Prompt photon production at HERA

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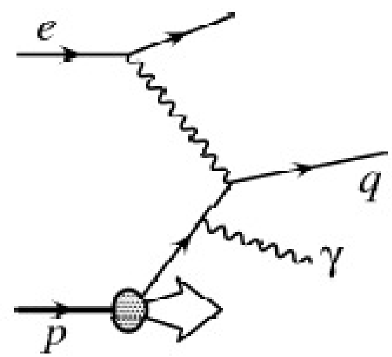
- Photoproduction
  (H1: Eur Phys J C66 (2010) 17)
- DIS
  (ZEUS: Phys Lett B687 (2010) 16)
- Test theories
  Collinear and k_T factorisation



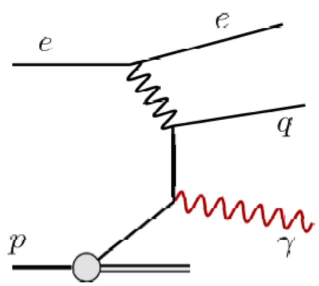
+ other diagrams

A reliable probe of dynamics

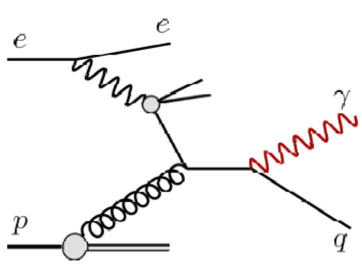
2 hard scales: Q^2 and E_T^{γ}

Photoproduction: γ 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:
Krawcyk @ Zambrzuski: (KZ) include higher terms ($\sim \alpha_s^2$). No instrinsic k_T.
GRV pdfs p,γ

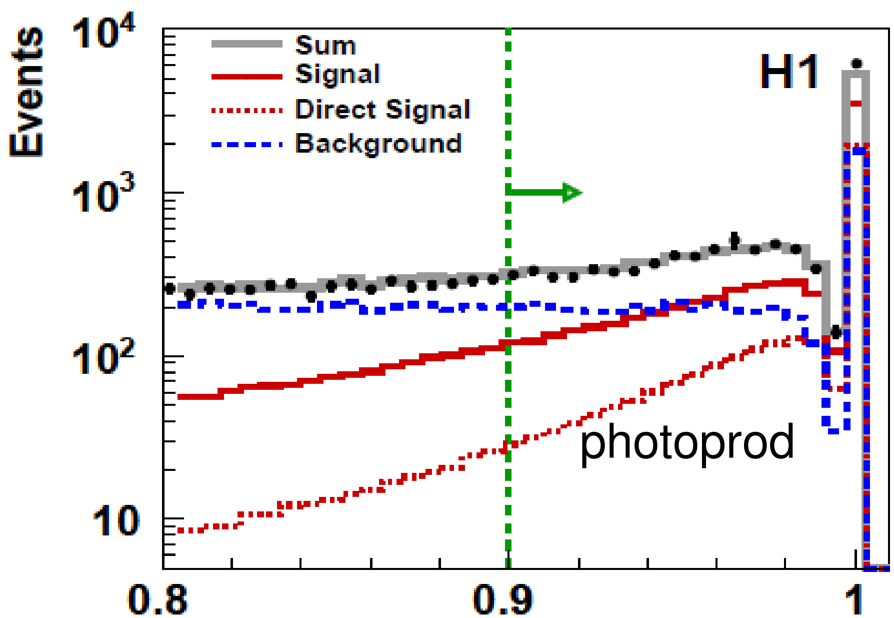
Fontannaz, Guillet & Heinrich (FGH)
additional higher order corrections
MRST01, AFG2

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

Hadronisation corrections (γ +jet)
PYTHIA (reweighted) estimate ~ 0.92

Two steps: Isolated EM cluster → single γ

1) Isolate EM-cluster (≥ 1 photon)



E(EM-cluster)/E(γ-jet) > 0.9

Cluster of 1 or more γ

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

ZEUS:

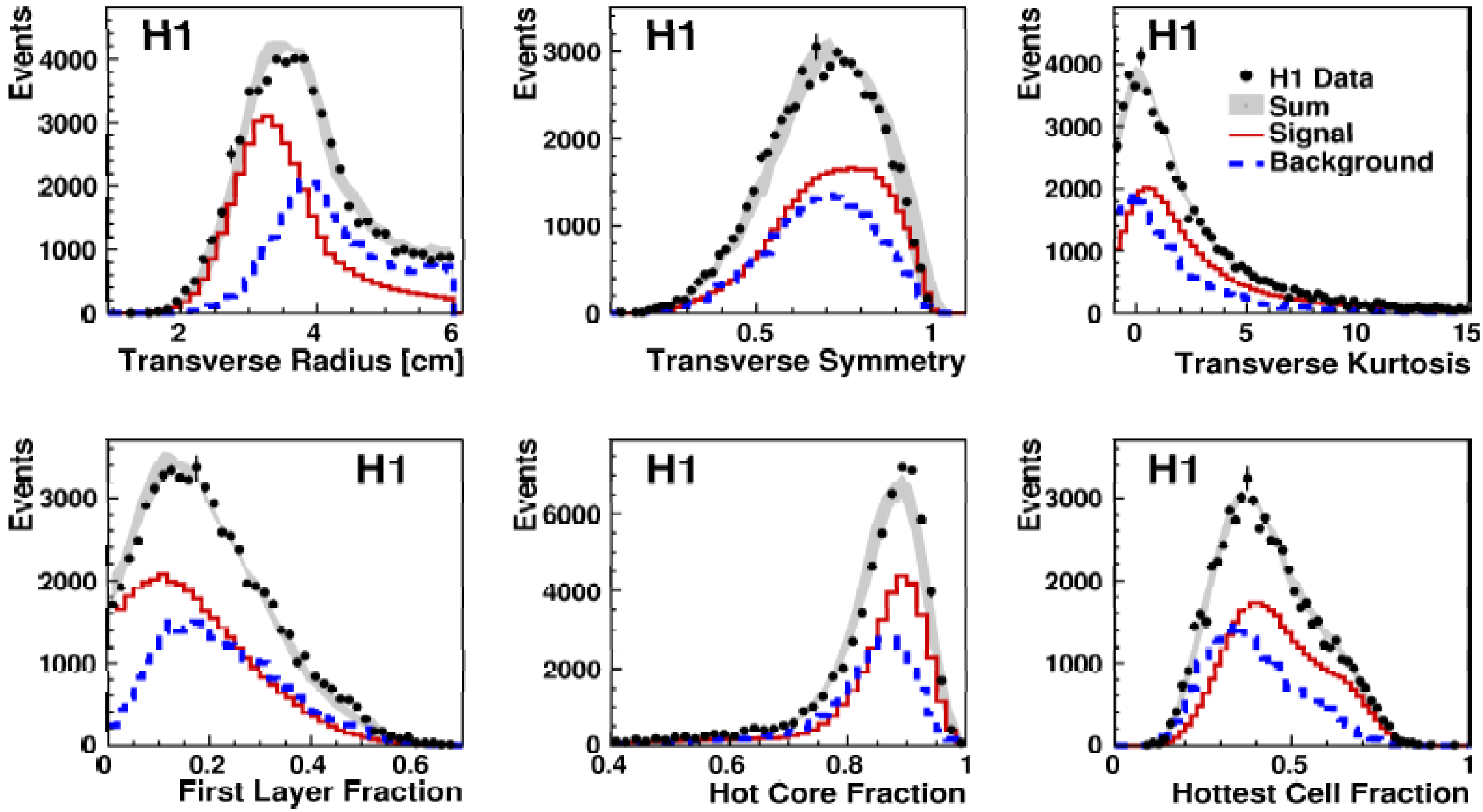
(a) Shower width:
$\pi^0 \rightarrow \gamma\gamma$, opening angle
$\theta > 2m(\pi)/E(\pi)$
2 cluster width parameters

(b) single-γ shower has lower conversion efficiency in presampler

H1:
6-parameter discriminant fit

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

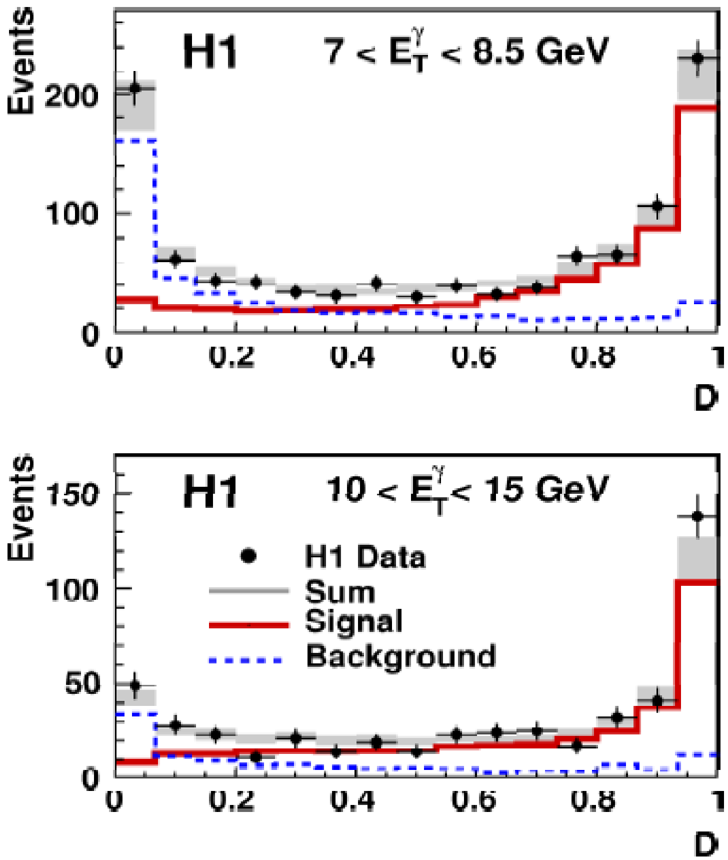
H1: isolated photons identified by shower shape (6 variables)



Photoproduction

H1 photoproduction: inclusive γ and (γ+jet)

Discriminant combines 6 shape features



Kinematic range:

Photon: 6 < $E^T(\gamma)$ < 15 GeV

$-1.0 < \eta < 2.4$

$E^T(\gamma)/E^T(\gamma\text{-jet}) > 0.9$

$Q^2 < 1$ GeV^2

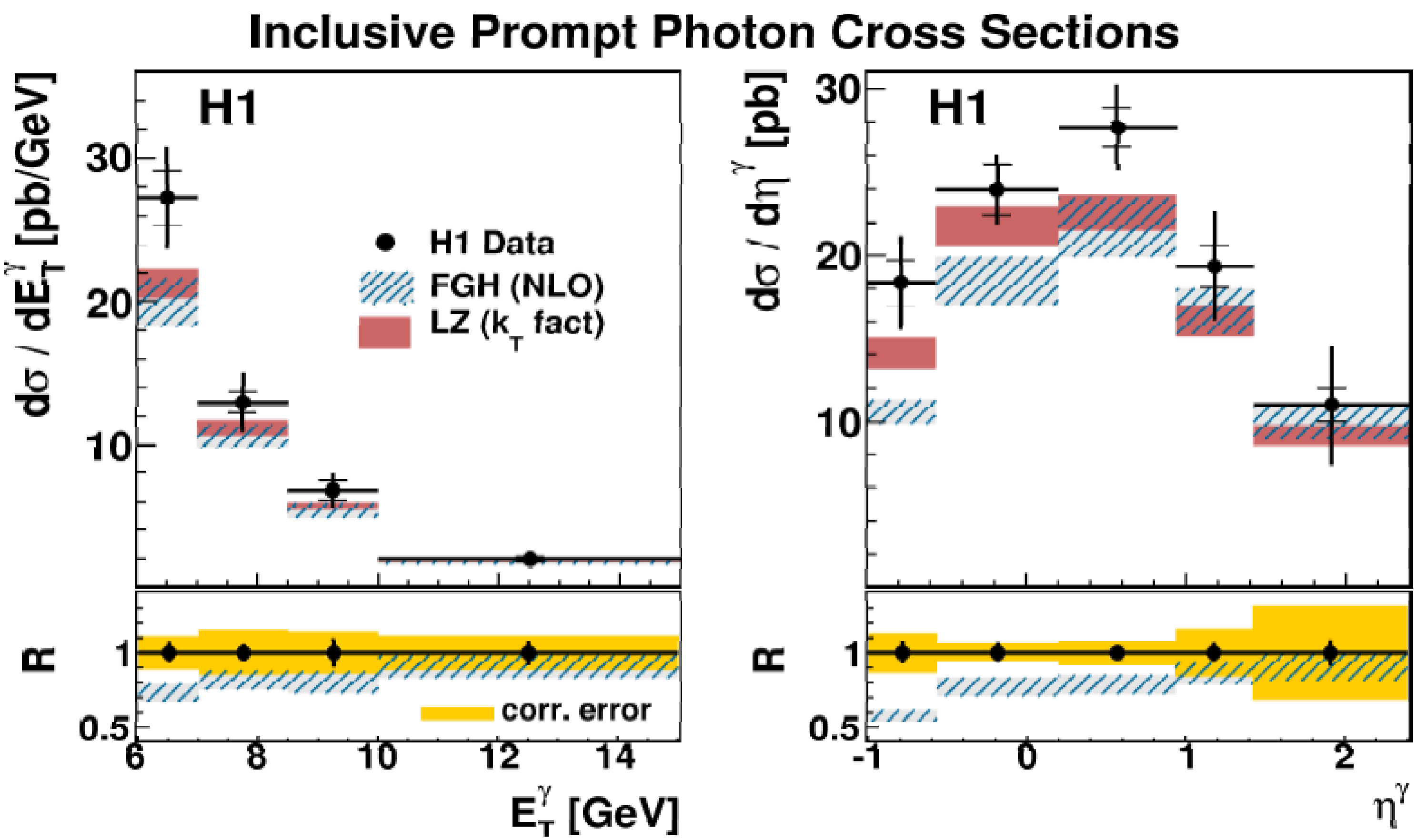
$0.1 < y_{JB} < 0.7$

Jets: E^T(jet) > 4.5 GeV

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

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

H1 photoproduction prompt photons



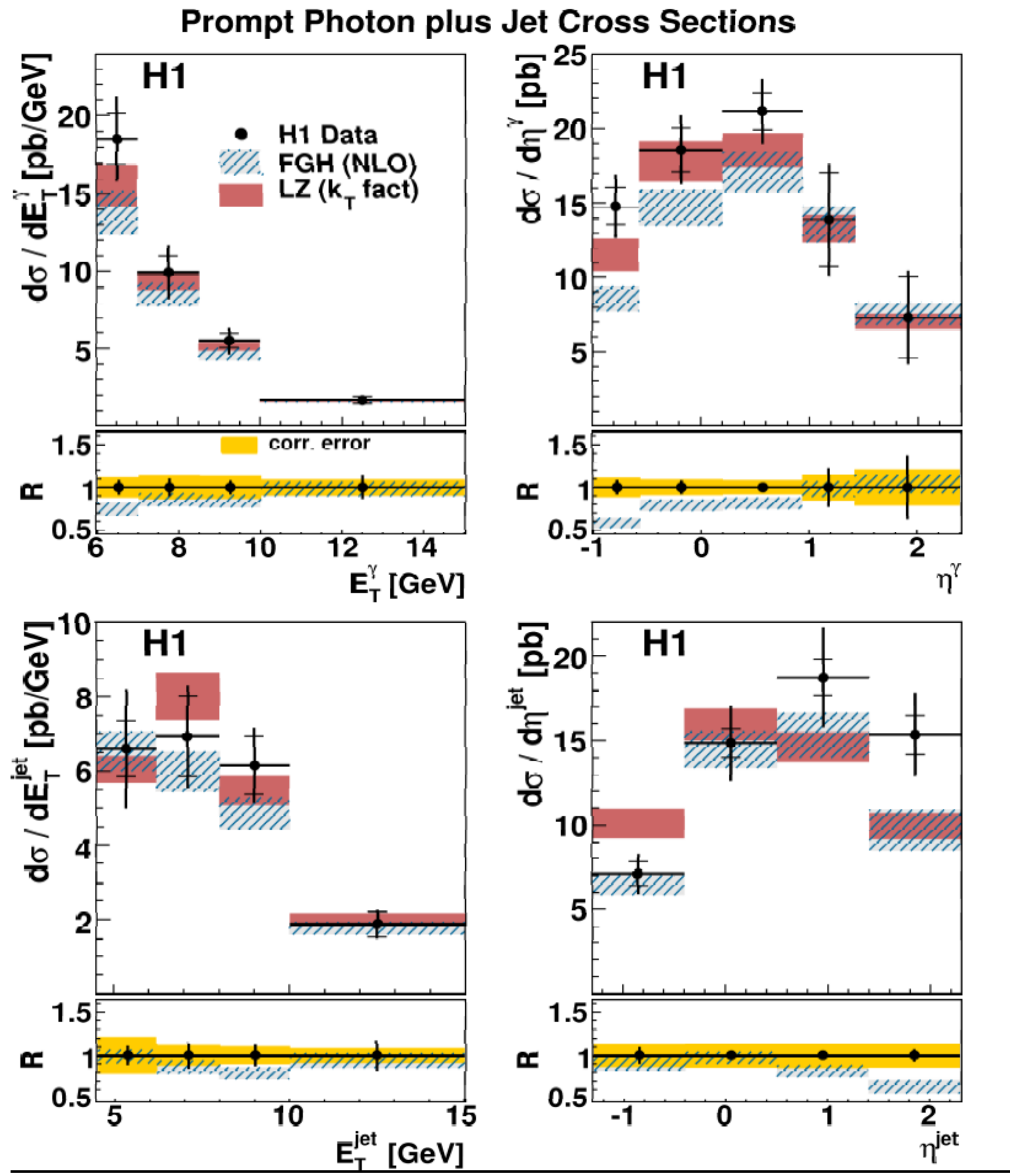
Theory: FGH Collinear factorisation+DGLAP evolution LZ k_T factorisation
Corrected for hadronisation, multiple interactions

H1 photoprod prompt (γ+jet)

E_T and η, for γ and jet separately.

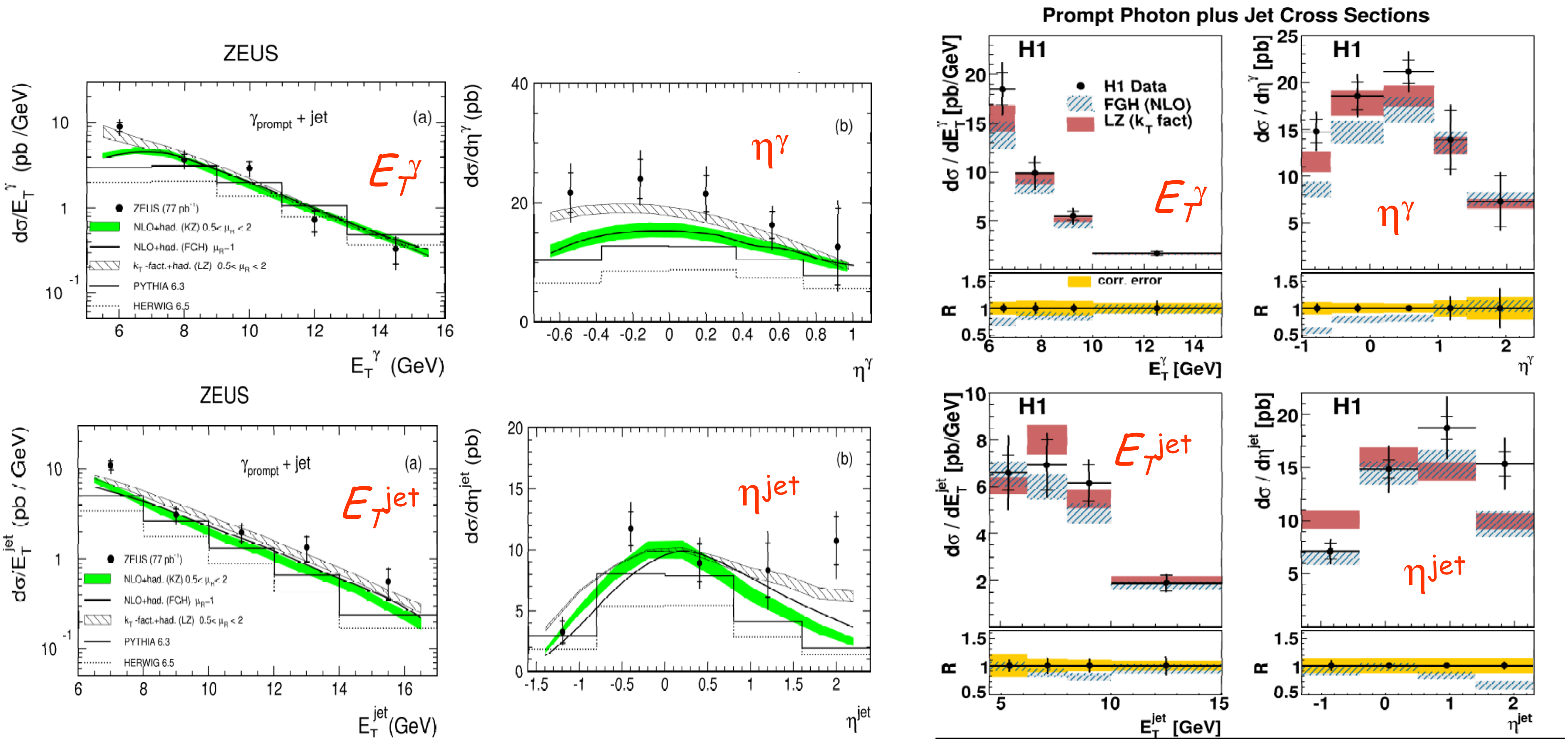
Comparisons to theory

LZ Favoured by η(γ) but not by η(jet)



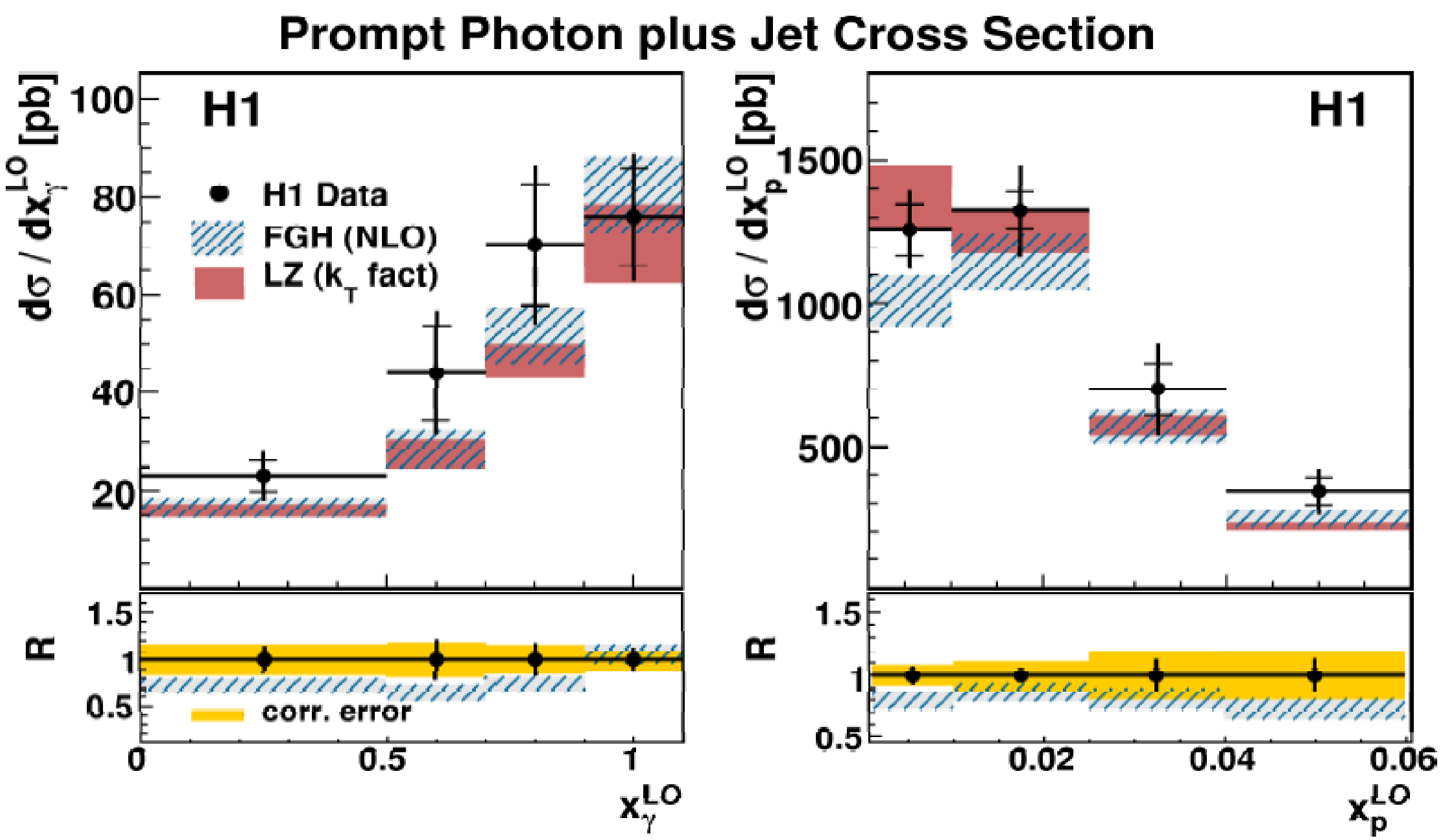
ZEUS-H1 comparison (γ+jet) photoprod.

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 η(jet) disfavours LZ

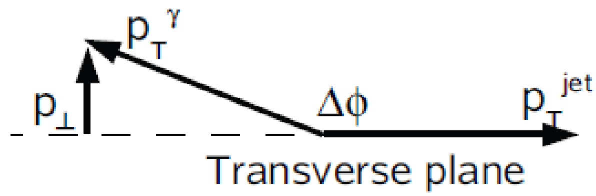
H1 photoprod prompt (γ+jet)



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

H1 photo. (γ-jet) correlations

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



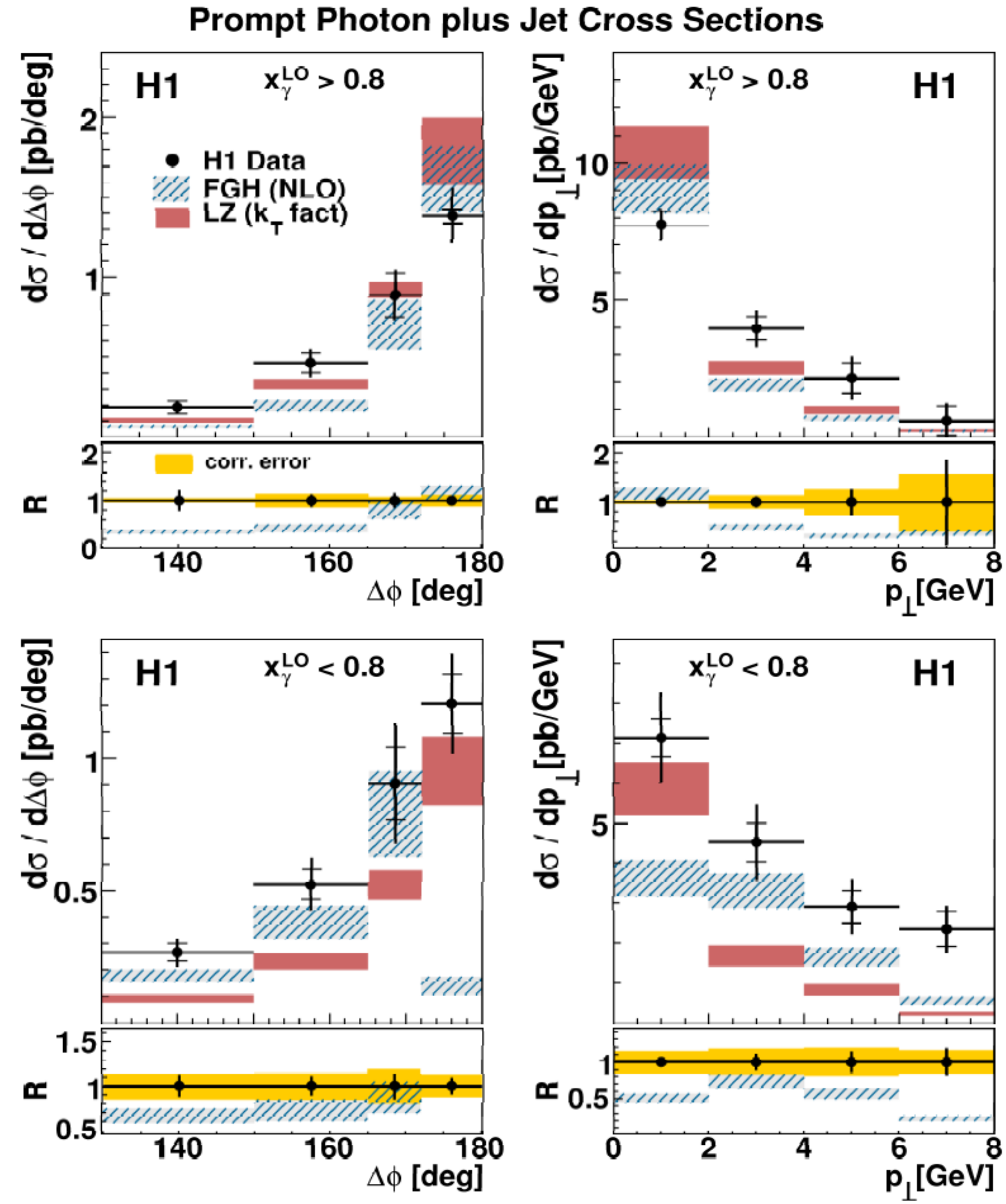
Direct process more back-to-back

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*

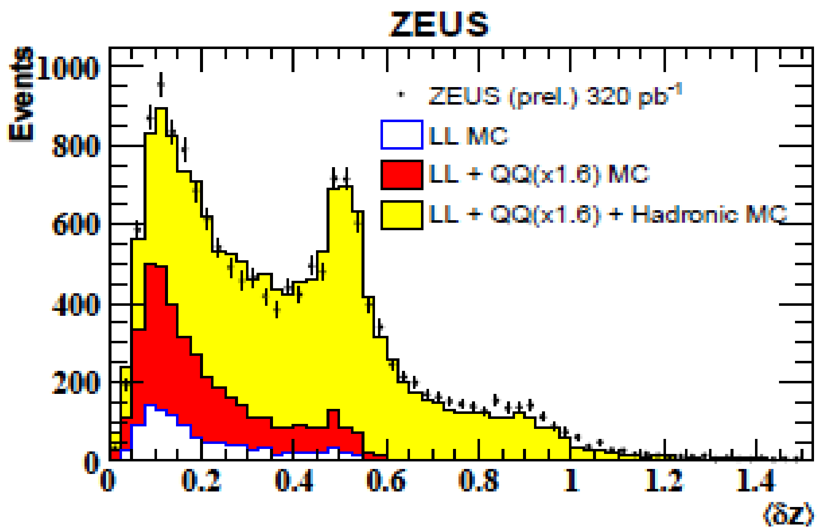
LZ missing diagrams are expected in tails of resolved cross sections

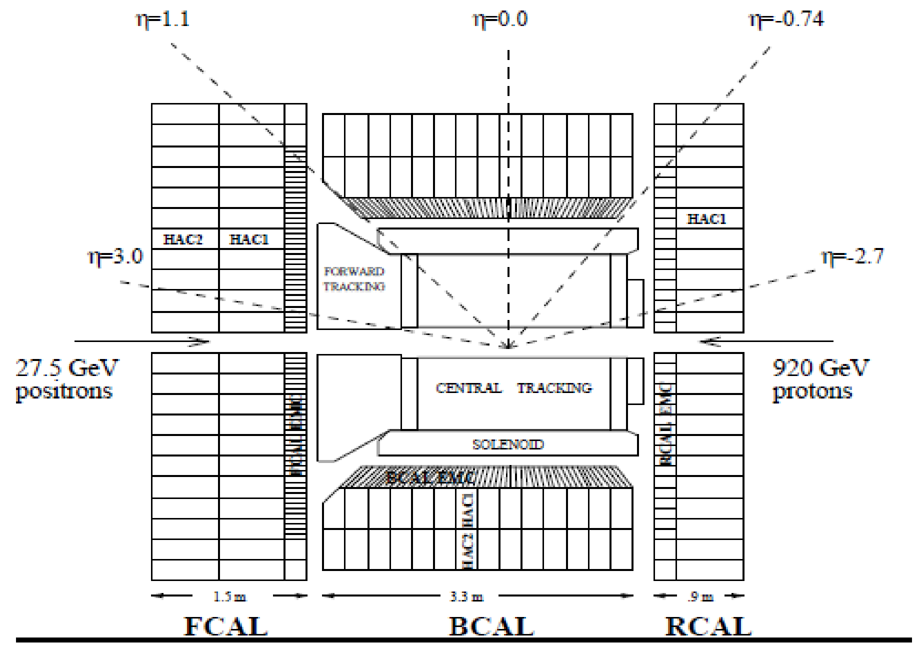
Nowak



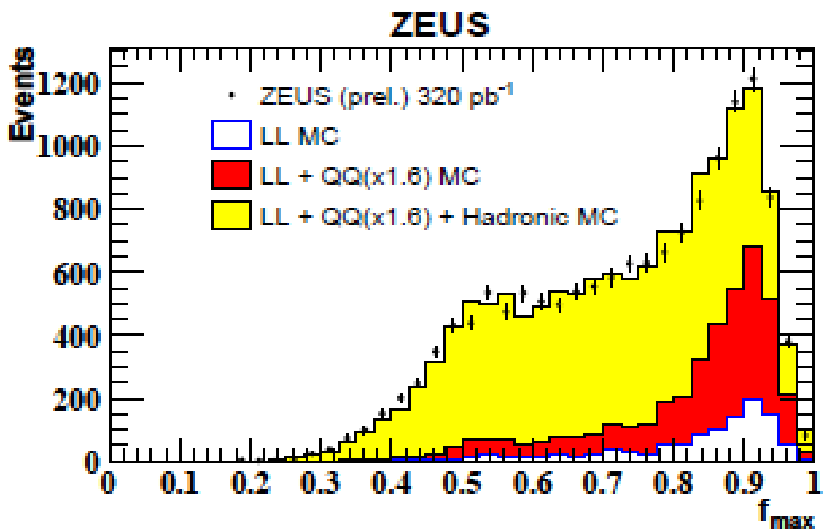
Data not well described by theory

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





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



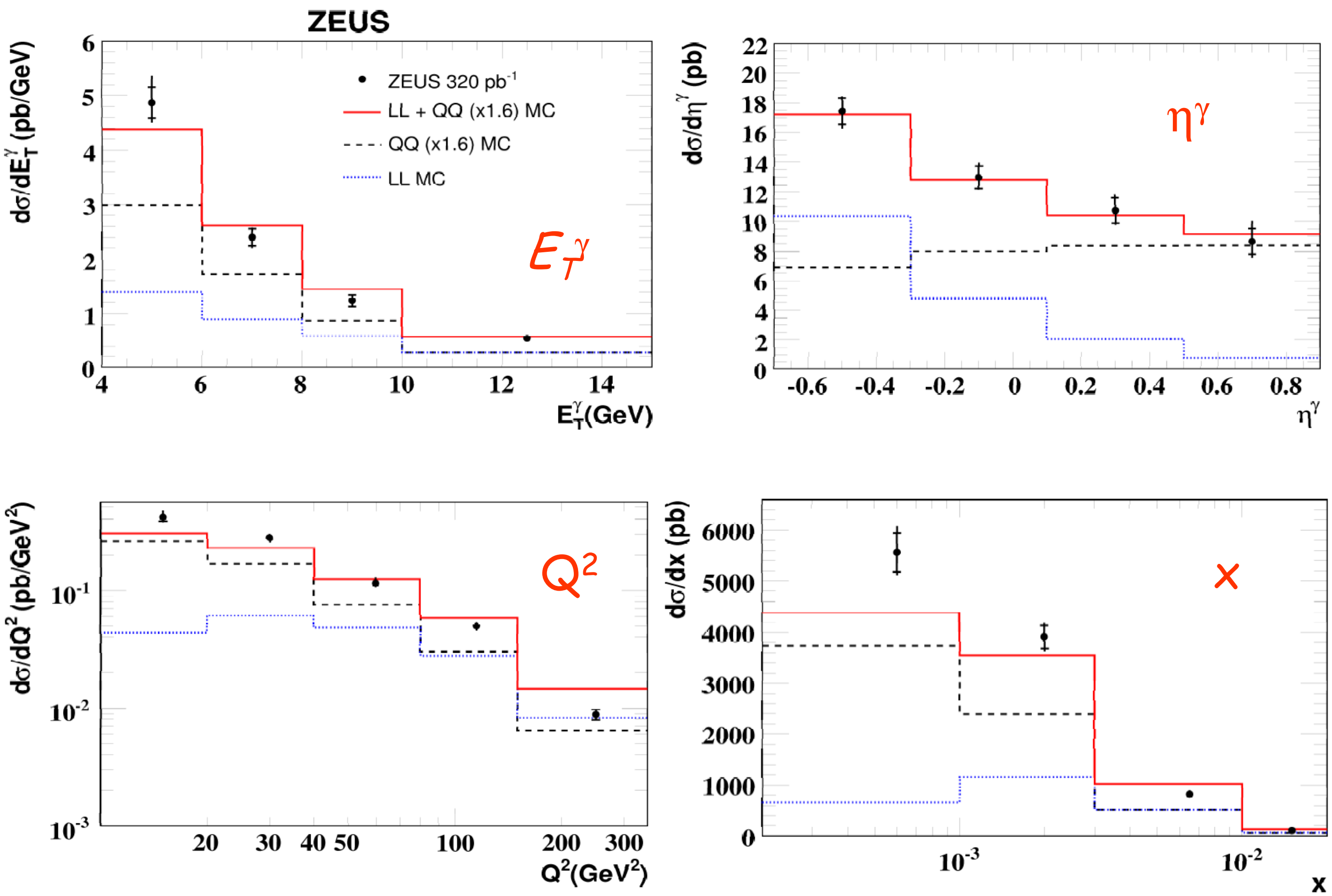
dZ plot resolves 1γ and 2γ peaks

f_{max}

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

ZEUS DIS inclusive γ: compare MC (LL+1.6xQQ)

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



$E_e > 10$ GeV

$139.8° < \theta_e < 171.8°$

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

$4 < E_T^\gamma < 15$ GeV

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

$W_x > 5$ GeV

E(EMC)/E(jet) > 0.9
(jets: k_T algorithm
with R = 1.0)

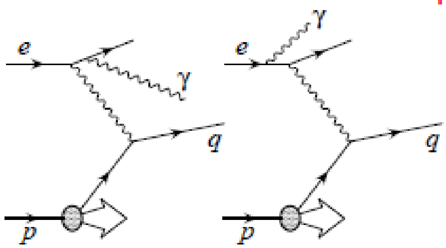
MC describes E_T^γ, η^γ
well but falls below
data at low Q^2 and
at low-x

2 hard scales: Q^2,E_T^γ

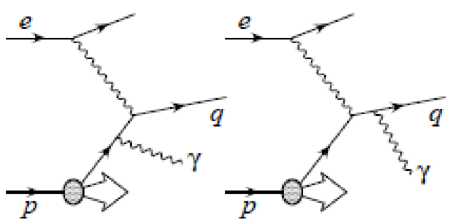
Prompt photons in DIS: k_T factorisation?

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

LL - hard radiation from leptons



QQ - hard radiation from quarks

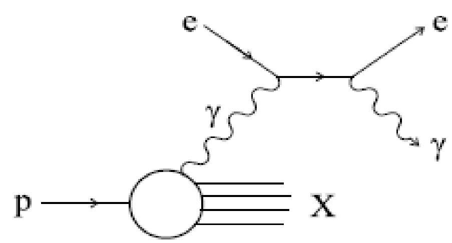


QL interference term
small and neglected here.

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

LO(α^3) from A. Gehrmann-De Ridder, T. Gehrmann and E. Poulson.
(Phys.Rev.Lett.96:132002,2006)

$\gamma^P \otimes \hat{\sigma}(e\gamma \to e\gamma)$
where γ^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

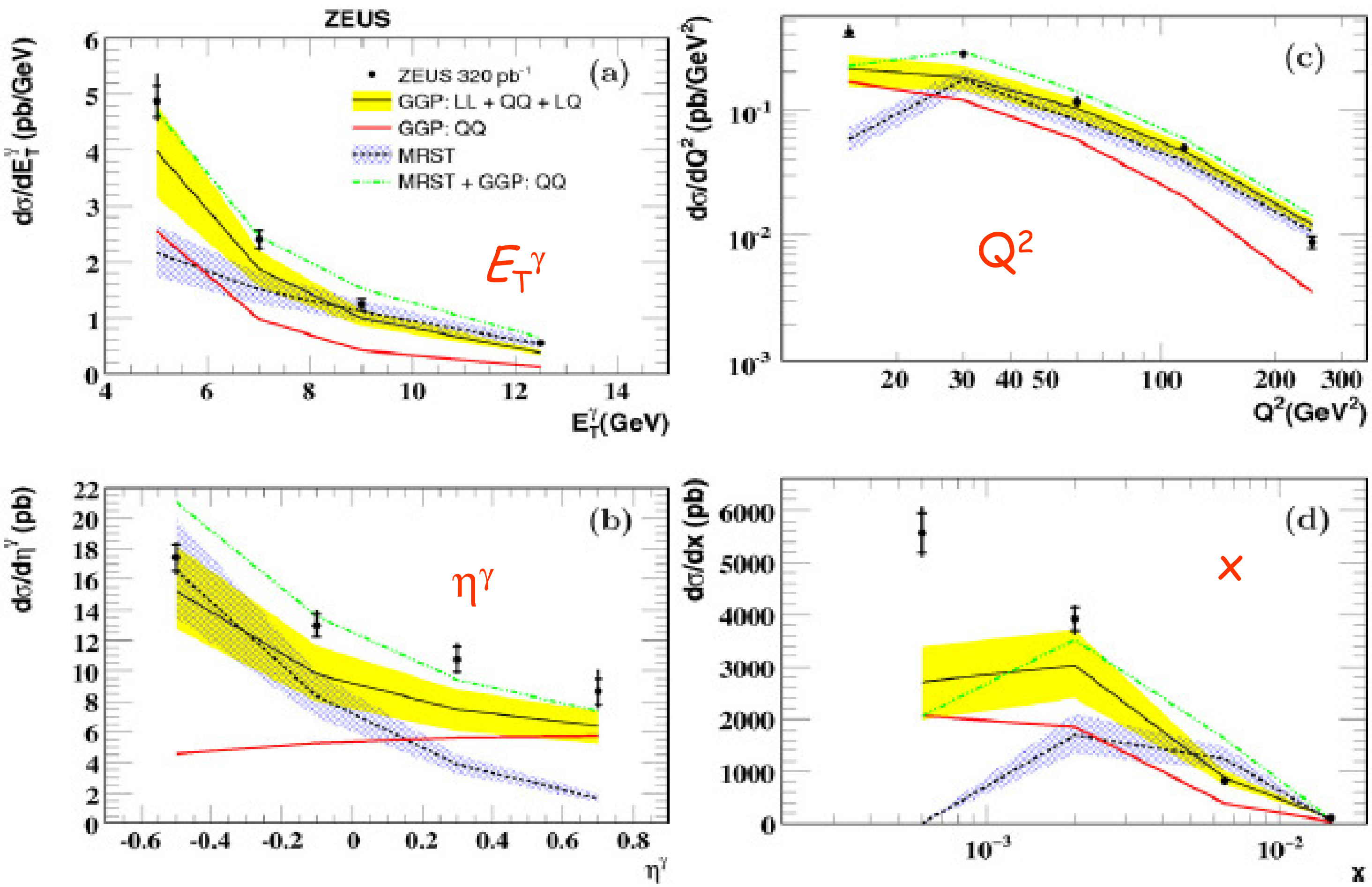
SP Baranov, AV Lipatov, NP Zotov
arXiv:1001.4782v1[hep-ph]

$eq^* \to e\gamma q$

KMR unintegrated quark densities in p

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

ZEUS DIS inclusive γ: GGP, QQ_{GGP}+$MRST_{LL}$ describe E_T,η but not Q^2,x



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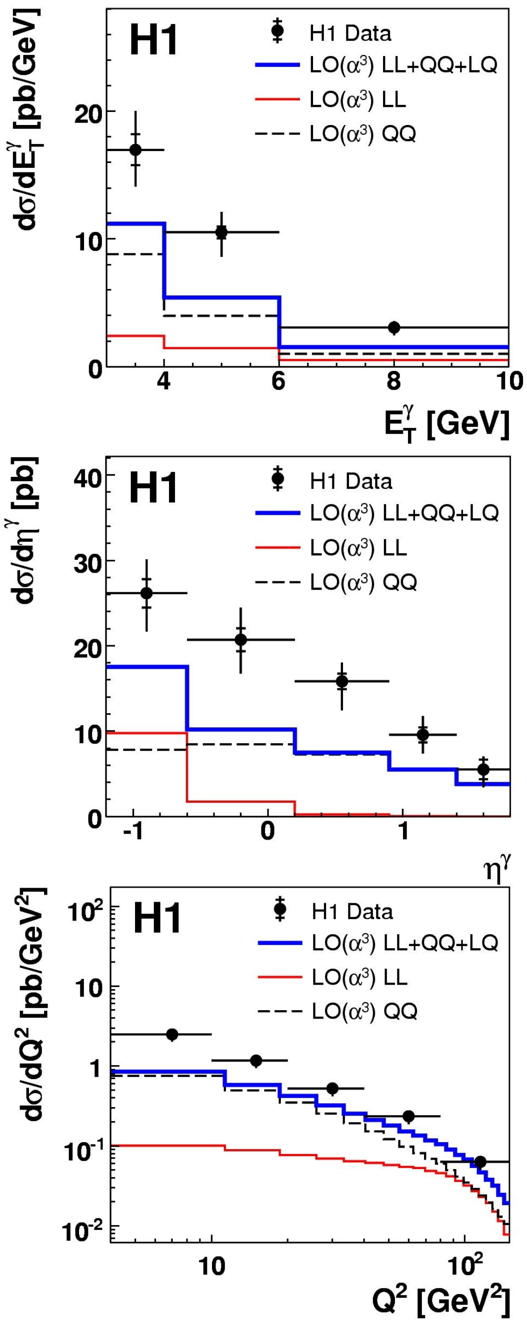
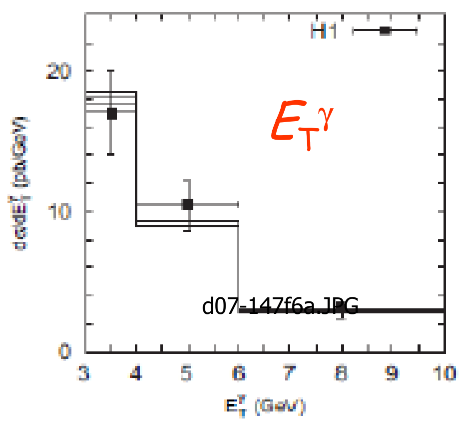
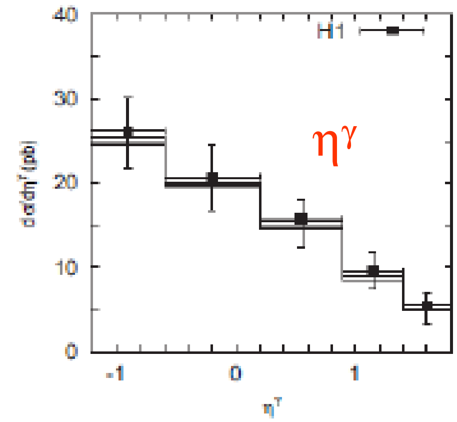


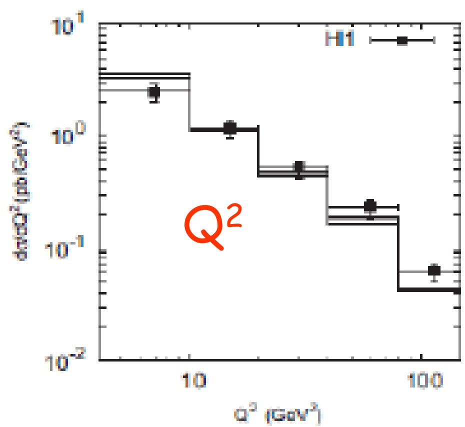
DIS inclusive γ: collinear & k_T-factorisation predictions compared to H1 data

← H1 own fit using GGP

↓ BLZ fit

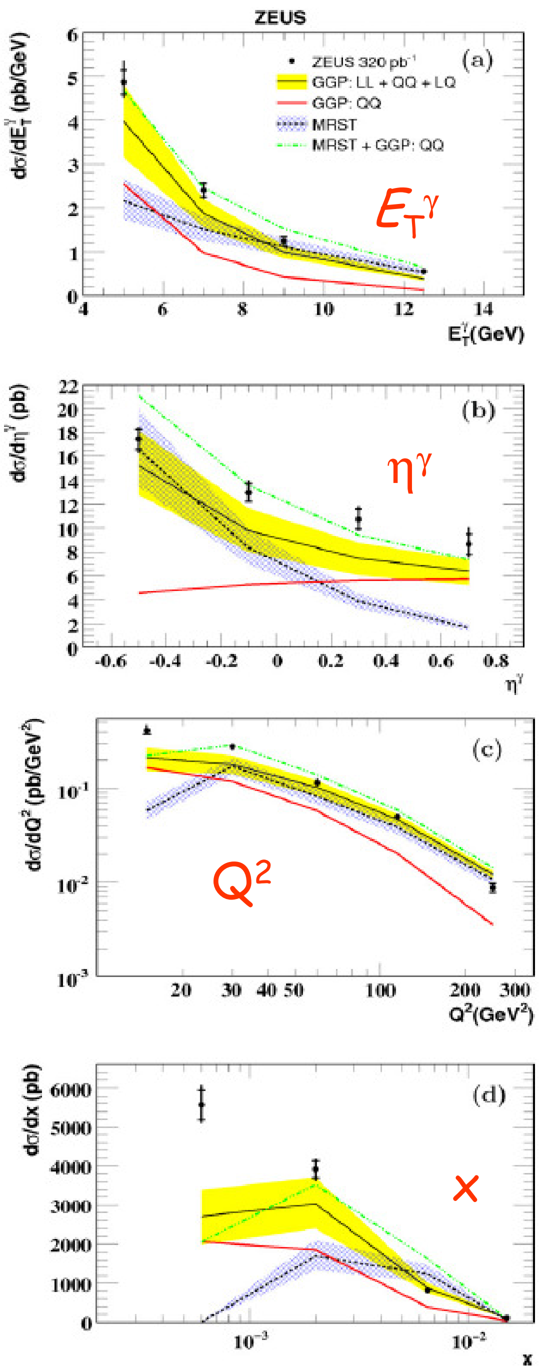






Success for BLZ

DIS inclusive γ: k_T-factorisation predictions compared to ZEUS data



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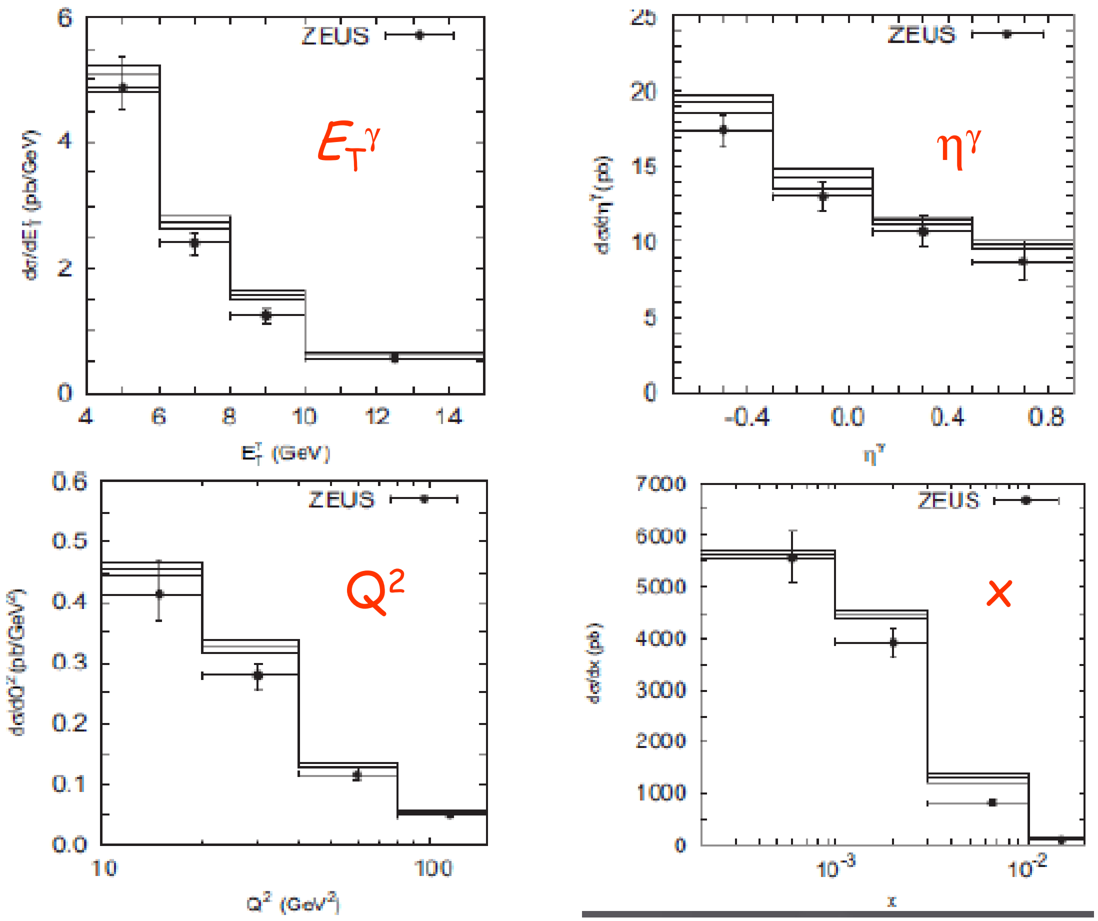


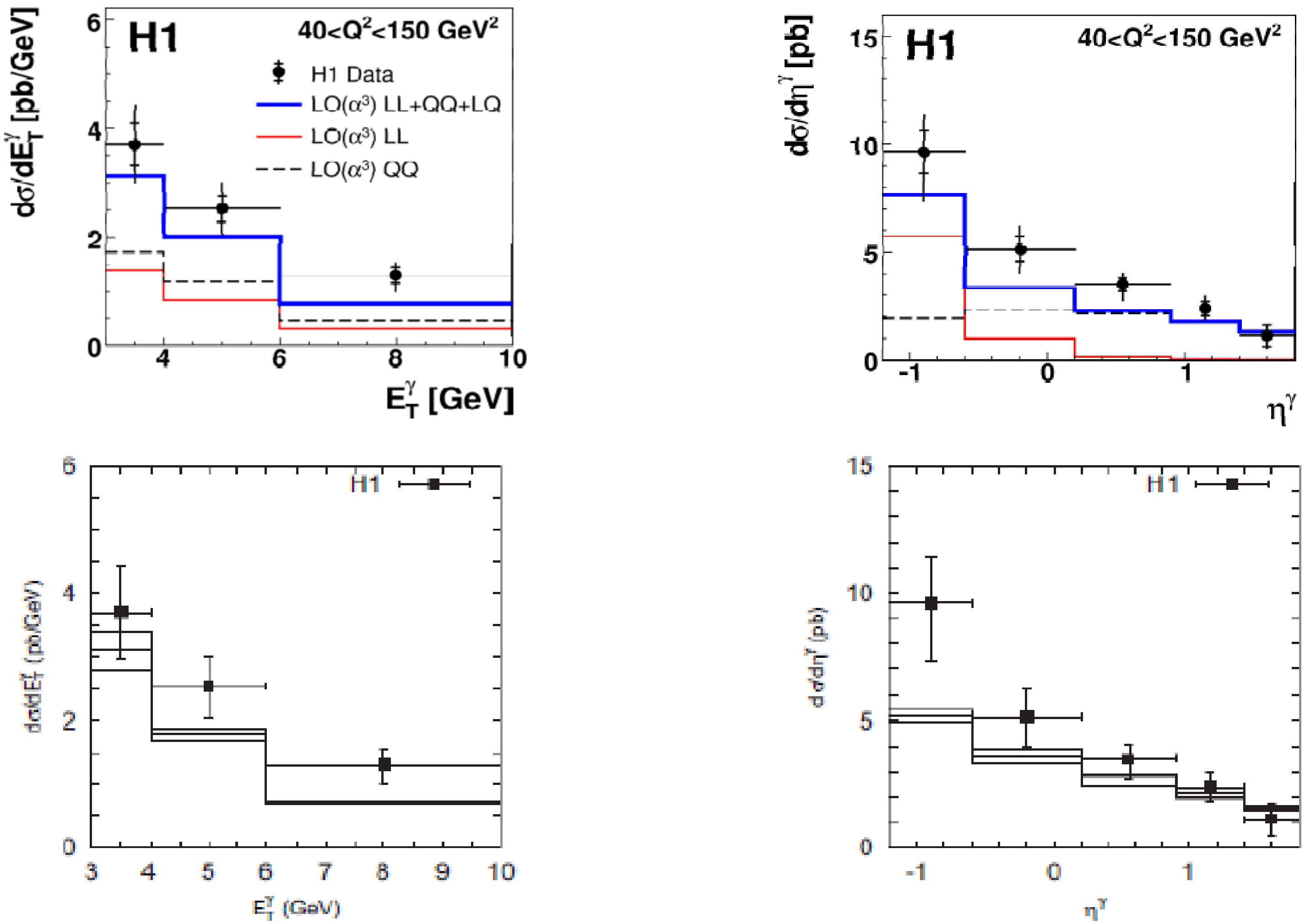
Success for BLZ

BLZ not better at high Q^2 (H1 data)

as expected (?)

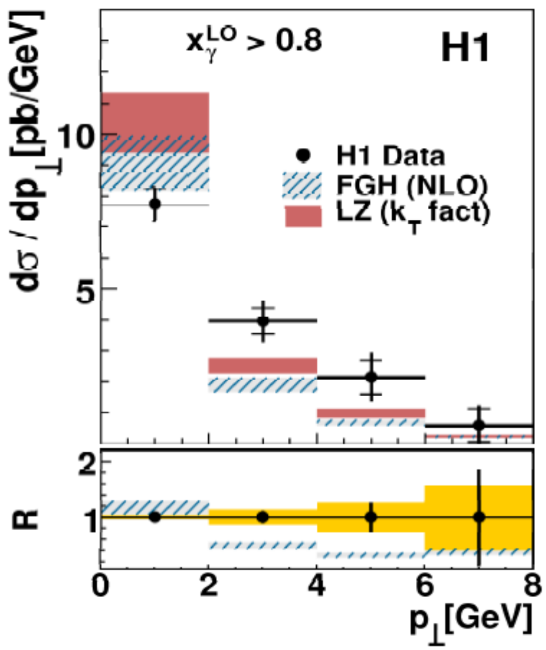
H1 fit →

BLZ →



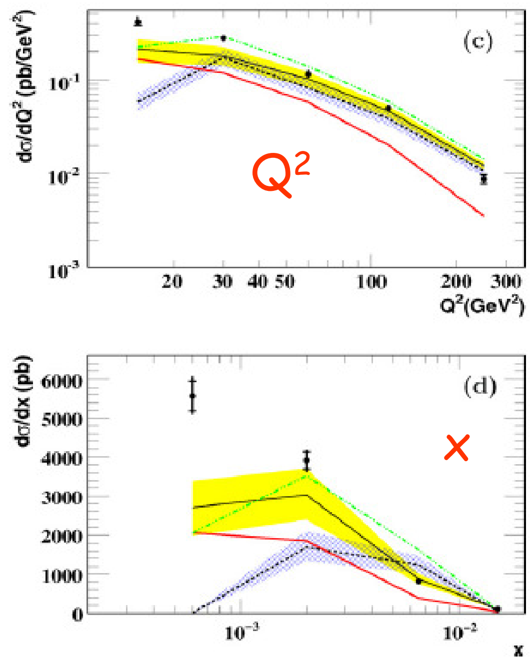
Prompt photons probe reaction dynamics: summary

H1 photoprod (γ+jet)
Extended η-range



γ/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