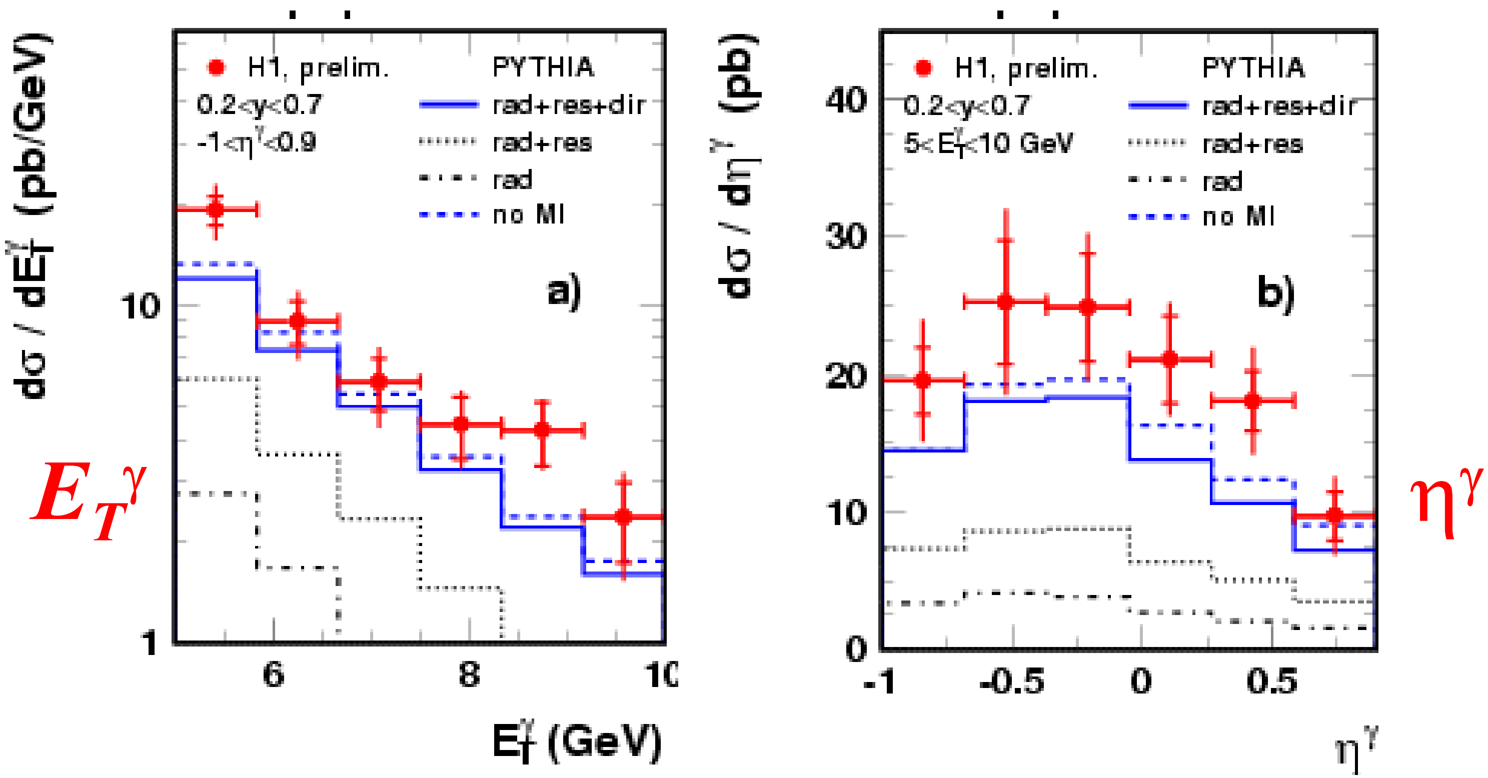
H1: compare to NLO and PYTHIA



pQCD (NLO, Fontannaz *et al*) agrees within errors
PYTHIA: describes shapes but a bit low.

Photoproduction:

PYTHIA – origin of prompt γ

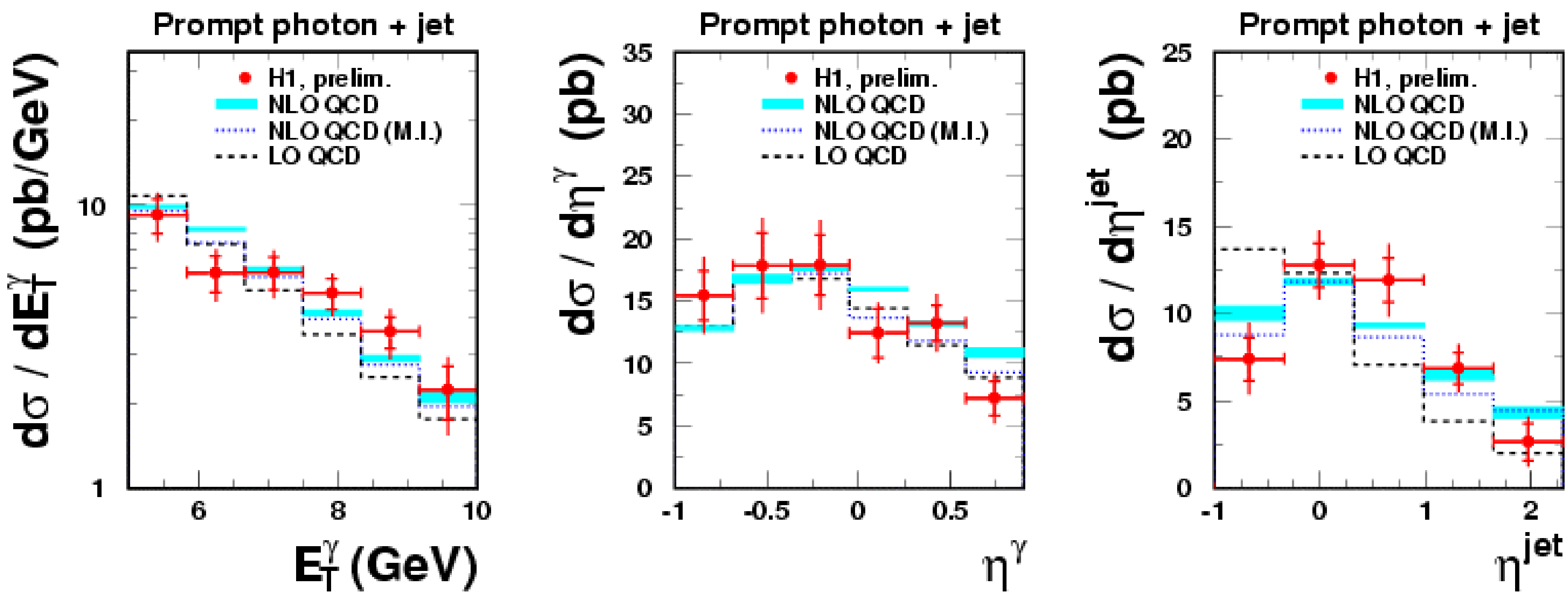


- >50% direct exchanged γ.
- Radiation from electron line small
- Multiple interactions hurt photon isolation cut and so reduce the cross-section

Photoproduction:

γ+jet – compare to LO and NLO (Fontannaz *et al*)

(NLO scale variation 0.5 E^{γ}_{T} to 2 E^{γ}_{T})



Correction to NLO for multiple interactions applied by PYTHIA

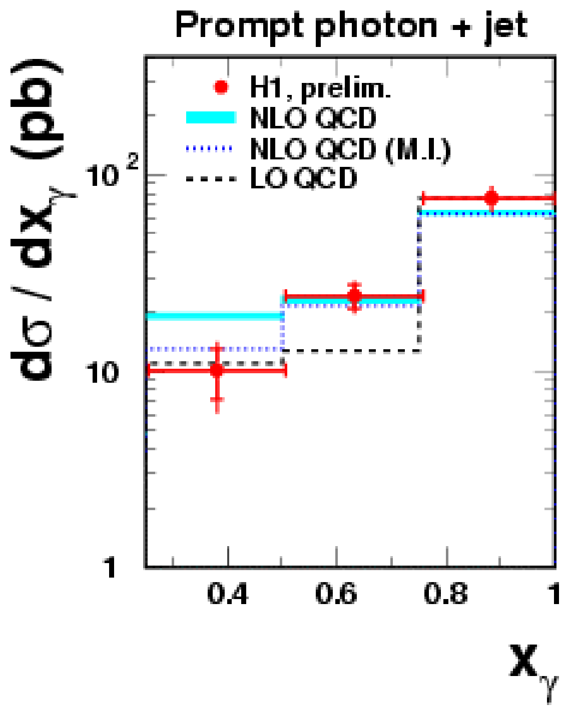
– improves fit at large η^{γ}

Large negative NLO corrections at $\eta^{jet} < 0$

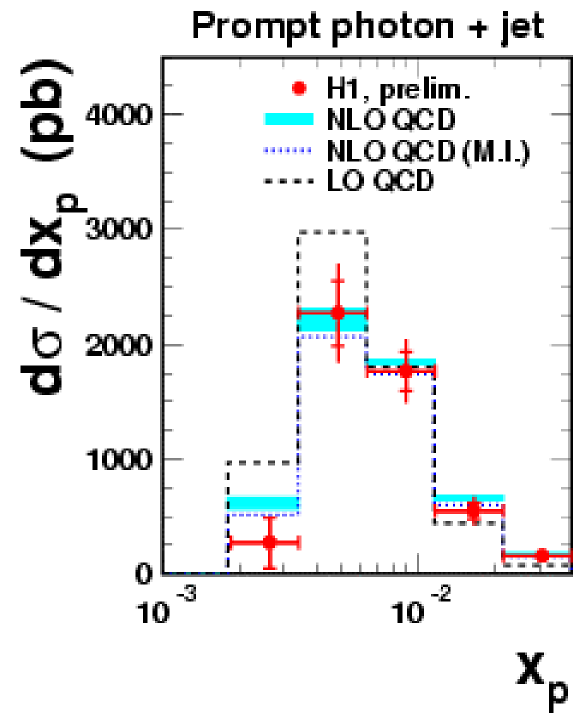
NLO describes the data within errors

Photoproduction:

(γ+jet) σ *vs.* x_γ, x_p



$x_\gamma = (E_T^{jet} e^{-\eta(jet)} + E_T^{\gamma} e^{-\eta(\gamma)})/2yE_e$



$x_p = (E_T^{jet} e^{\eta(jet)} + E_T^{\gamma} e^{\eta(\gamma)})/2E_p$

- Multiple interactions matter at $x_\gamma < 0.5$ (resolved γ region)
- NLO + MI describes the data

Summary

ZEUS: First Observation of prompt photon emission in DIS

Measured σ,η and E_T for inclusive e+γ and for (e+γ+jet)

MCs (PYTHIA, HERWIG) differ. Neither is a good description of the data

NLO theory (Kramer and Spiesberger) agrees on rates and on general trend of distributions

Ample room for work: theory, phenomenology, data

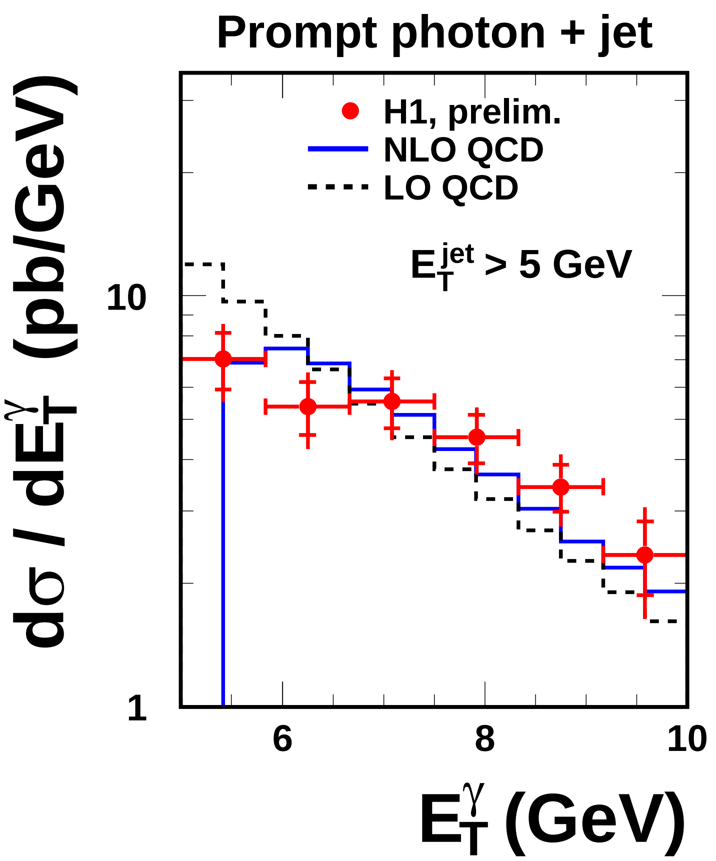
H1: Photoproduction: σ,η & E_T for inclusive γ and for (γ+jet)

Consistent with earlier data

Inclusive distributions well described by NLO theory (Fontannaz *et al*) and shapes by PYTHIA

(γ+jet) well described by NLO theory, (especially if multiple interaction corrections made *a la* PYTHIA)

(γ+jet) Avoid symmetric E_T cuts



Fontannaz *et al:*

NLO infrared instabilities with symmetric cuts *e.g.*

$E^{jet}_{T,min} = E^{\gamma}_{T,min} = 5$ GeV

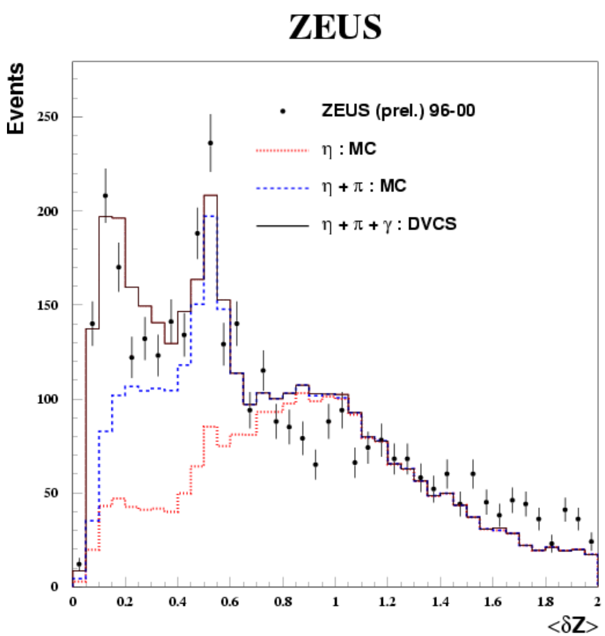
Unphysical drop in prediction just above cut (similar to dijets)

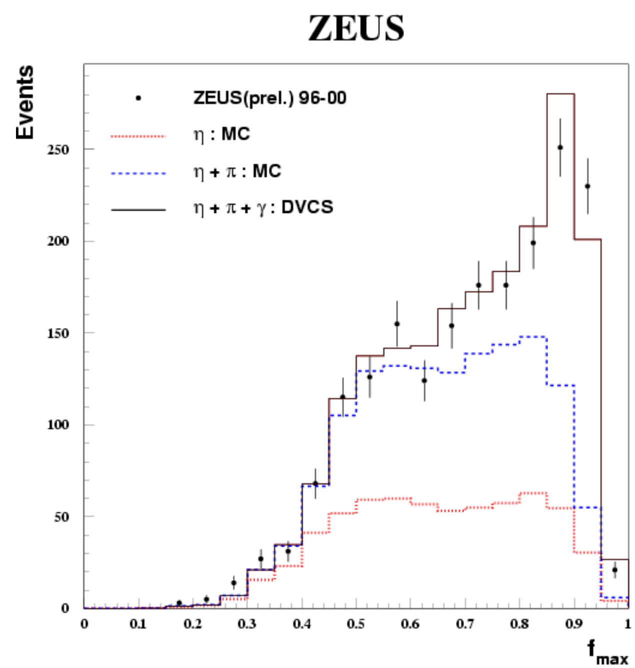
γ signal extraction in ZEUS

Shower shape variables for γ (from DVCS data), π^0,η (from MC)
Using 5 cm z-strips in Barrel e.m. calorimeter (-0.7 < η < 0.9)

$\delta Z = \Sigma_i E_i . |Z_i - <Z>| / \Sigma_i E_i$

f_{max} = fraction of γ energy in highest cell





(use δZ>0.65 only)

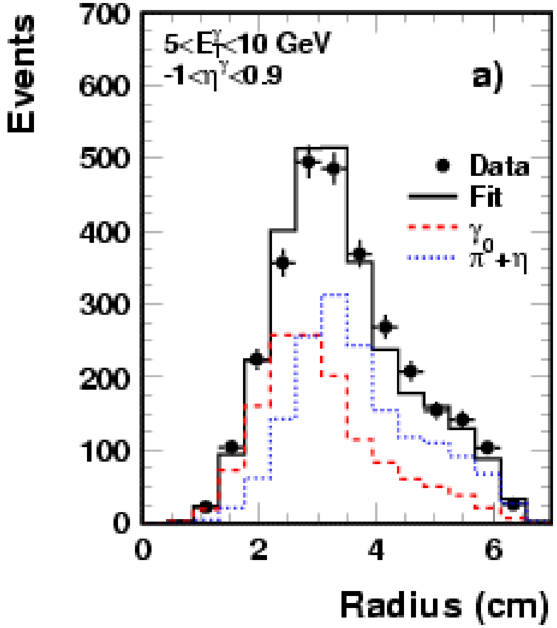
S/B~0.44

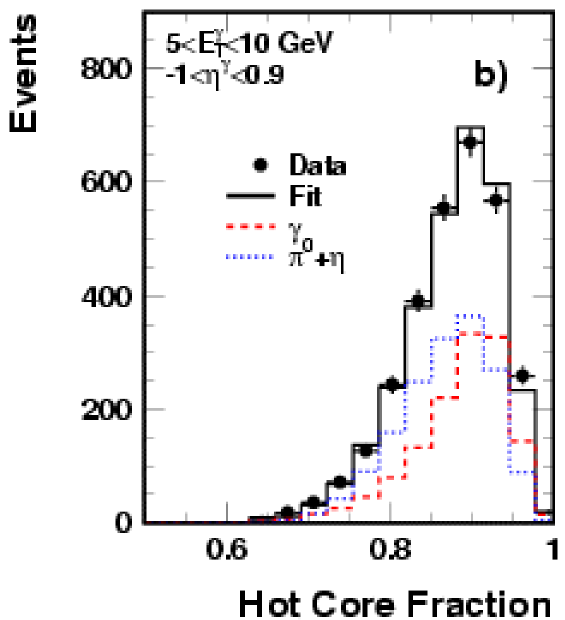
η fraction fixed from background at $\delta Z > 0.65$
Background subtraction from f_{max} plot. Rather insensitive to errors in modelling showers (included in systematic errors)

γ signal extraction in H1

Use shower shape variables for γ, $(\pi^0 + \eta)$ (η fraction from MC)

Radius $= \Sigma_{\text{cells}}\, w_i r_i / \Sigma_{\text{cells}}\, w_i$ *Hot core fraction* $= E_{core}/E_{tot}$





Likelihood discriminator used in (E_T,η) bins to allow for energy dependence and varying calorimeter granularity.

- Shower shape variables well described.
- photoproduction S/B ~ 1