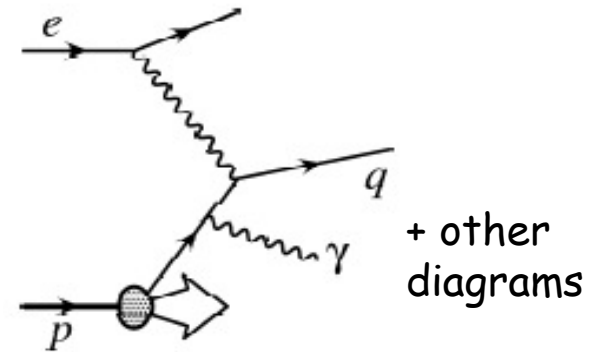


# Prompt photon production at HERA

D H Saxon  
University of Glasgow

- **Photoproduction**  
(H1: Eur Phys J C66 (2010) 17)
- **DIS**  
(ZEUS: Phys Lett B687 (2010) 16)
- **Test theories**  
Collinear and  $k_T$  factorisation



A reliable probe of dynamics

2 hard scales:  $Q^2$  and  $E_T^\gamma$



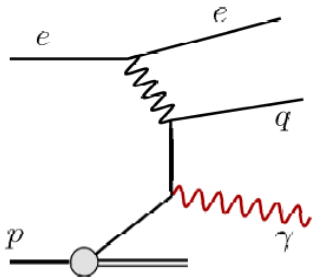
Saxon, DIS10, Firenze



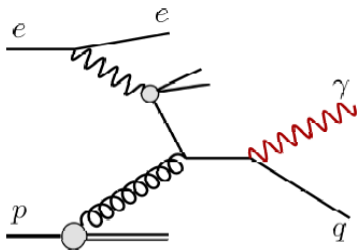
# Photoproduction: $\gamma$ emitted by quark

direct  $\gamma q \rightarrow \gamma q$ , resolved  $gq \rightarrow \gamma q$

$\gamma q \rightarrow \gamma q$



$gq \rightarrow \gamma q$



Theory: prompt=Feynman line

Expt: prompt=isolated

Theory: NLO QCD

Collinear factorisation+DGLAP evol:  
Krawczyk @ Zambrzuski: (KZ) include  
higher terms ( $\sim \alpha_s^2$ ). No intrinsic  $k_T$ .  
GRV pdfs  $p, \gamma$

Fontannaz, Guillet & Heinrich (FGH)  
additional higher order corrections  
MRST01, AFG2

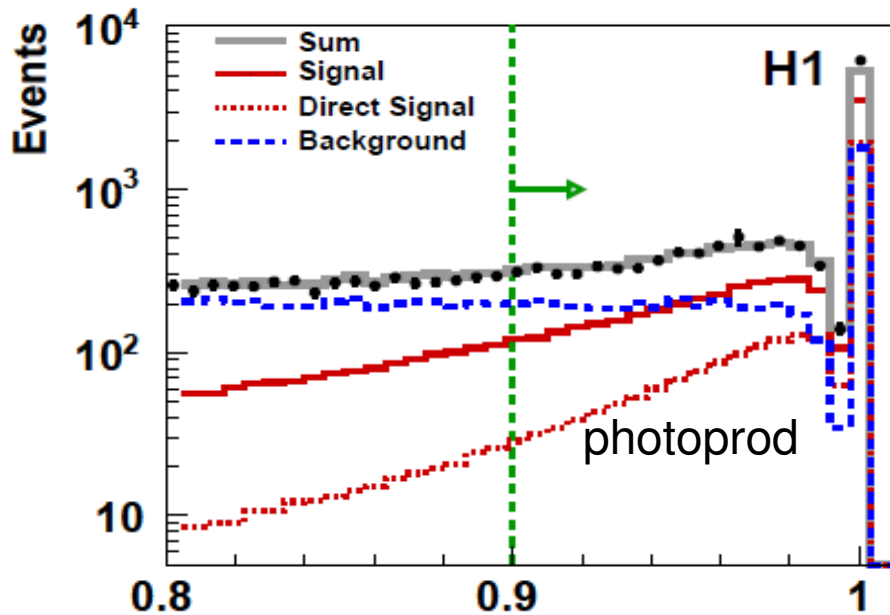
$k_T$  factorisation: Lipatov & Zotov (LZ),  
direct+resolved integrated parton  
densities - KMR, GRV

Hadronisation corrections ( $\gamma$ +jet)  
PYTHIA (reweighted) estimate  $\sim 0.92$

# Two steps: Isolated EM cluster $\rightarrow$ single $\gamma$

1) Isolate EM-cluster ( $\geq 1$  photon)

2) Find single  $\gamma$ . Eliminate  $\pi^0, \eta^0 \rightarrow \gamma\gamma$



ZEUS:

(a) Shower width:

$\pi^0 \rightarrow \gamma\gamma$ , opening angle  
 $\theta > 2m(\pi)/E(\pi)$

2 cluster width parameters

(b) single- $\gamma$  shower has lower conversion efficiency in presampler

H1:

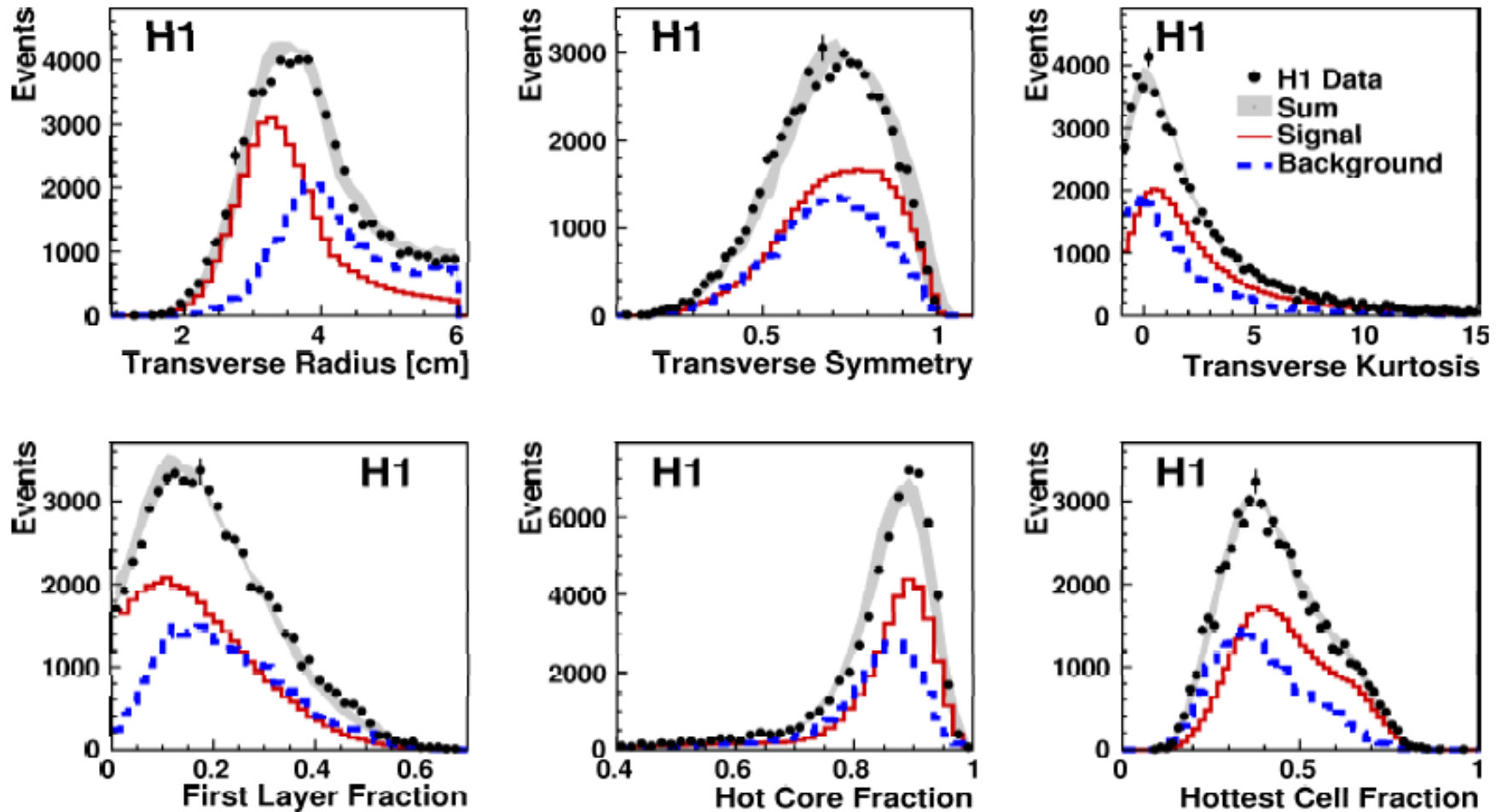
6-parameter discriminant fit

$E(\text{EM-cluster})/E(\gamma\text{-jet}) > 0.9$

$\gamma$ -jet = jet found by inclusive  $k_T$  algorithm ( $R_0 = 1.0$ ) and includes the EM-cluster

Cluster of 1 or more  $\gamma$

# H1: isolated photons identified by shower shape (6 variables)

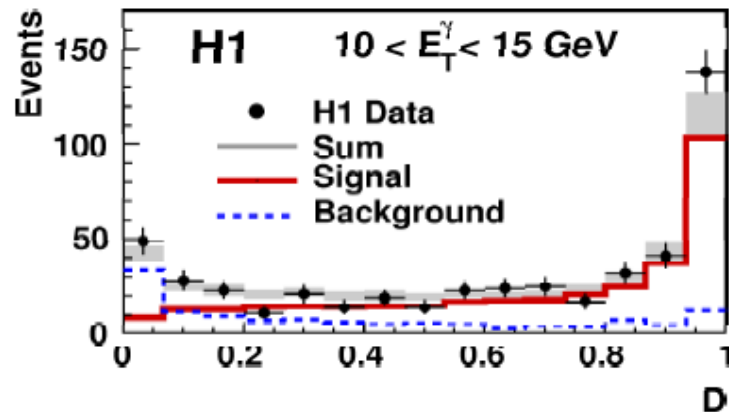
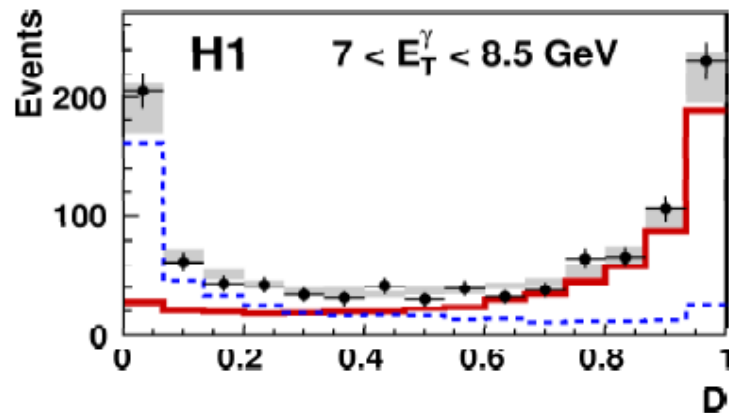


Photoproduction

Saxon, DIS10, Firenze

# H1 photoproduction: inclusive $\gamma$ and ( $\gamma$ +jet)

Discriminant combines 6 shape features



Kinematic range:

**Photon:**  $6 < E_T^\gamma < 15 \text{ GeV}$

$-1.0 < \eta < 2.4$

$E_T^\gamma / E_T^{\gamma\text{-jet}} > 0.9$

$Q^2 < 1 \text{ GeV}^2$

$0.1 < y_{JB} < 0.7$

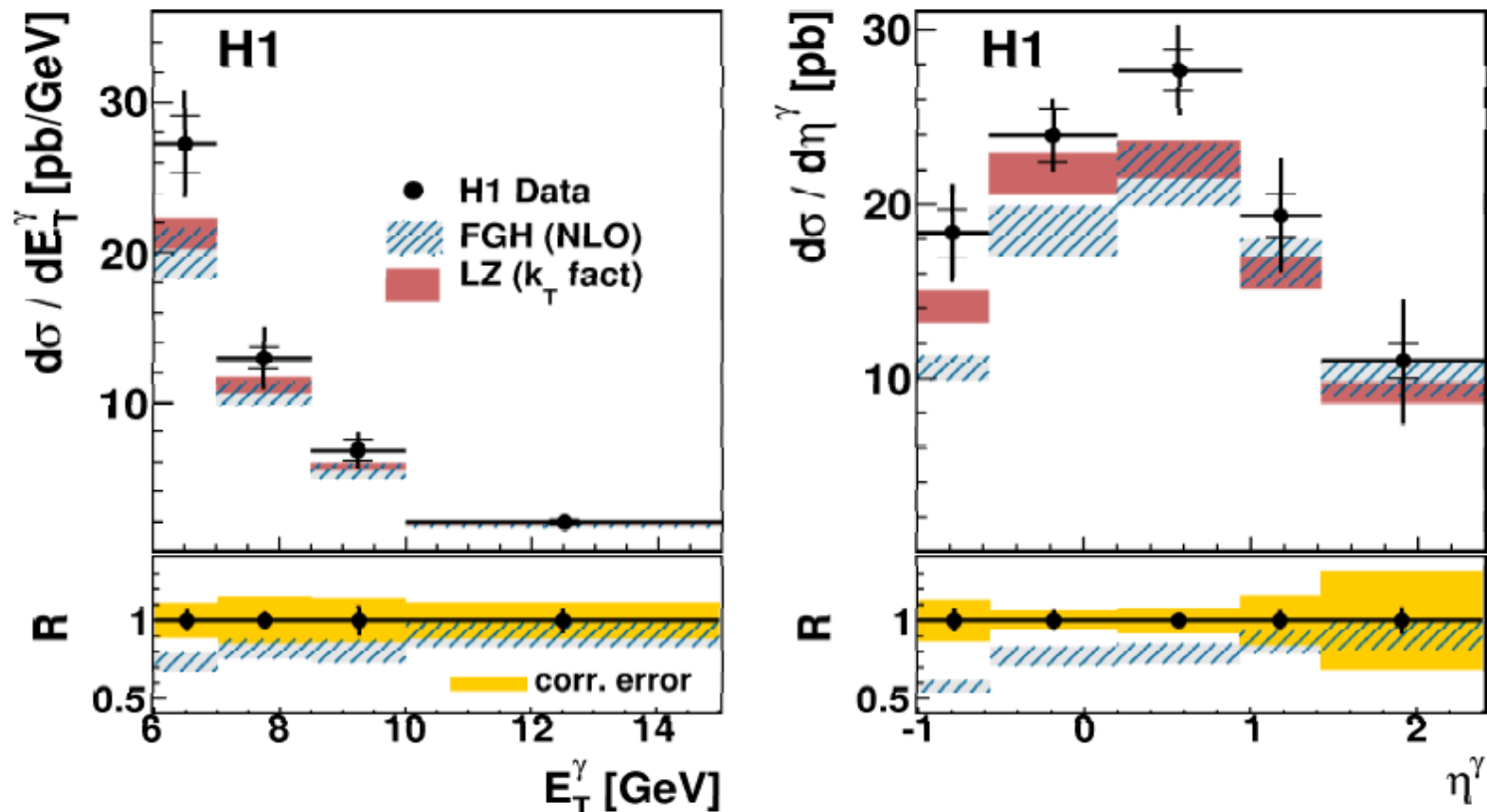
**Jets:**  $E_T^{\text{jet}} > 4.5 \text{ GeV}$

$-1.3 < \eta_{\text{jet}} < 2.3$

MC: PYTHIA6.2, string frag,  
incl hard gluon in final state.  
CTEQ6L & SASG-1D struct.  
fns, multiparton interactions.  
HERWIG alternate

# H1 photoproduction prompt photons

Inclusive Prompt Photon Cross Sections

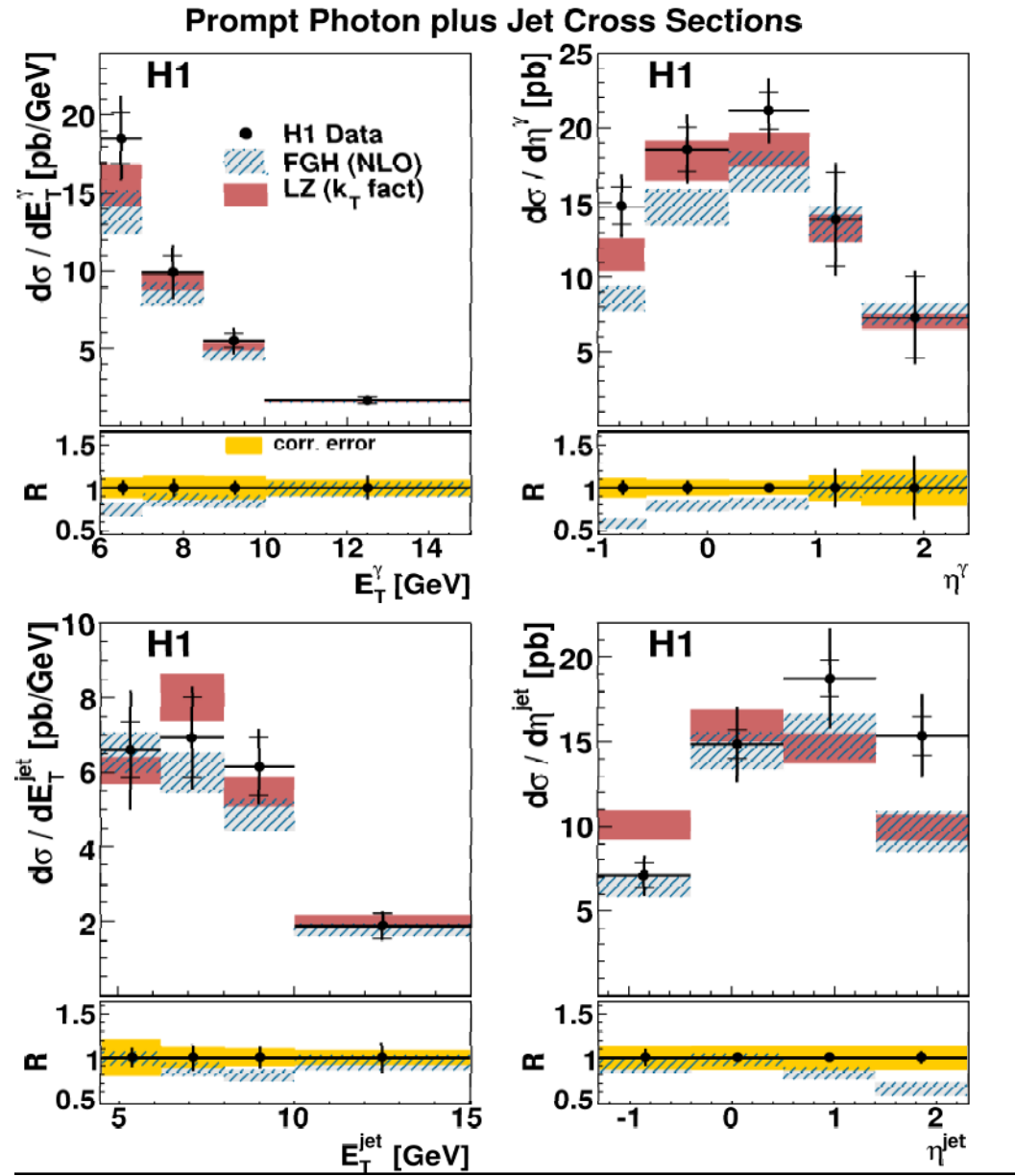


Theory: FGH Collinear factorisation+DGLAP evolution LZ  $k_T$  factorisation  
 Corrected for hadronisation, multiple interactions

# H1 photoprod prompt ( $\gamma$ +jet)

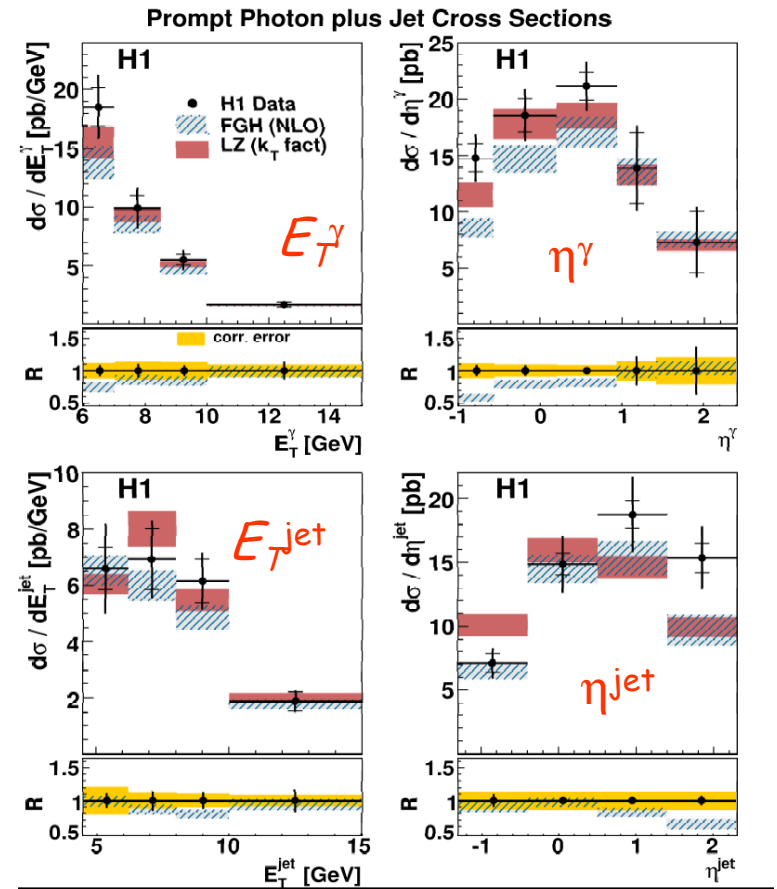
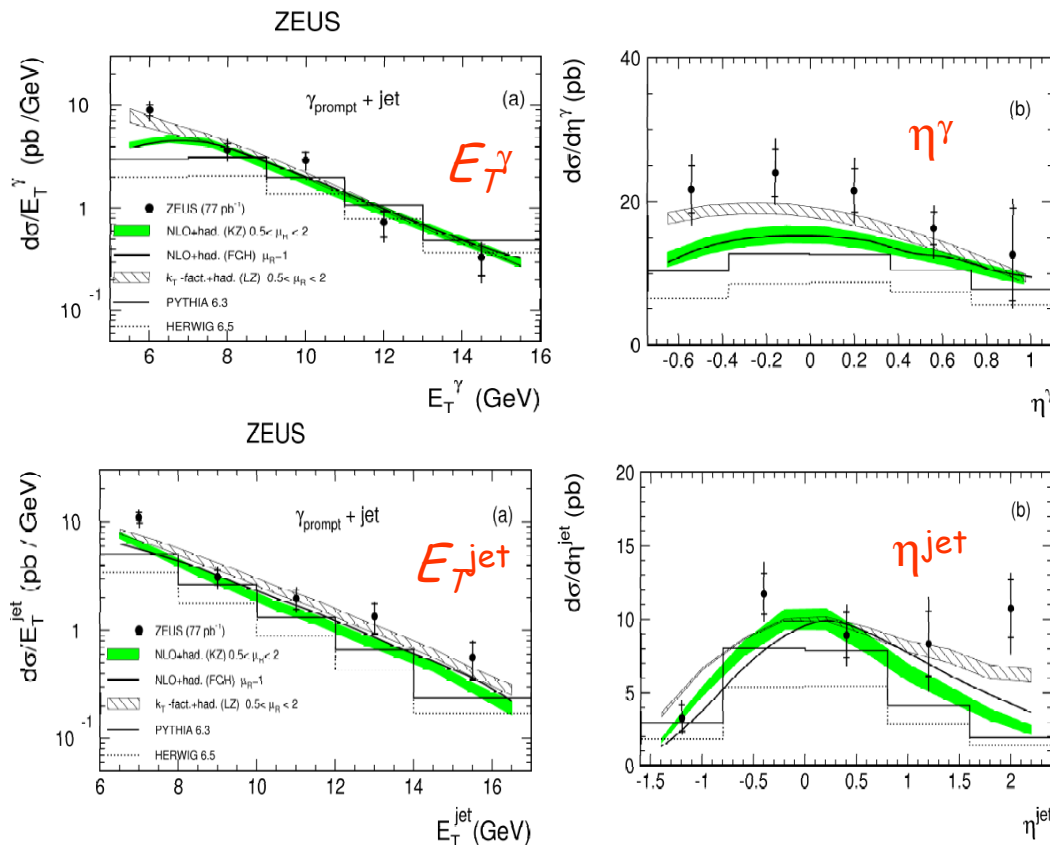
$E_T$  and  $\eta$ , for  $\gamma$  and jet separately.  
Comparisons to theory

LZ Favoured by  $\eta(\gamma)$   
but not by  $\eta(\text{jet})$



# ZEUS-H1 comparison ( $\gamma$ +jet) photoprod.

ZEUS: Eur Phys J C49 (2007) 511

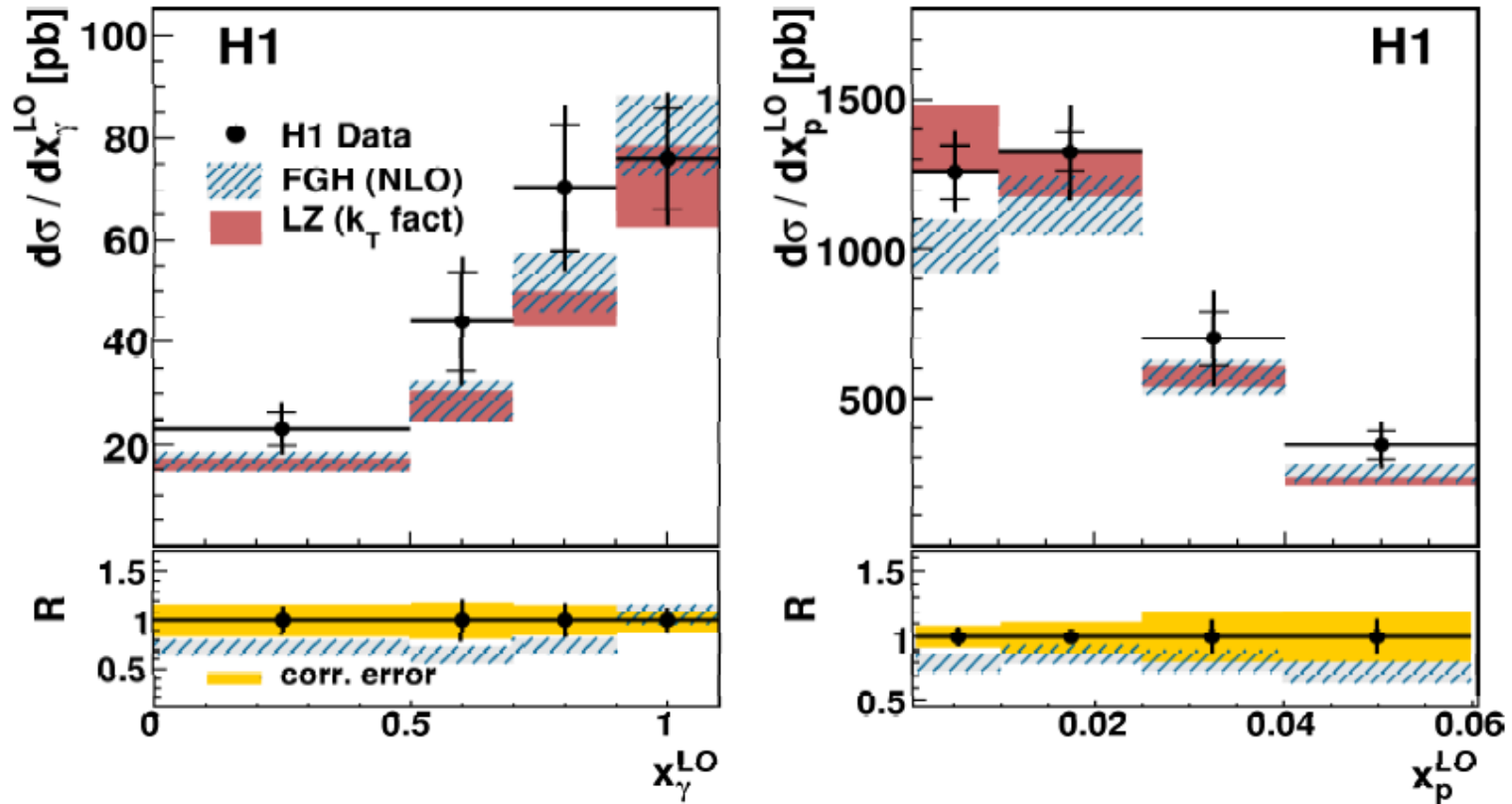


Note - different  $E_T$  cuts affect low  $E_T$  shape comparison.  
 H1,Z seem to agree  $\eta(\gamma)$  favours LZ. H1  $\eta(\text{jet})$  disfavors LZ



# H1 photoprod prompt ( $\gamma$ +jet)

Prompt Photon plus Jet Cross Section

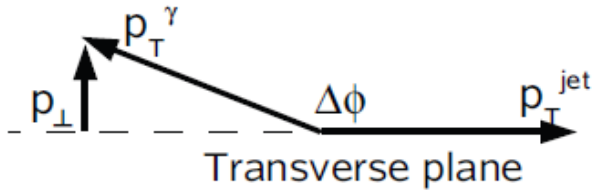


$$x_\gamma^{LO} = E_T^\gamma \frac{e^{-\eta^{jet}} + e^{-\eta^\gamma}}{2yE_e}$$

$$x_p^{LO} = E_T^\gamma \frac{e^{\eta^{jet}} + e^{\eta^\gamma}}{2E_p}$$

# H1 photo. ( $\gamma$ -jet) correlations

- ✓ Photon – jet correlations in direct (resolved) enhanced phase space



Direct process more back-to-back

Sensitivity to soft gluon emission in the highest  $\Delta\phi$  bin in the resolved case

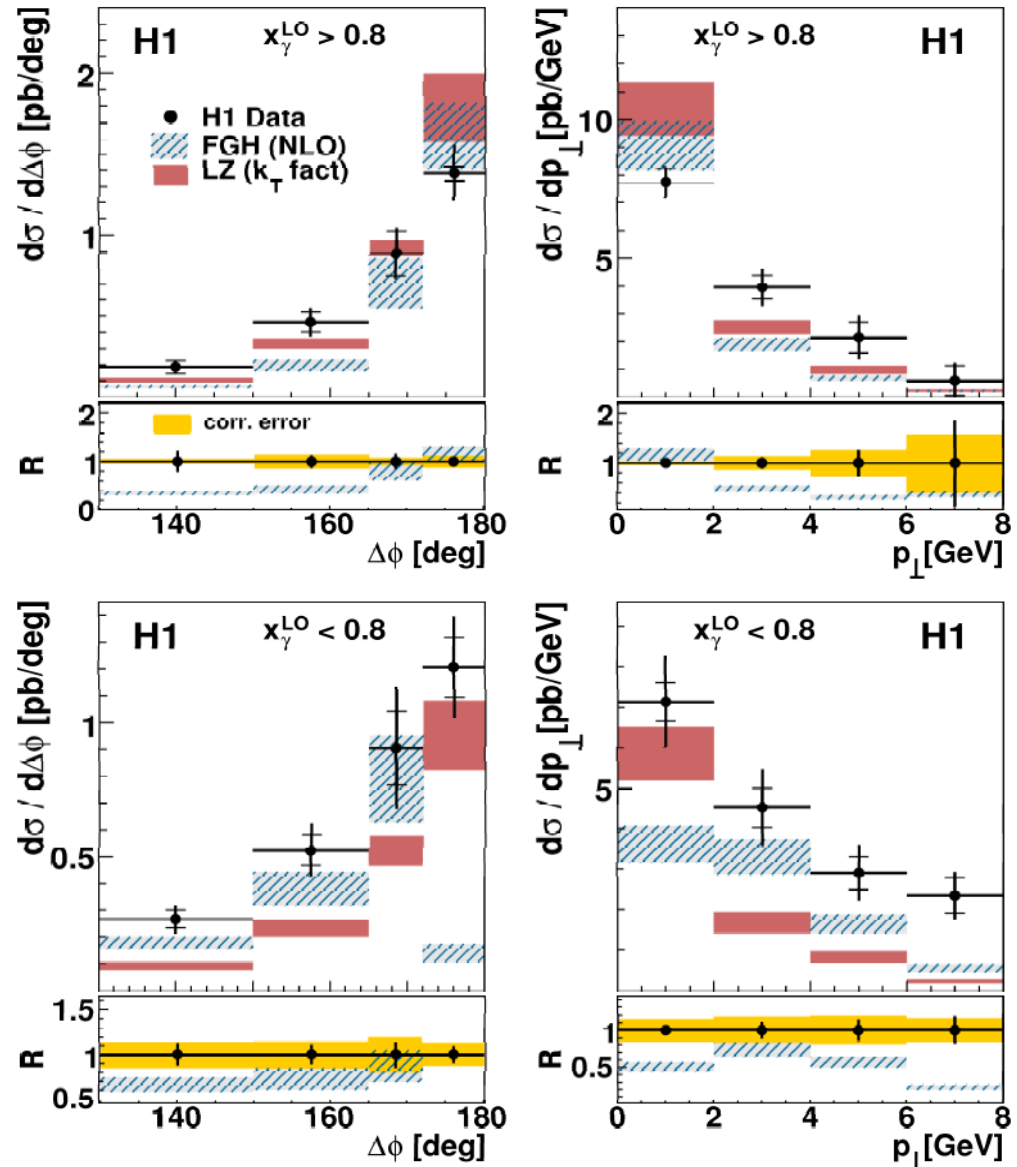
- ✓ fixed order FGH calculation not reliable
- ✓  $k_T$  factorisation absorbs soft gluons in pdf

LZ missing diagrams are expected in tails of resolved cross sections

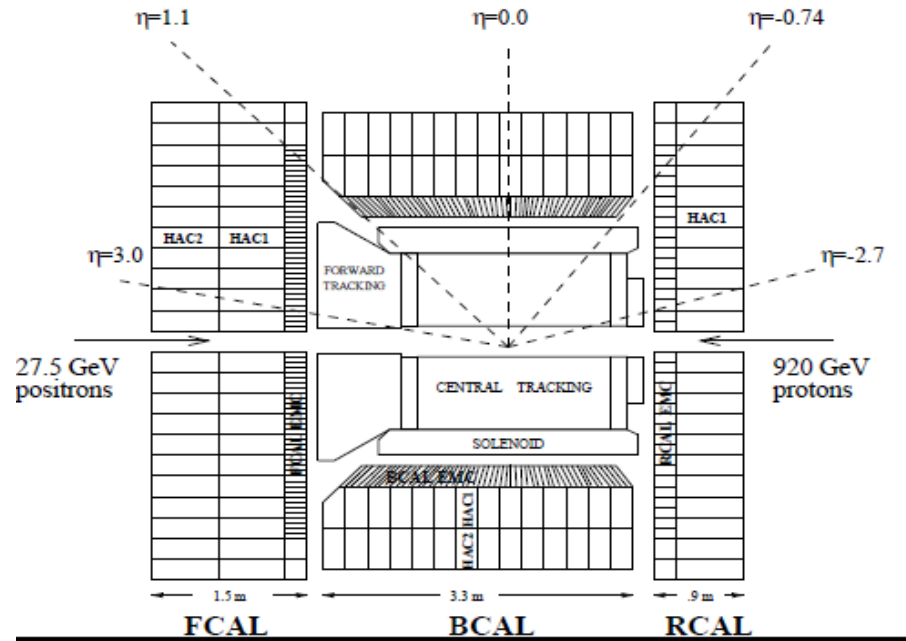
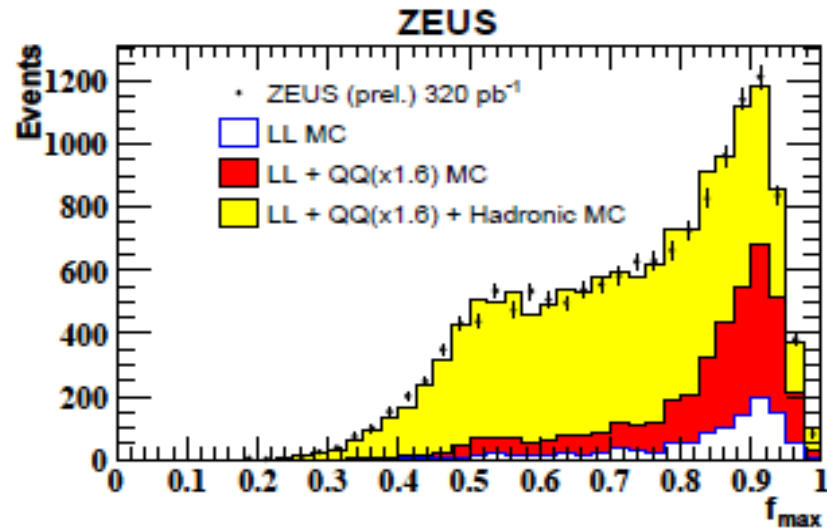
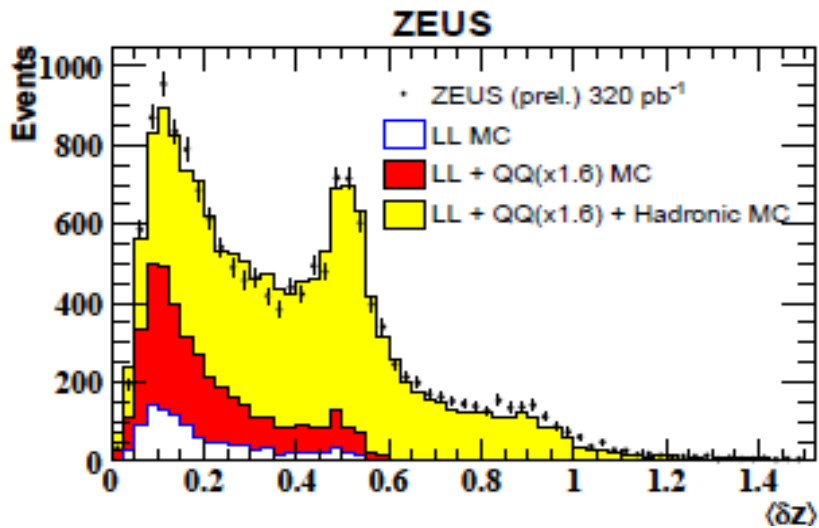
Nowak

Data not well described by theory

## Prompt Photon plus Jet Cross Sections



# ZEUS DIS signal extraction using shower width in fine granularity projective geometry



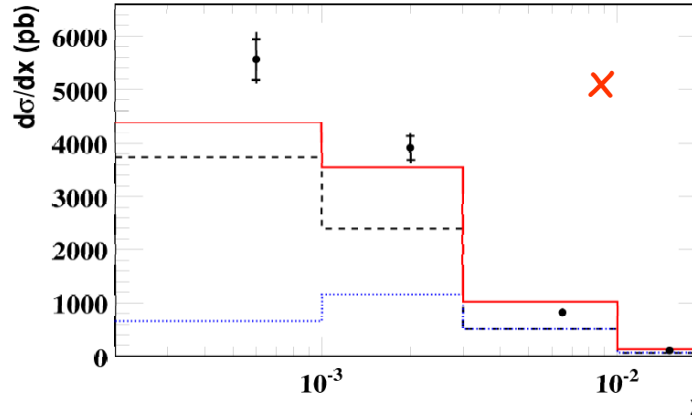
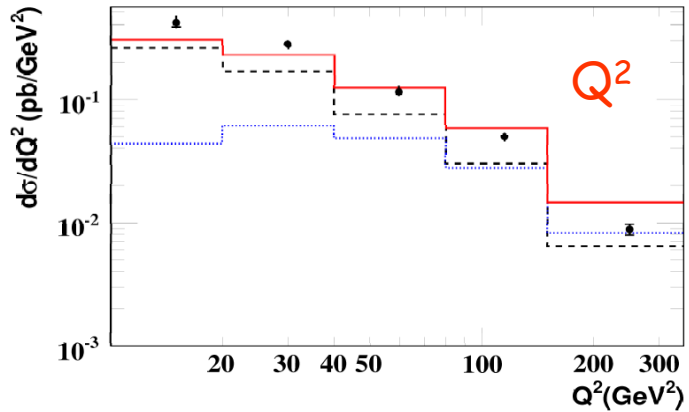
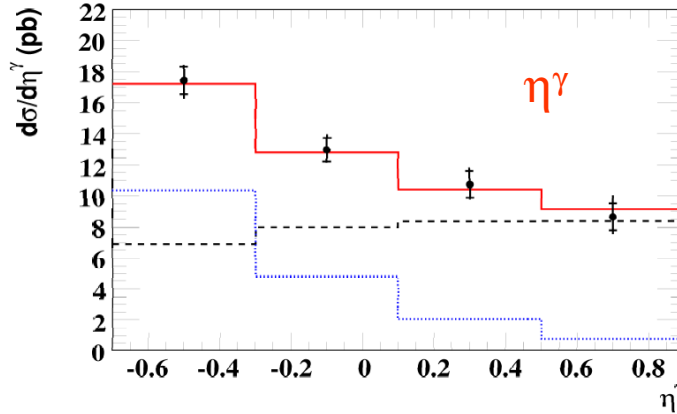
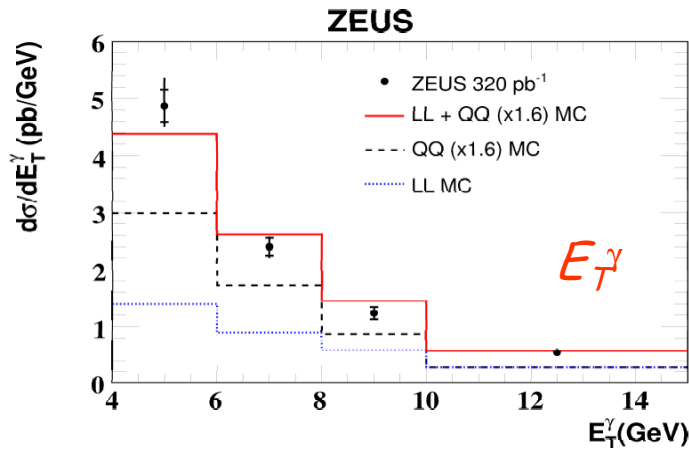
$$\langle \delta Z \rangle = \frac{\sum_i E_i |Z_i - Z_{\text{cluster}}|}{W_{\text{cell}} \sum_i E_i}$$

dZ plot resolves 1 $\gamma$  and 2 $\gamma$  peaks

$$f_{\text{max}} = \frac{\text{Energy in most energetic electromagnetic calorimeter cell}}{\text{Total energy of cluster}}$$

# ZEUS DIS inclusive $\gamma$ : compare MC (LL+1.6xQQ)

MC: QQ=PYTHIA6.416, LL+Backg'd=DJANGO6/HERACLES4.8.6/ARIADNE



$E_e > 10$  GeV

$139.8^\circ < \theta_e < 171.8^\circ$

$10 < Q^2 < 350$  GeV<sup>2</sup>  
 ( $Q^2$  meas from  $e, e'$ )

$4 < E_T^\gamma < 15$  GeV

$-0.7 < \eta^\gamma < 0.9$

$W_x > 5$  GeV

$E(\text{EMC})/E(\text{jet}) > 0.9$   
 (jets:  $k_T$  algorithm  
 with  $R = 1.0$ )

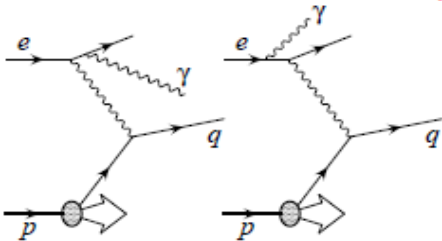
MC describes  $E_T^\gamma, \eta^\gamma$   
 well but falls below  
 data at low  $Q^2$  and  
 at low- $x$

2 hard scales:  $Q^2, E_T^\gamma$

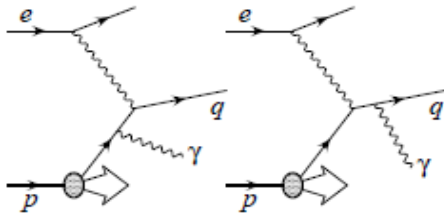
# Prompt photons in DIS: $k_T$ factorisation?

ZEUS: Phys Lett B687 (2010) 16. H1: Eur Phys J C54 (2008) 371

LL - hard radiation from leptons

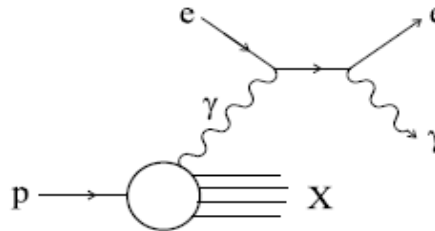


QQ - hard radiation from quarks



QL interference term  
small and neglected here.

$\gamma^P \otimes \hat{\sigma}(e\gamma \rightarrow e\gamma)$   
where  $\gamma^P$  is photon content of proton



Calculated by MRST group  
Sensitive to photon content of proton.  
(Eur.Phys.J.C39:155-161,2005)

Consider 'enhanced' LL  
from MRST + QQ from  
GGP

$k_T$ -factorisation

SP Baranov, AV  
Lipatov, NP Zotov  
arXiv:1001.4782v1[hep-ph]

$eq^* \rightarrow e\gamma q$

KMR unintegrated  
quark densities in p

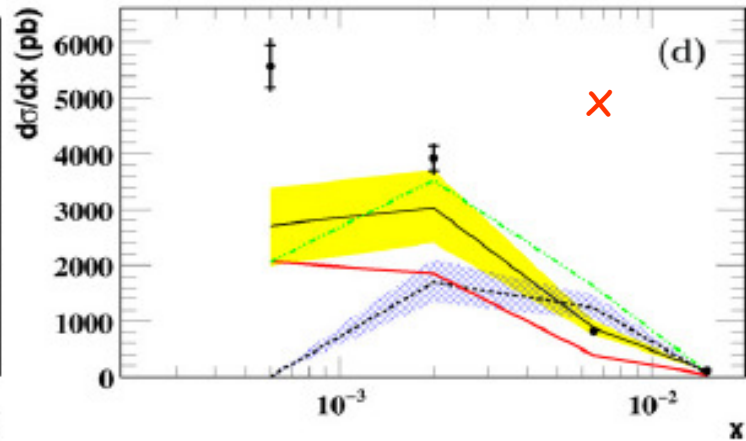
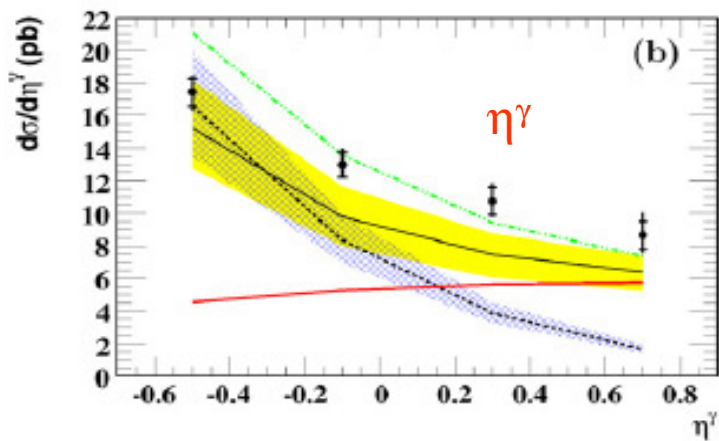
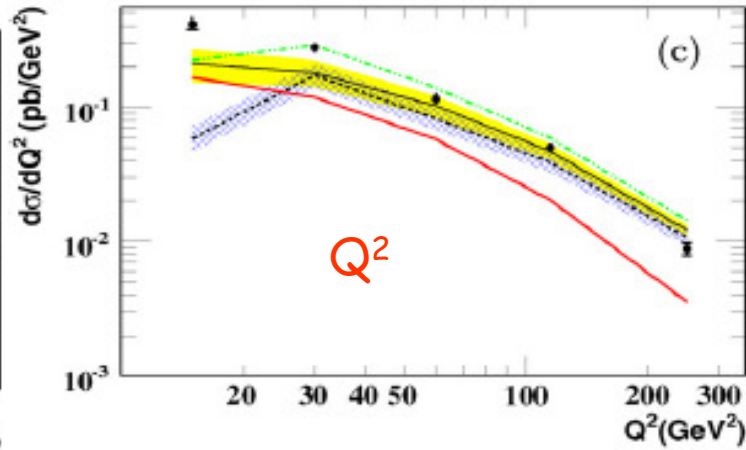
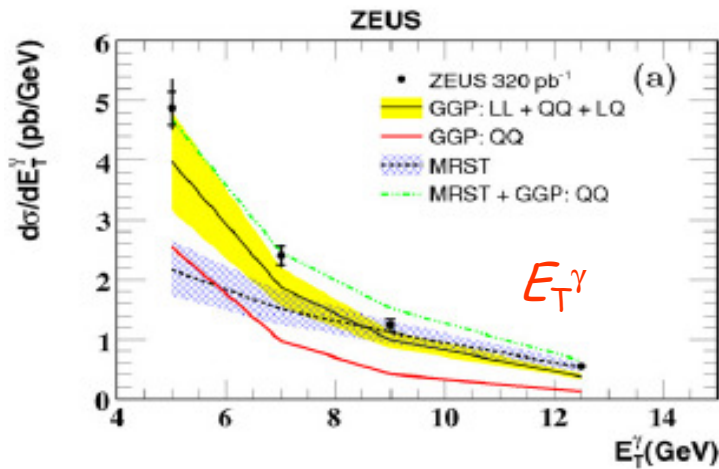
Expect differences  
from collinear fact.  
At low  $\ln(Q^2)$  and high  
 $\ln(1/x)$

Prediction: LL + QQ +  $D_{q \rightarrow \gamma}(z)$

LO( $\alpha^3$ ) from A. Gehrmann-De  
Ridder, T. Gehrmann and E. Poul-  
son.

(Phys.Rev.Lett.96:132002,2006)

# ZEUS DIS inclusive $\gamma$ : GGP, $QQ_{GGP+MRST_{LL}}$ describe $E_T, \eta$ but not $Q^2, x$



$E_e > 10 \text{ GeV}$

$139.8^\circ < \theta_e < 171.8^\circ$

$10 < Q^2 < 350 \text{ GeV}^2$   
( $Q^2$  meas from  $e, e'$ )

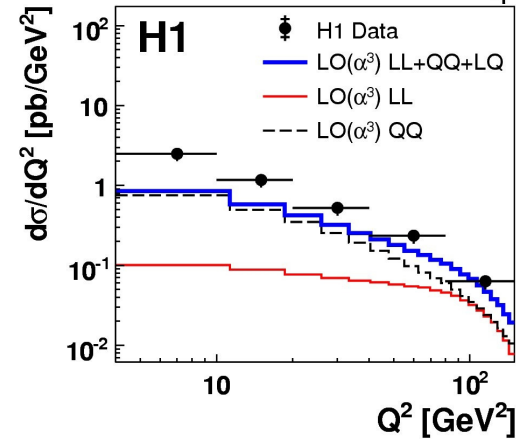
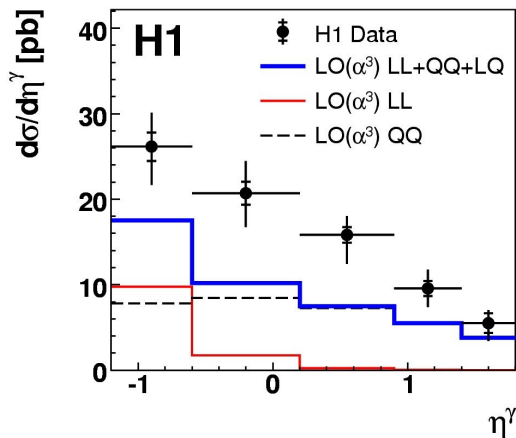
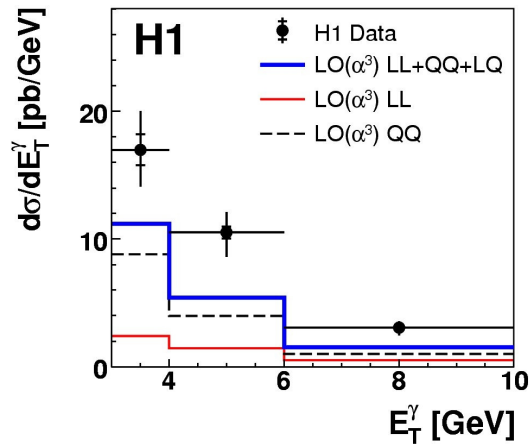
$4 < E_T^\gamma < 15 \text{ GeV}$

$-0.7 < \eta^\gamma < 0.9$

$W_x > 5 \text{ GeV}$

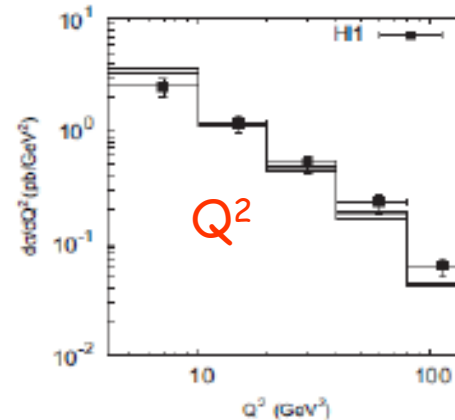
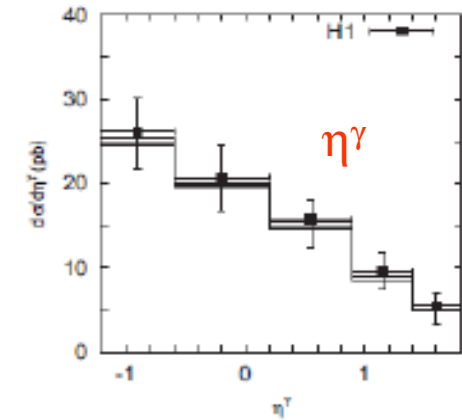
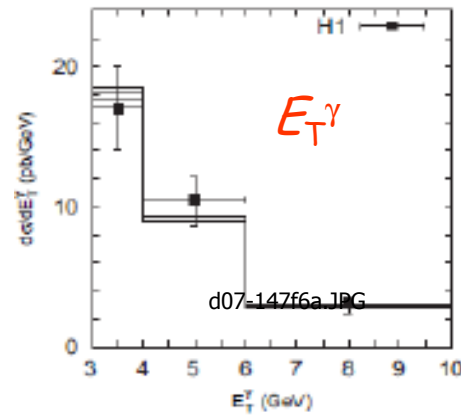
$E(\text{EMC})/E(\text{jet}) > 0.9$   
(jets:  $k_T$  algorithm  
with  $R = 1.0$ )

# DIS inclusive $\gamma$ : collinear & $k_T$ -factorisation predictions compared to H1 data



← H1 own fit using GGP

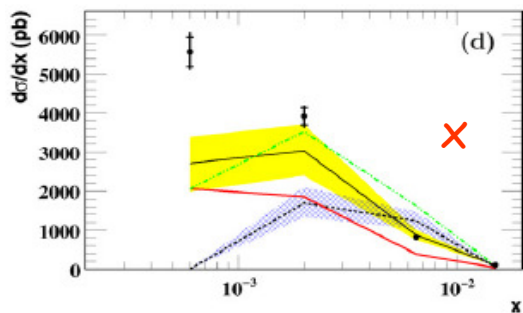
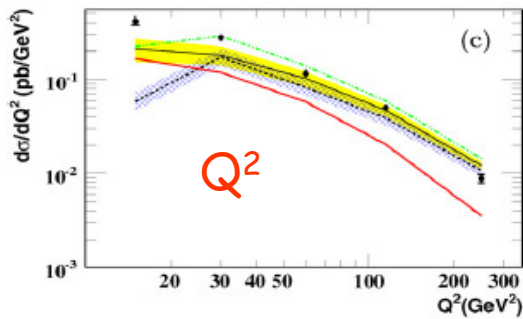
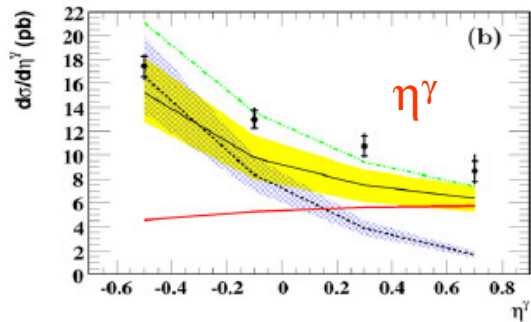
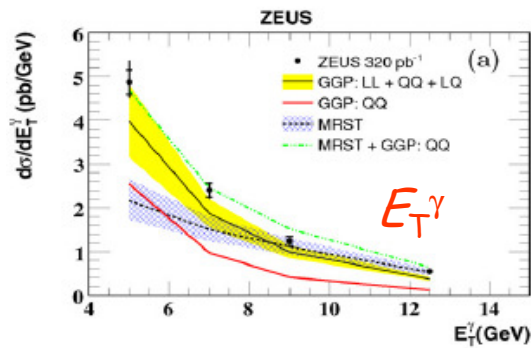
↓ BLZ fit



Success for BLZ

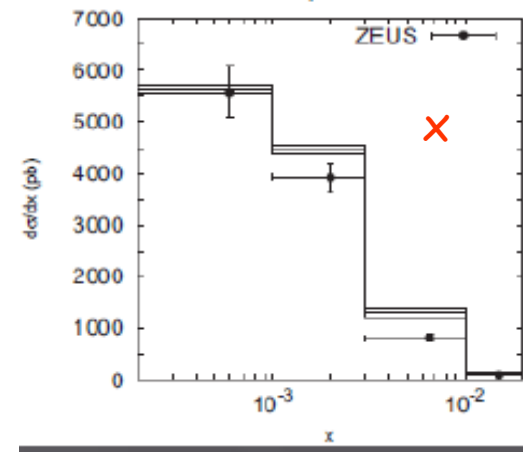
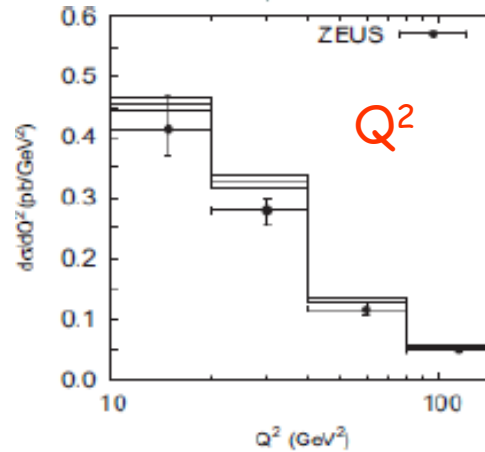
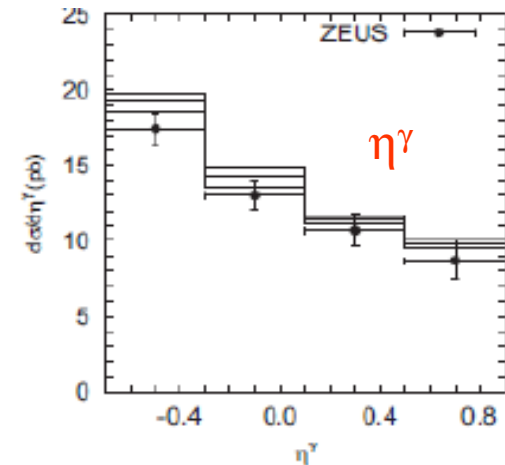
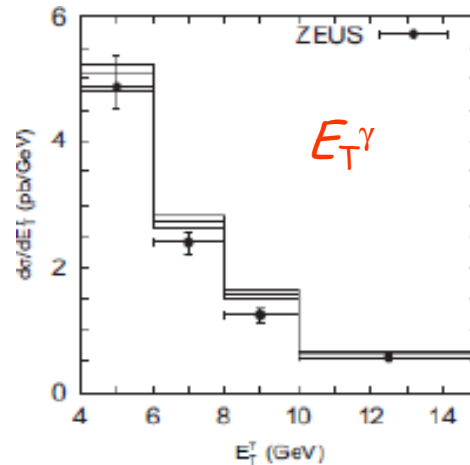


# DIS inclusive $\gamma$ : $k_T$ -factorisation predictions compared to ZEUS data



← ZEUS own fit using GGP

↓ BLZ fit

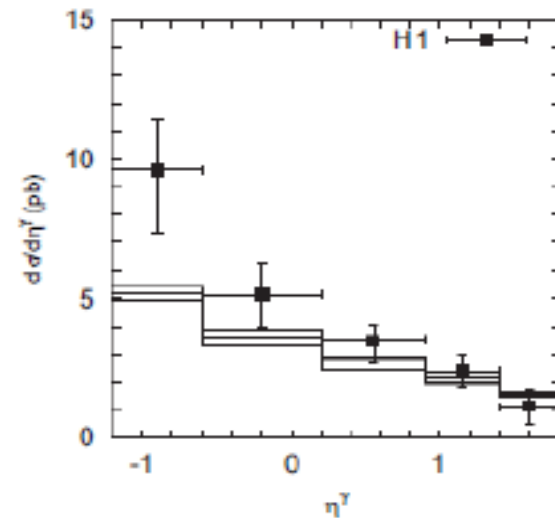
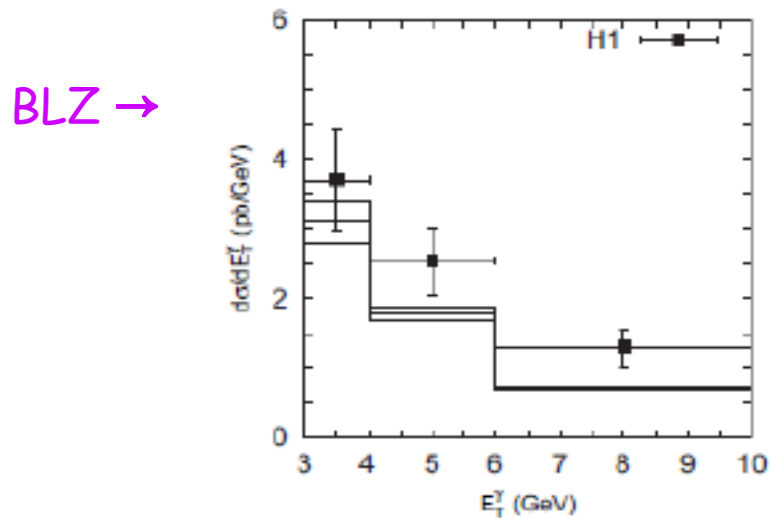
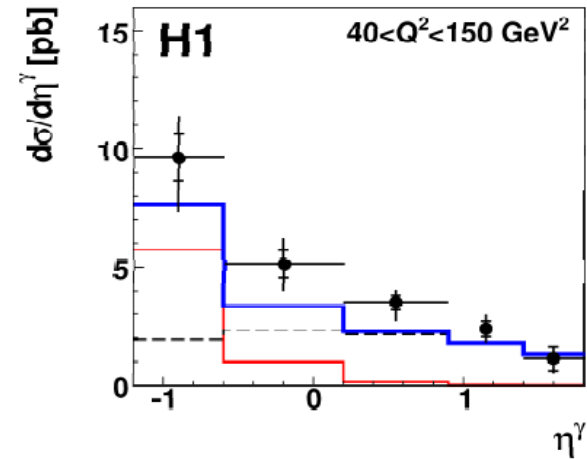
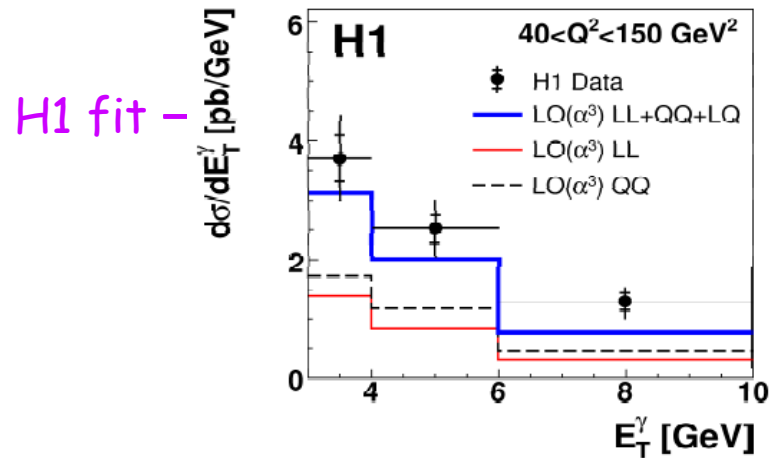


Saxon, DIS10, Firenze

Success for BLZ

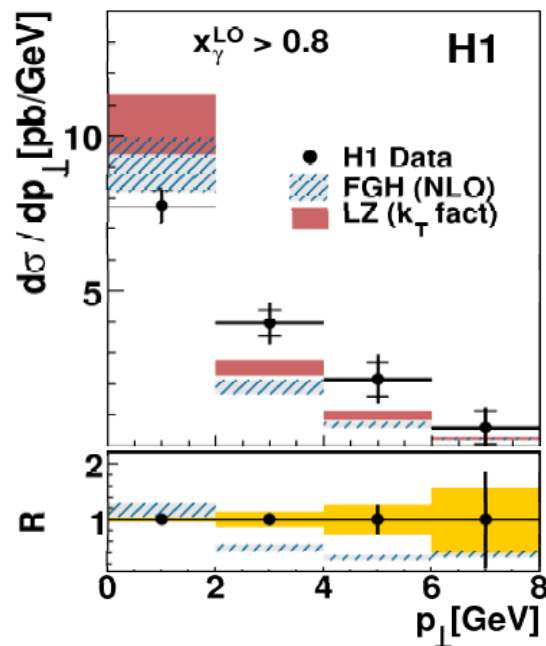


# BLZ not better at high $Q^2$ (H1 data) as expected (?)



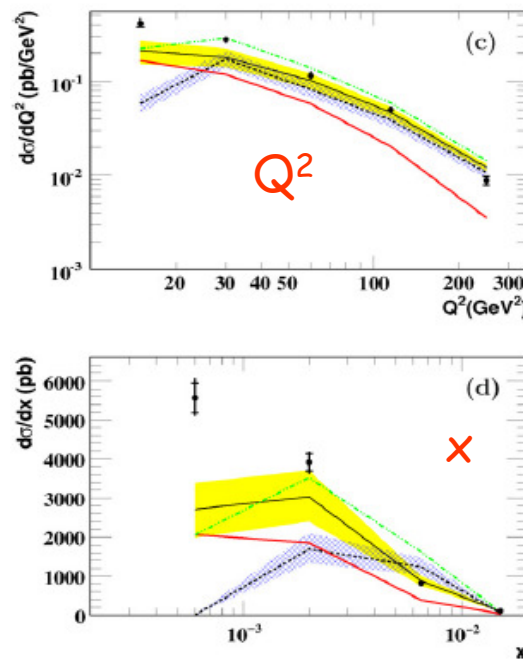
# Prompt photons probe reaction dynamics: summary

H1 photoprod ( $\gamma$ +jet)  
Extended  $\eta$ -range



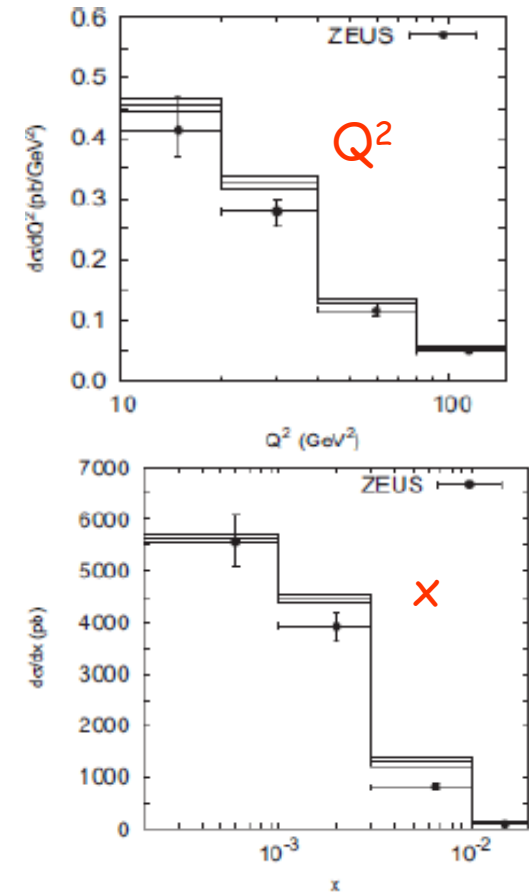
$\gamma$ /jet correlations  
test theories

ZEUS DIS inclusive  
collinear fact'zn fails



low  $x$ , low  $Q^2$  poor fit  
GGP, MRST poor fit  
BLZ good fit

Baranov, Lipatov, Zotov  
 $k_T$ -fact'zn success



Saxon, DIS10, Firenze