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Prompt Photons and Particle Momentum Distributions at HERA

Nelly Gogitidze
LPI/Moscow & DESY/Hamburg

for the H1 and ZEUS Collaborations

Outline

- Inclusive prompt photons in DIS

  (H1 preliminary, ZEUS: Phys.Lett. B595, 86-104, 2004)

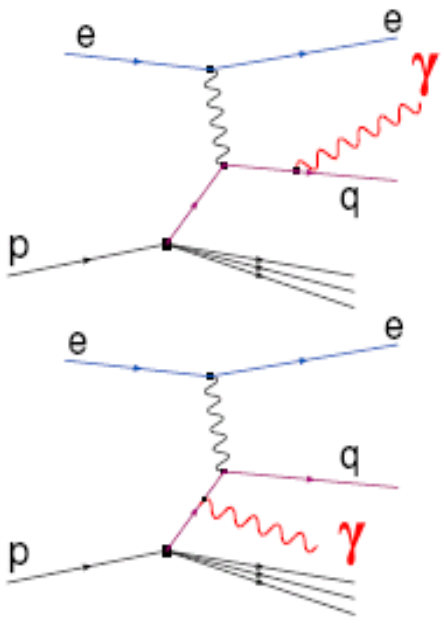
- Prompt photons with associated jets in photoproduction

  (ZEUS preliminary)

- Scaled momentum distributions of charged particles at high Q^2

  (H1 preliminary)

Prompt Photons



Why is it interesting?

+ Direct probe of hard process dynamics, test of QCD
+ Direct information about involved quark,
  complementary to jet studies
+ No hadronisation corrections, good energy measurement
+ Important for searches for New Physics at LHC

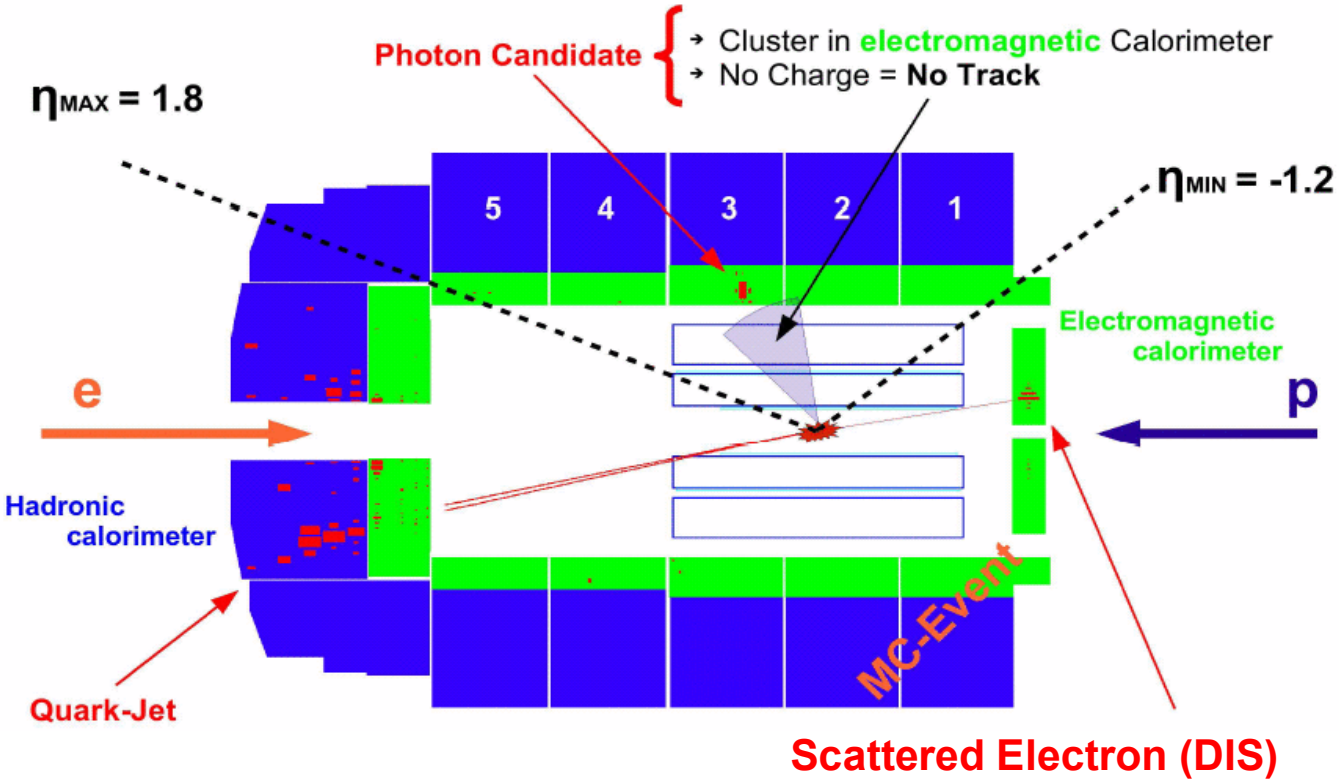
(H → γγ, QCD induced background must be well understood)

Disadvantages:

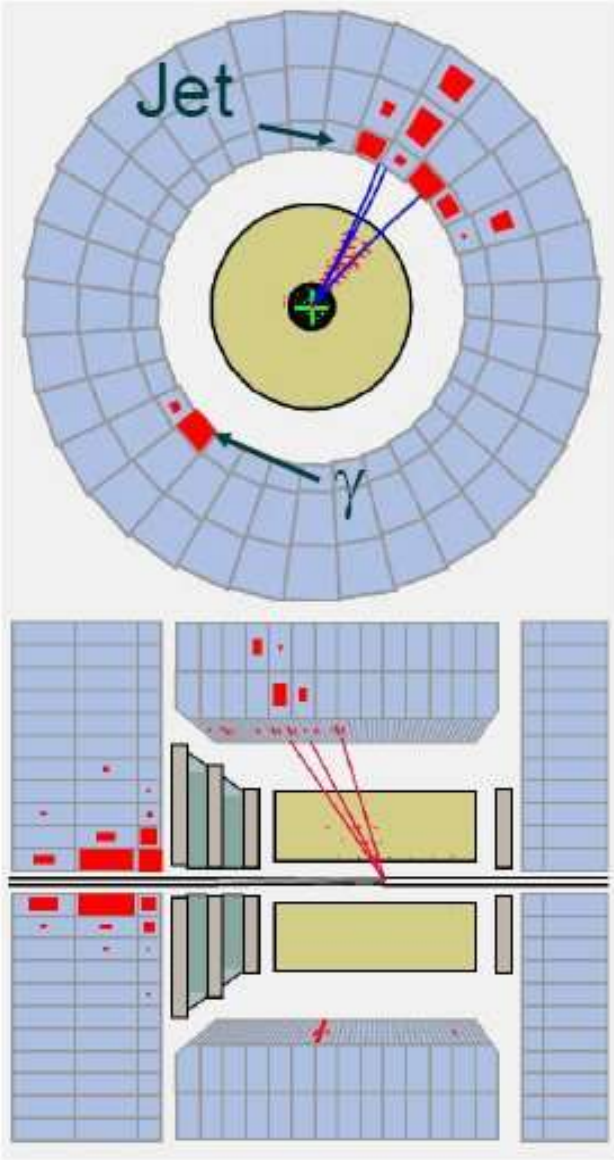
- Small cross section
- Background from neutral hadrons (π^o, η, ω...) difficult to suppress
  ==> need sophisticated shower shape analysis
  ==> background subtraction on statistical basis

Examples: Prompt Photons in the Detectors

H1

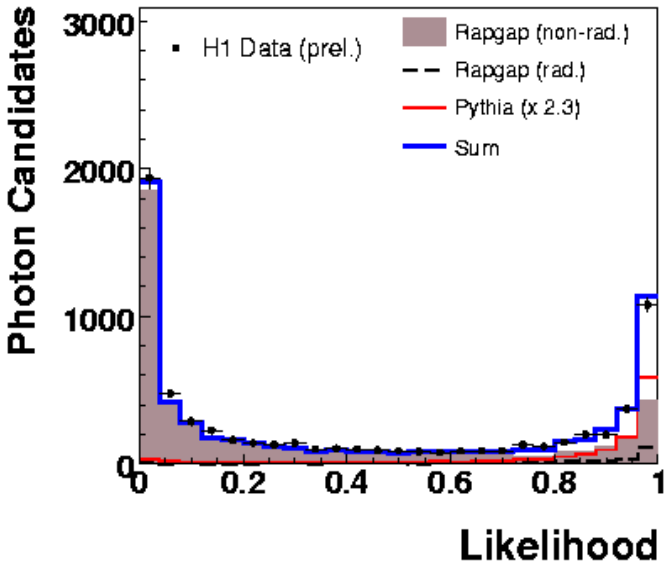


ZEUS



Prompt Photons as Experimental Challenge:

separating the signal (γ) from the background (π^o, η, ω, ...)



H1

Lar calorimeter: high granularity, multilayer

Shower shape variables

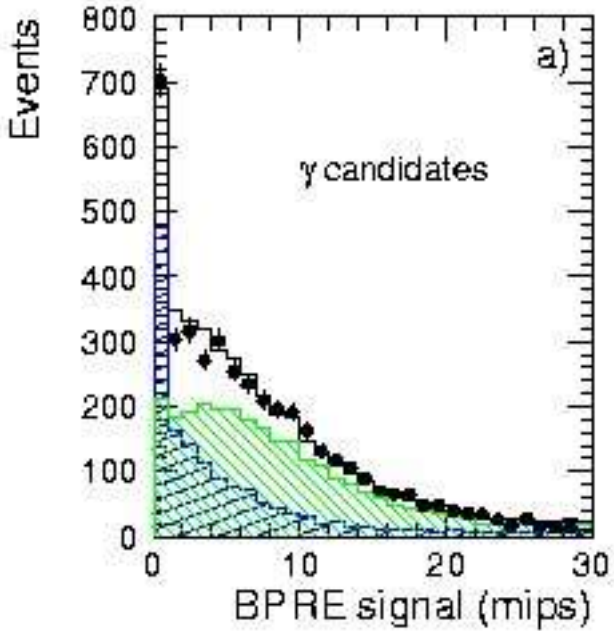
(Geometry: Radius, Symmetry, Kurtosis,

Energy fraction: Hot-Core, most energetic Cell, 1-st Layer in Calorimeter)

combined in a Likelihood function

Fit the prompt γ fraction by MC, in all analysis bins

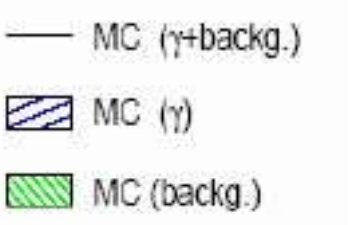
Data well described by MC



ZEUS

Barrel calorimeter and scintillator tiles in front of it (BPRE)

Fit sum of prompt γ MC and background MC to BPRE signal: determine relative amounts , in all analysis bins



Large fraction of events with <1 MIP

==> high purity of prompt γ

Inclusive Prompt Photons in DIS: H1 and ZEUS data

1999-2000	H1 preliminary	ZEUS: Phys.Lett. B595, 86, 2004
$\mathcal{L}$	70.6 pb^{-1}	121.0 pb^{-1}
Q^2	> 4 GeV^2	> 35 GeV^2
$E_{e'}$	> 10 GeV	> 10 GeV

Photon selection, by shower shape analysis

E_T^γ	$3 < E_T^\gamma < 10$ GeV	$5 < E_T^\gamma < 10$ GeV
η^γ	$-1.2 < \eta^\gamma < 1.8$	$-0.7 < \eta^\gamma < 0.9$
isolation	$E\gamma > 0.9\, E\gamma\text{-jet}$	$E\gamma > 0.9\, E_{cone}$

(γ-jet determined by k_T algorithm)

Inclusive PP: DIS Cross Sections and LO(α^3) Calculations

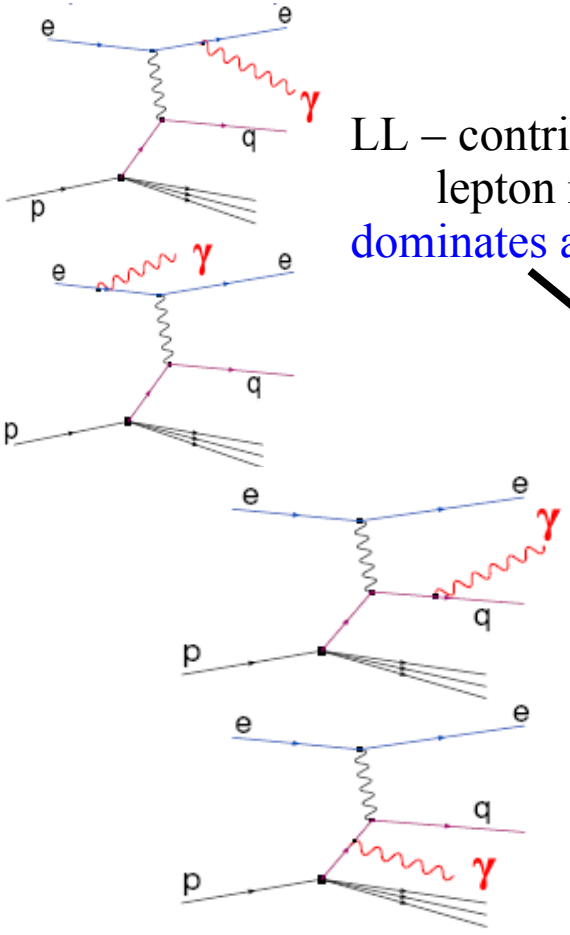
Calculation in LO(α^3)
for prompt photon cross section
at HERA (A.Gehrmann et al.):

hep-ph/0601073

hep-ph/0604030

Includes :

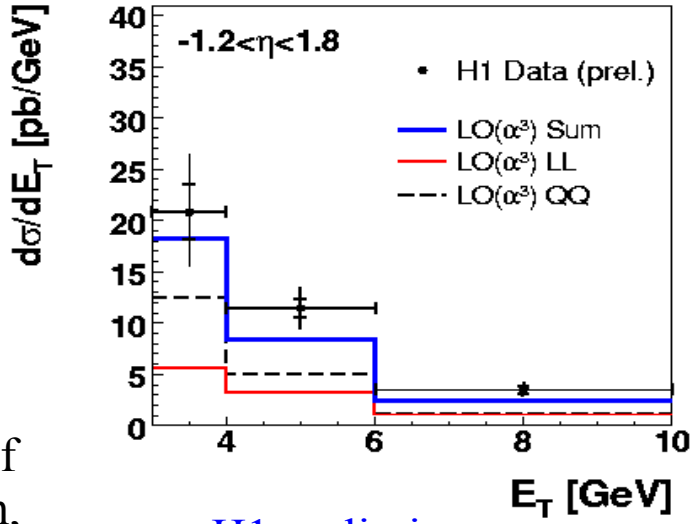
- full Matrix Elements (LO)
- quark-to-photon fragmentation



LL – contribution of lepton radiation, dominates at small η

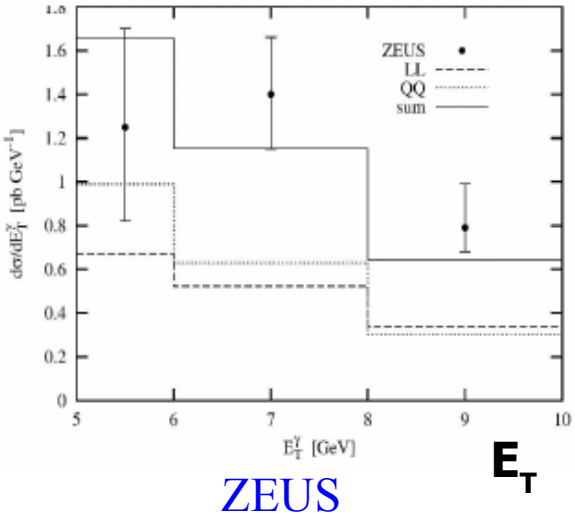
QQ – contribution of quark radiation, dominates at large η

H1: $Q^2 > 4$ GeV^2

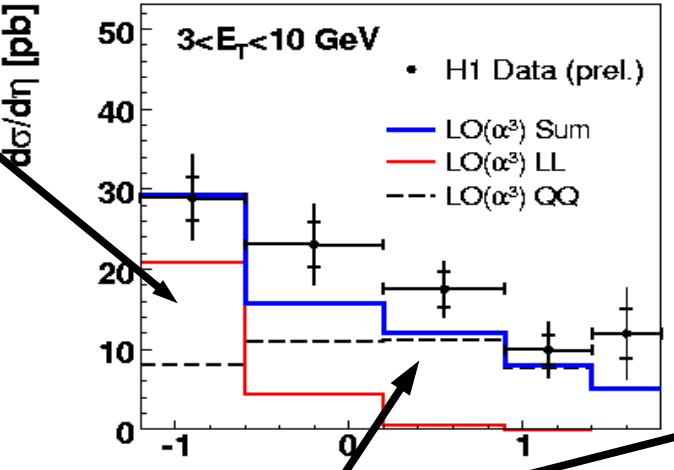


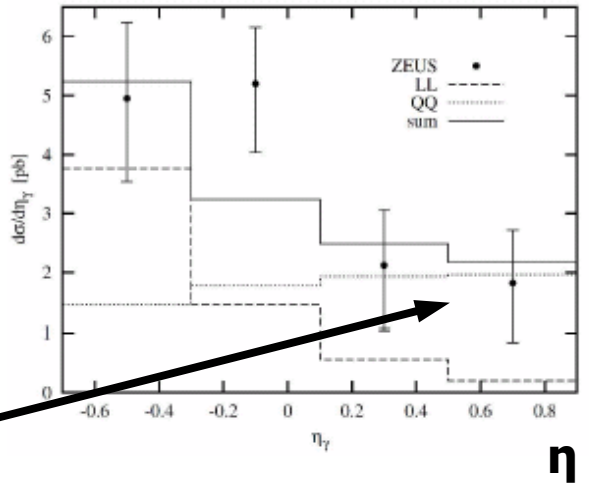
H1 preliminary

ZEUS: $Q^2 > 35$ GeV^2



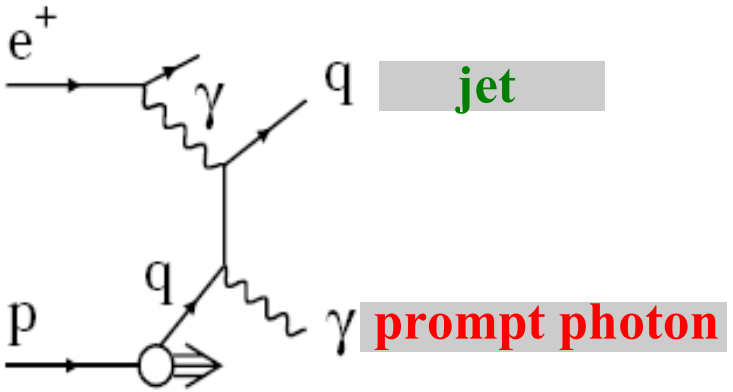
ZEUS
Phys.Lett. B595, 86, 2004

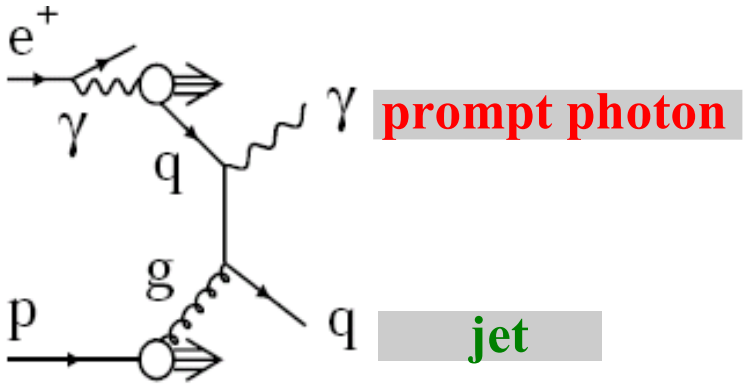




Data described reasonably well

Prompt Photon + Jet, in Photoproduction:
Theoretical Predictions and MC





NLO pQCD

M. Fontanaz, J.P. Guillet and G. Heinrich (FGH)

Eur. Phys. J. C 21, 303(2001)

proton structure function: MRST01 (ZEUS), MRST02 (H1)
photon structure function: AFG02
fragmentation function: BFG

K. Krawczyk and A. Zembrzuski (KZ)

hep-ph/0309308

treatment equivalent to FGH,
but no higher order corrections for resolved γ process
proton, photon, fragmentation functions:
for H1: as FGH for ZEUS: GRV

k_T factorisation, LO

A. Lipatov and N. Zotov (LZ)

Phys.Rev. D 72, 054002 (2005)

unintegrated quark/gluon densities of proton and photon
using Kimber-Martin-Ryskin prescription

Prompt Photon Monte Carlo models PYTHIA 6.3 HERWIG 6.5

Prompt Photon + Jet in photoproduction: ZEUS data

1999-2000 ZEUS preliminary

$\mathcal{L}$	**77.1 pb^{-1}**
Q^2	**< 1 GeV^2**
y	**0.2 < y < 0.8**

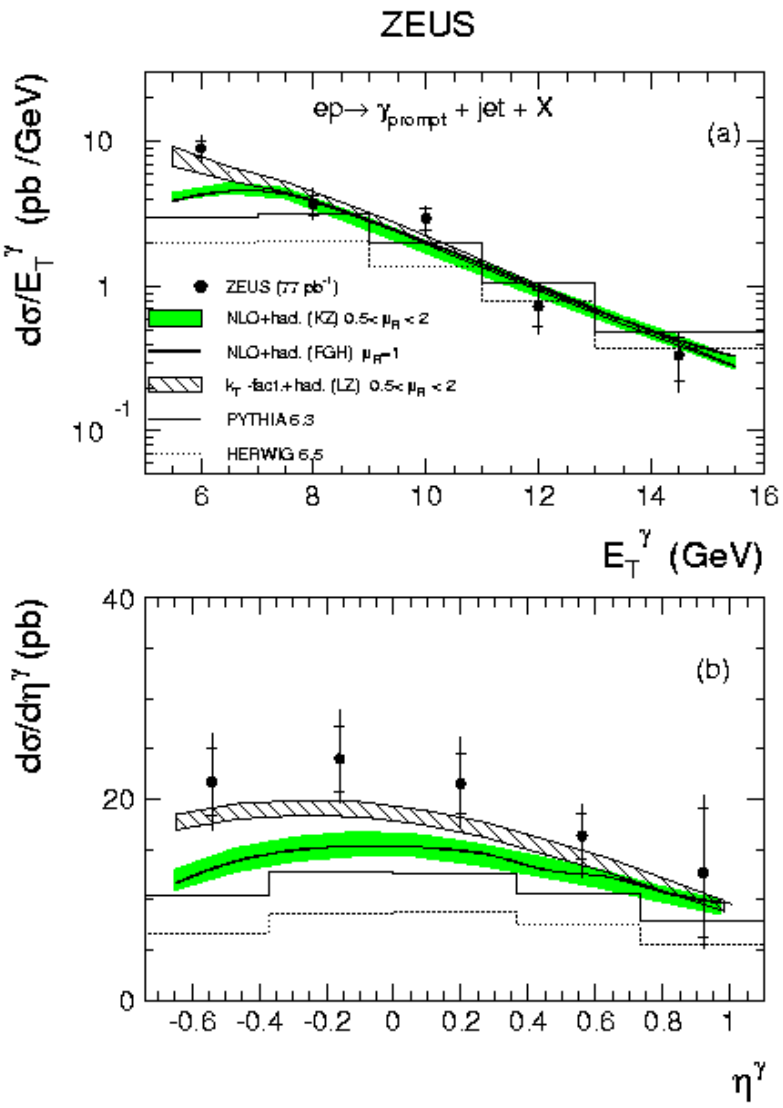
Photon selection, by preshower analysis

E_T^γ	**$5 < E_T^\gamma < 17$ GeV**
η^γ	**$-0.7 < \eta^\gamma < 1.1$**
isolation	**$E_\gamma > 0.9\, E_{\gamma\text{-jet}}$**

Jet selection, with k_t algorithm

E_T^{jet}	**$6 < E_T^{jet} < 17$ GeV**
η^{jet}	**$-1.6 < \eta^{jet} < 2.4$**

Prompt Photon + Jet: E_T and η of Photon and of Jet (ZEUS)



HERWIG and PYTHIA:
underestimate the data

FGH and KZ:

agreement with the measured cross section

For $E_T^\gamma > 5$ GeV:
deviates at low E_T^γ
and at low η^γ

LZ:

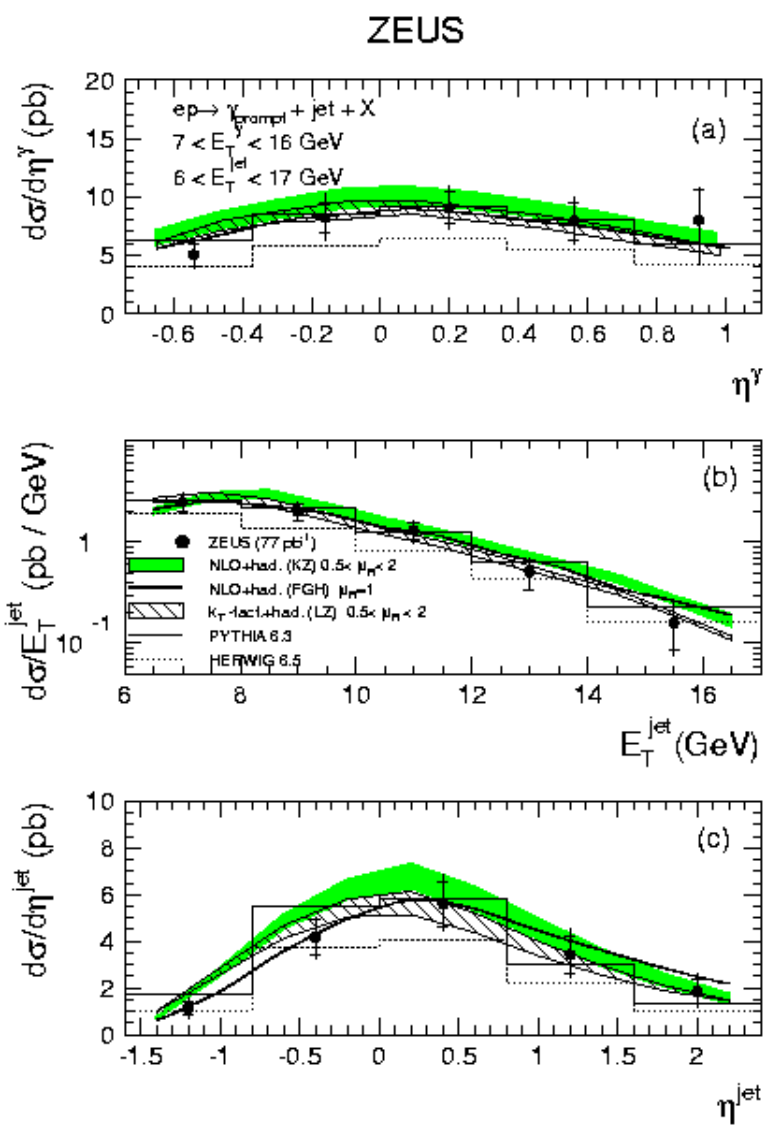
k_T fact. approach
improves description
at low E_T^γ and low η^γ

FGH, KZ and LZ:

For $E_T^\gamma > 7$ GeV
and $E_T^{jet} > 6$ GeV

good description

as also seen by H1
hep-ex/0407018

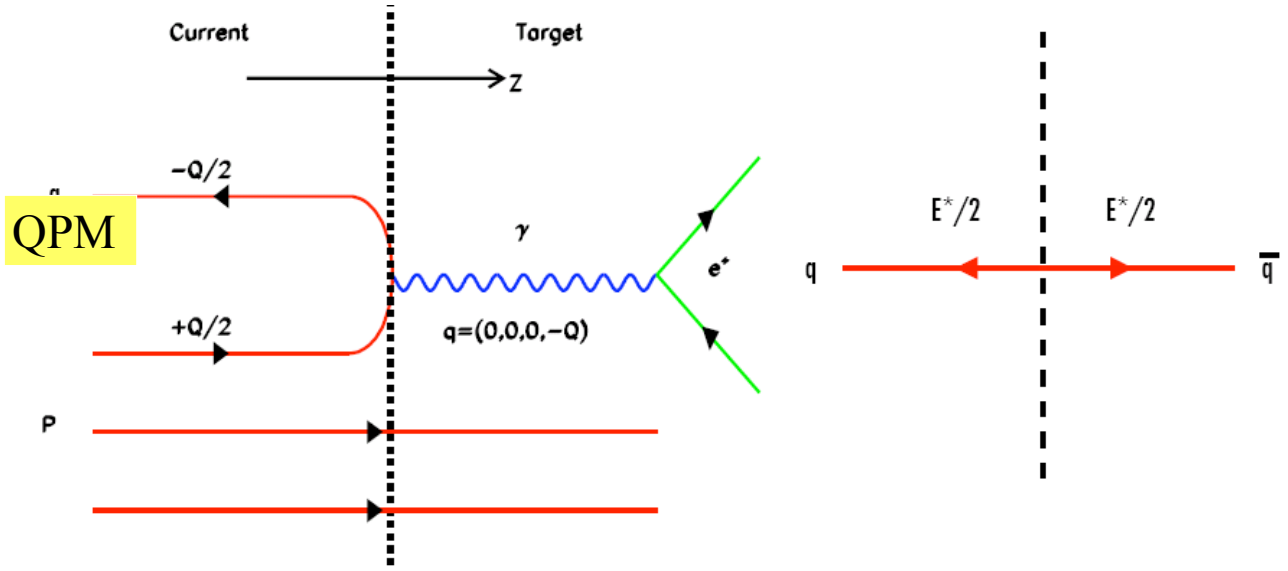


Data agree reasonably well with QCD calculations,
differences are small in view of experimental uncertainties

Scaled Charged Particle Momentum Distributions at High Q^2 at HERA (H1 preliminary)

ep: Current hemisphere in Breit Frame

e^+e^- : Half sphere



QPM

Q (E*)- scale in current region of Breit Frame (half sphere)

$$x_p = \frac{(2P_h)}{Q}$$

scaled momentum variable

P_h - momentum of charged track in current region of BF

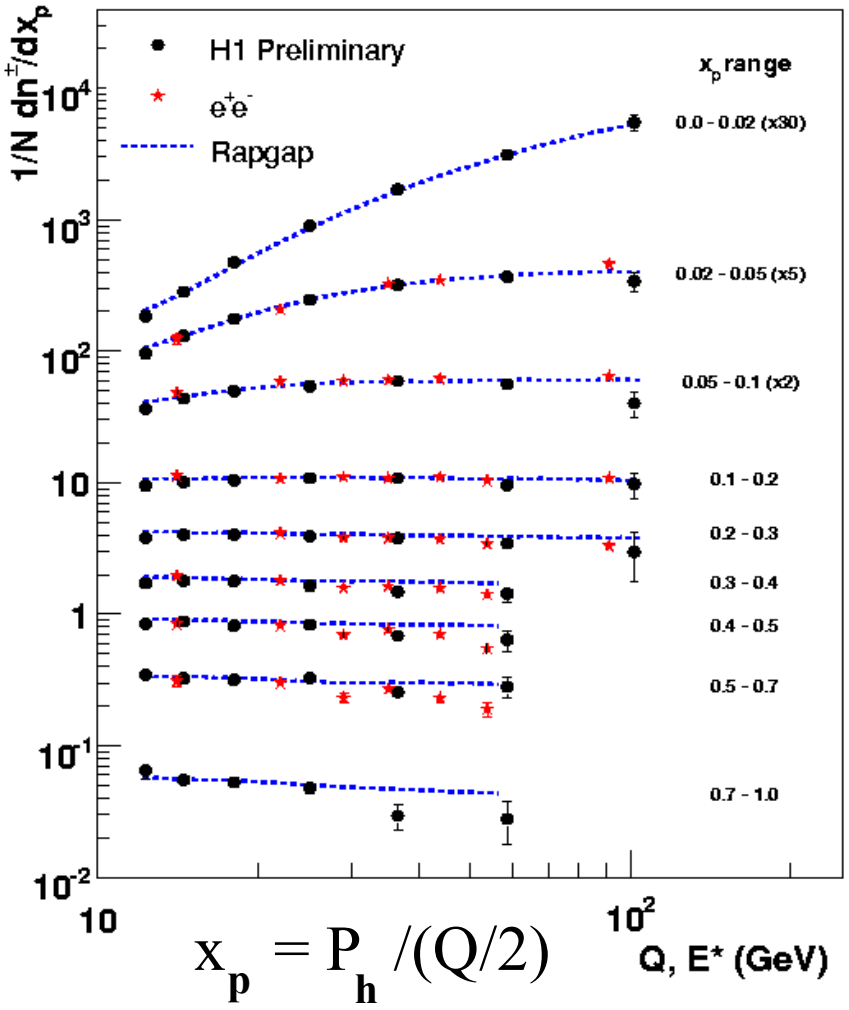
- Test Quark Fragmentation Universality and Factorisation by comparing ep data with e^+e^- data.
- Test pQCD.
  Parton splitting in pQCD causes scaling violations in fragmentation functions (like in structure functions).
- Model tests ("testing npQCD")
  Fragmentation (Color Dipole Model, Parton showers) and Hadronisation (String and Cluster) and their tuning.

$$D(x_p) = \frac{1}{N_{event}} dn/dx_p$$

scaled momentum distribution of charged particles, event normalised

Scaling Violations

Hadron production in ep and e^+e^-

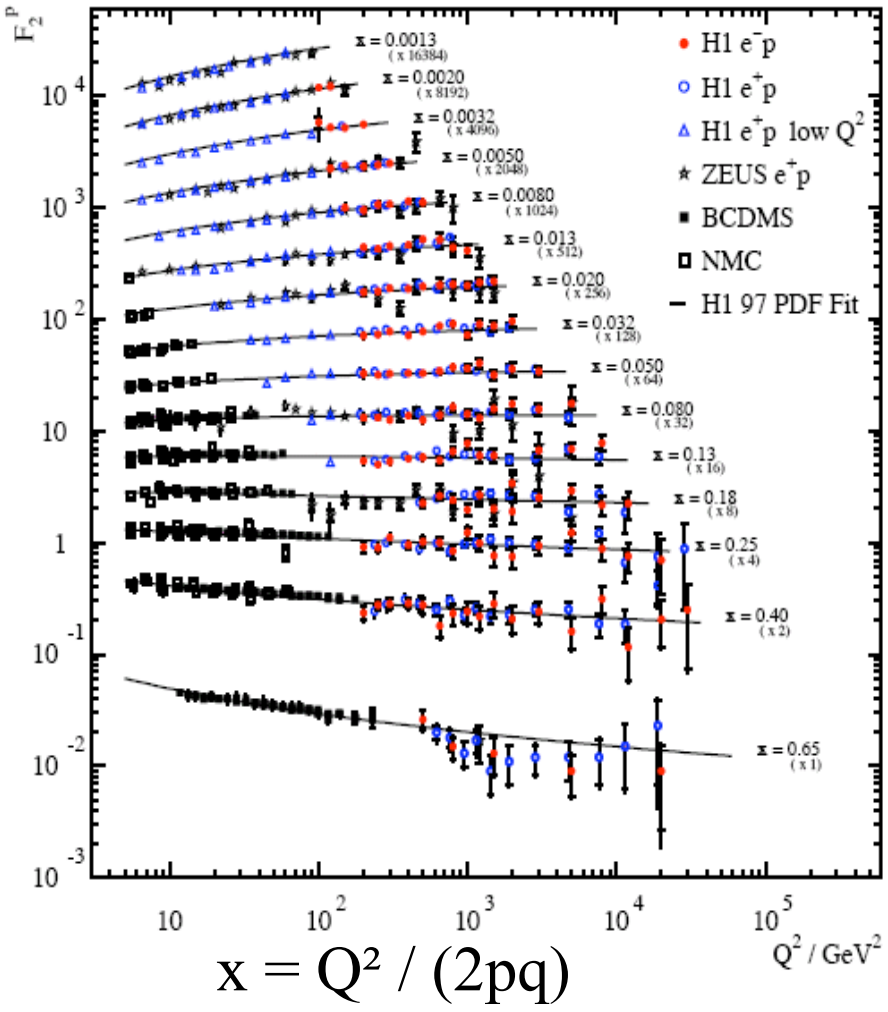


$x_p = P_h / (Q/2)$

Data: HERA-I (2000) Int.Lumi 44 pb^{-1}

$100 < Q^2 < 20000\ GeV^2$

Inclusive NC



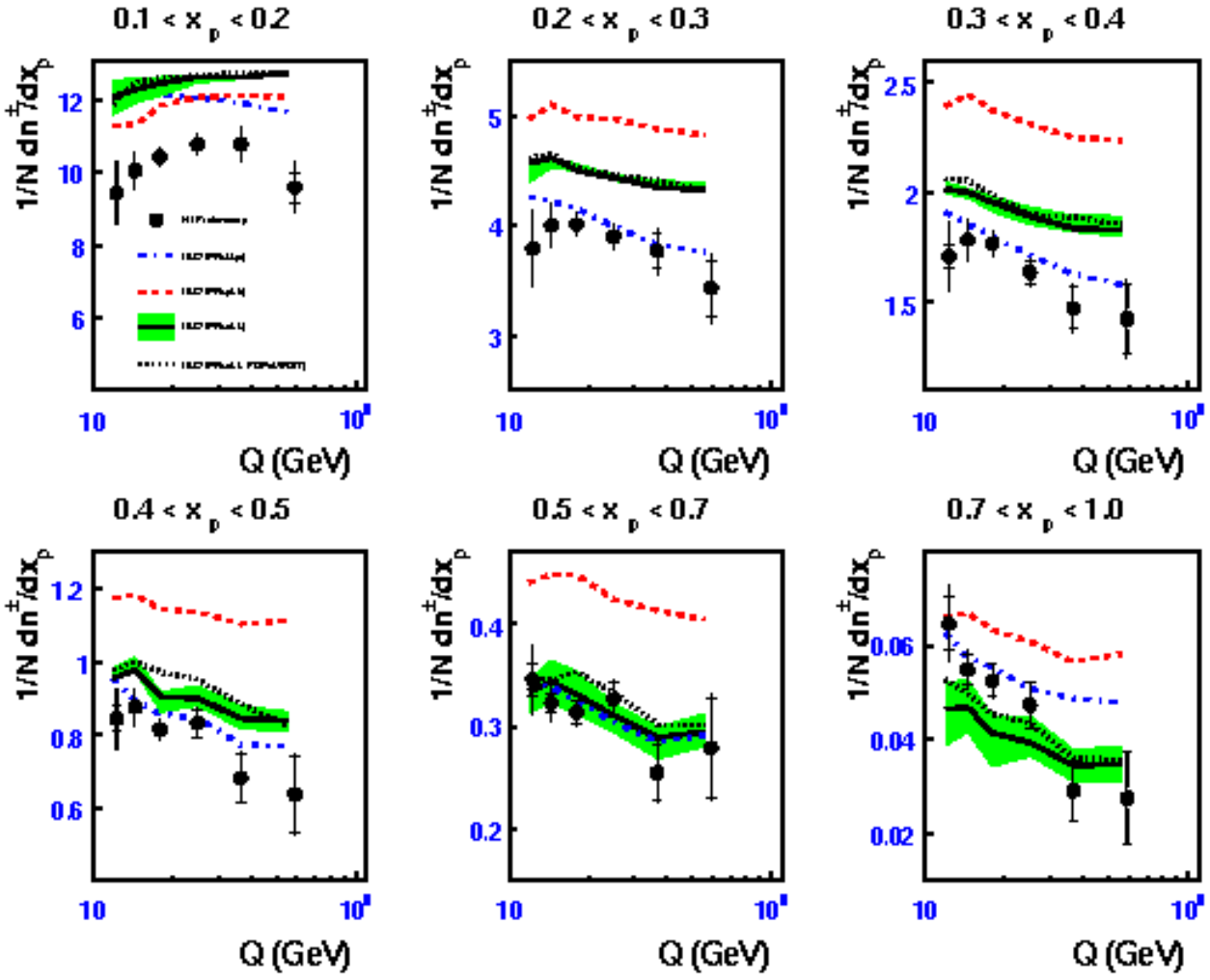
$x = Q^2 / (2pq)$

- Comparable pattern of scaling violations in hadron production and NC inclusive data
- ep ~ e+e⁻ data: Good demonstration of quark fragmentation universality

$D(x_p)$: comparison with NLO QCD calculations

Infrared safe region ($Q^2 > 100$ GeV^2), $x_p > 0.1$

Parameterisation of fragmentation functions, for $x_p > 0.1$



CYCLOPS (D.Graudenz)
+
fragmentation functions

determined using e+e- data with different quark flavour mixture (more heavy quarks)

akk (Albino,Kniehl,Kramer)
hep-ph/0502188, 0510173

include light quark tagging probability from OPAL
(more appropriate for ep scattering ?)

kkp (Kniehl, Kramer, Pötter)
hep-ph/0010289

pkh (Kretzer)
hep-ph/0003177

CTEQ6.1 PDF used

Lowest x_p : all predictions fail to describe the data

$x_p > 0.2$: kkp describes data well; pkh and akk fail

Large uncertainty related to fragmentation functions

Summary

Prompt Photons

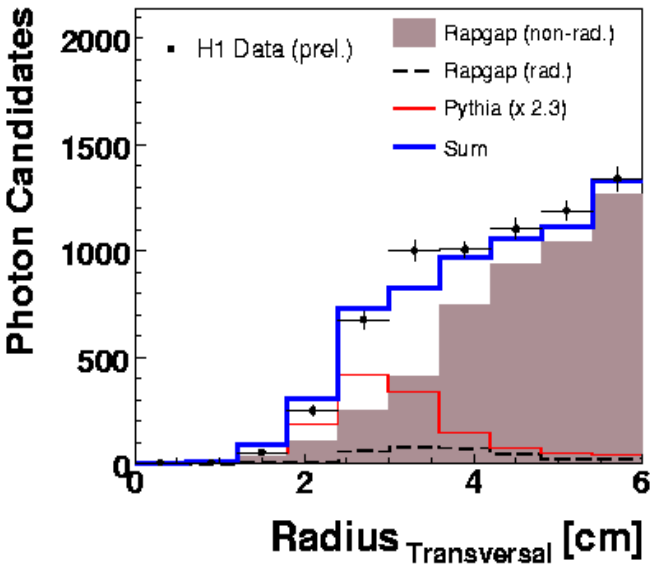
- ep DIS: γ inclusive
  - well described by LO (α^3) calculations (Gehrmann et al.)
- Photoproduction: γ + jet
  - For E_T^γ > 5 GeV : NLO calculations (FGH, KZ) fail to describe the data
    k_T factorisation calculations (LZ) improve data description
  - For E_T^γ > 7 GeV :
    NLO QCD and k_T factorisation calculations describe data well
  - PYTHIA & HERWIG differ from the data in both shape and normalisation

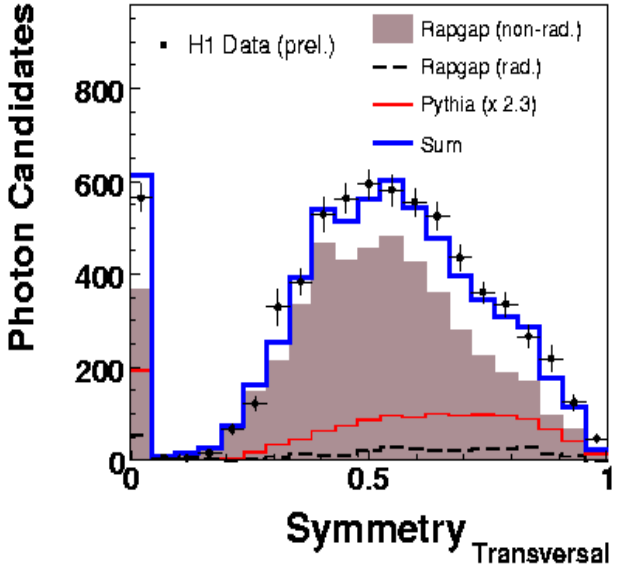
Scaled Momentum Distributions

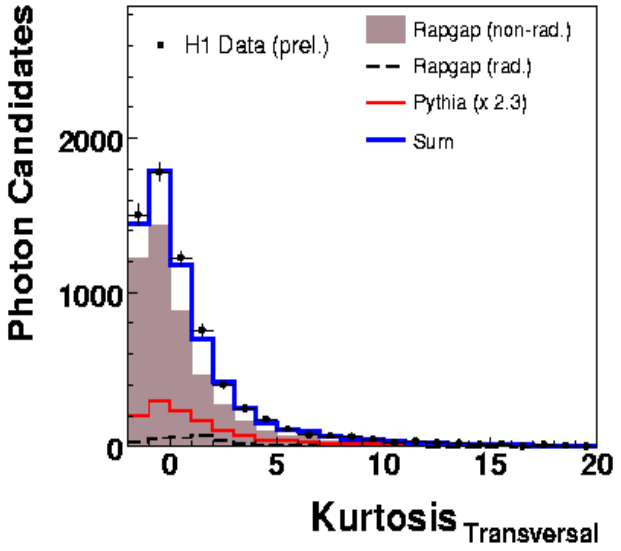
- $D(x_p)$ distribution in current region of Breit frame in DIS ep:
  in agreement with e^+e^- results
- MC models describe data reasonably well
- NLO calculations show strong sensitivity to fragmentation functions

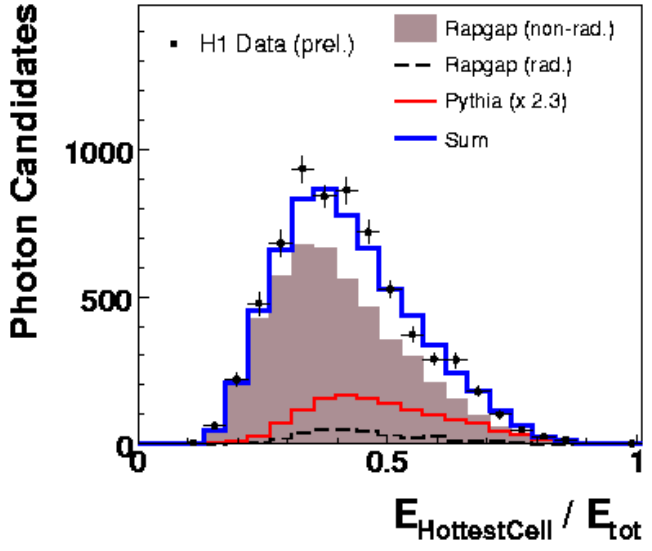
Backup

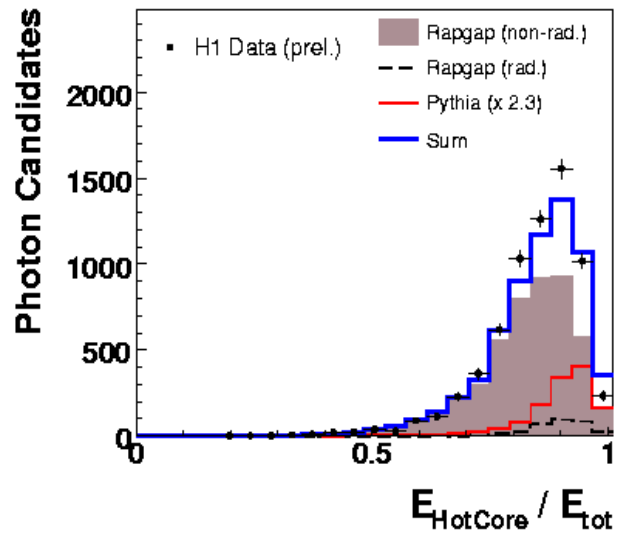
All shower shape variables well described by MC

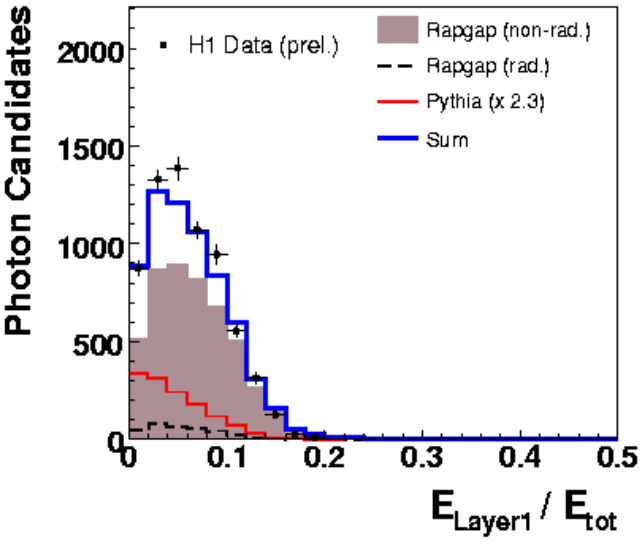




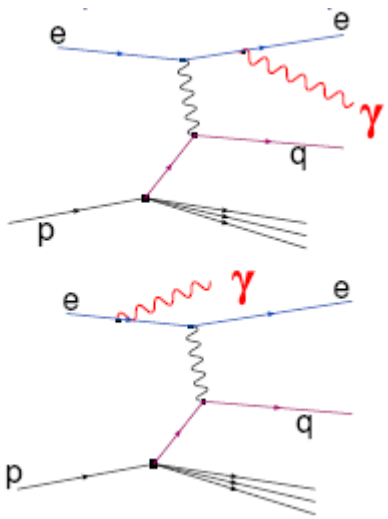








Inclusive PP: DIS Cross sections and Generators

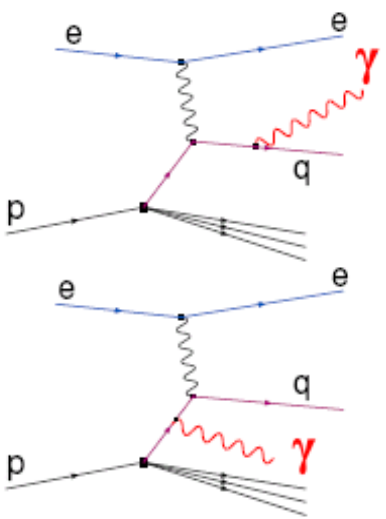


Rapgap (rad.)

==> γ from electron

Inclusive and radiative NC DIS MC

electron radiation in these events taken as approximation of photons off the electron line



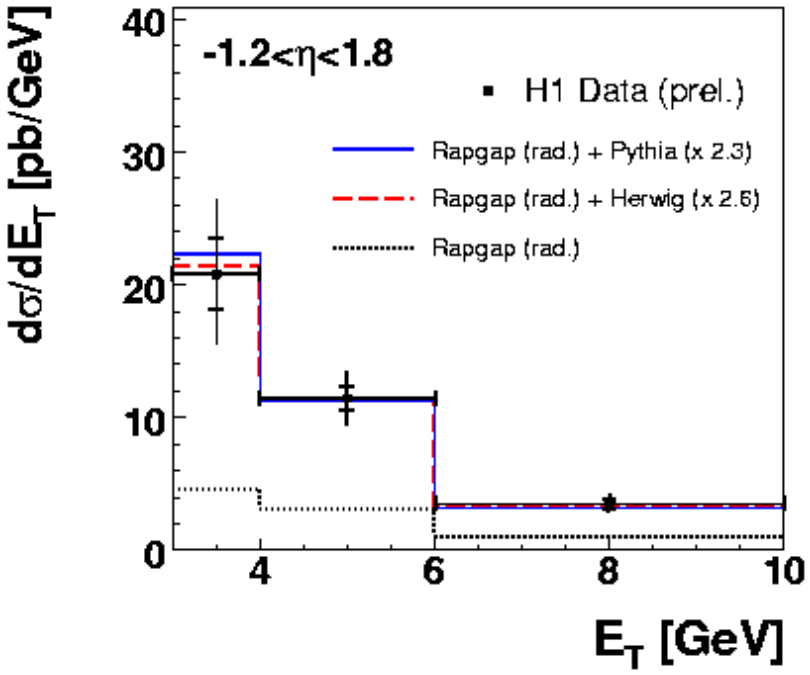
Pythia/Herwig

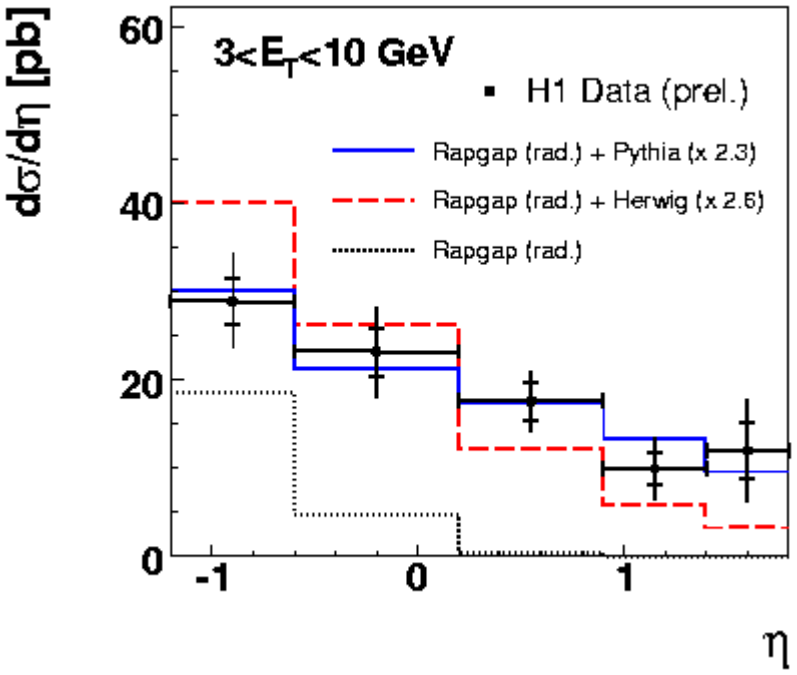
==> γ from quark

Matrixelement: γ+q --> γ+q

flux of incoming photons is approximated in the DIS mode

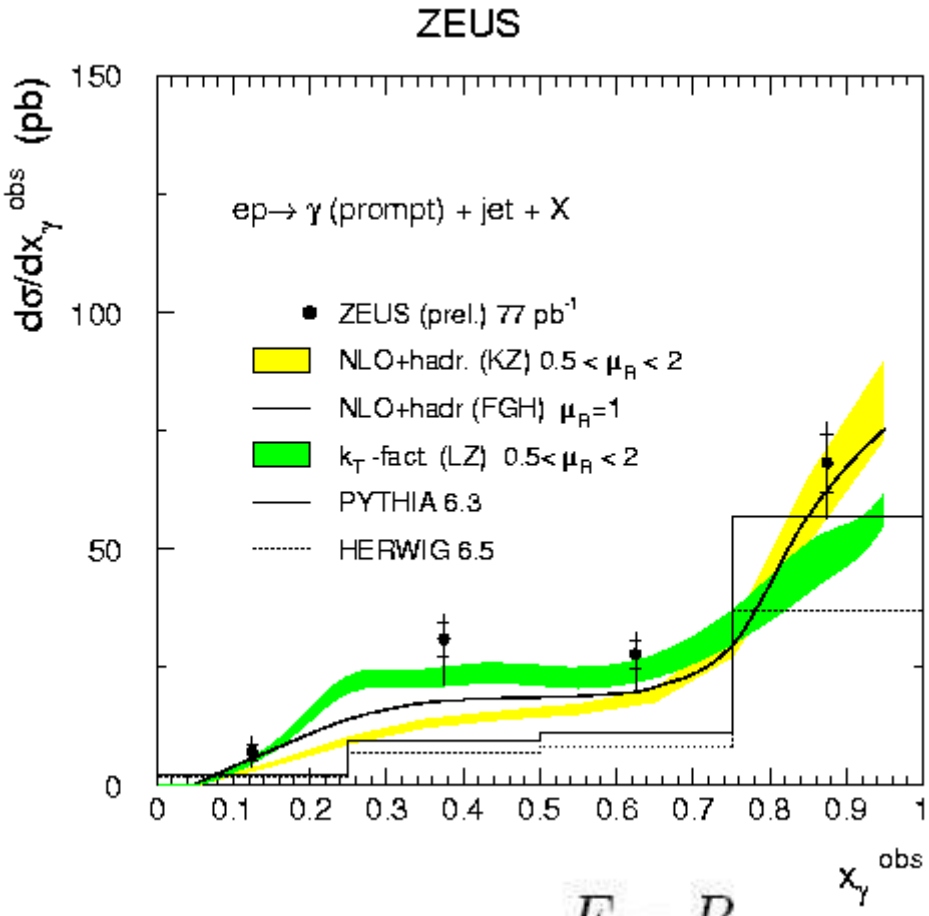
radiation off the electron is not included (only rad.corr. --> 2nd photon)



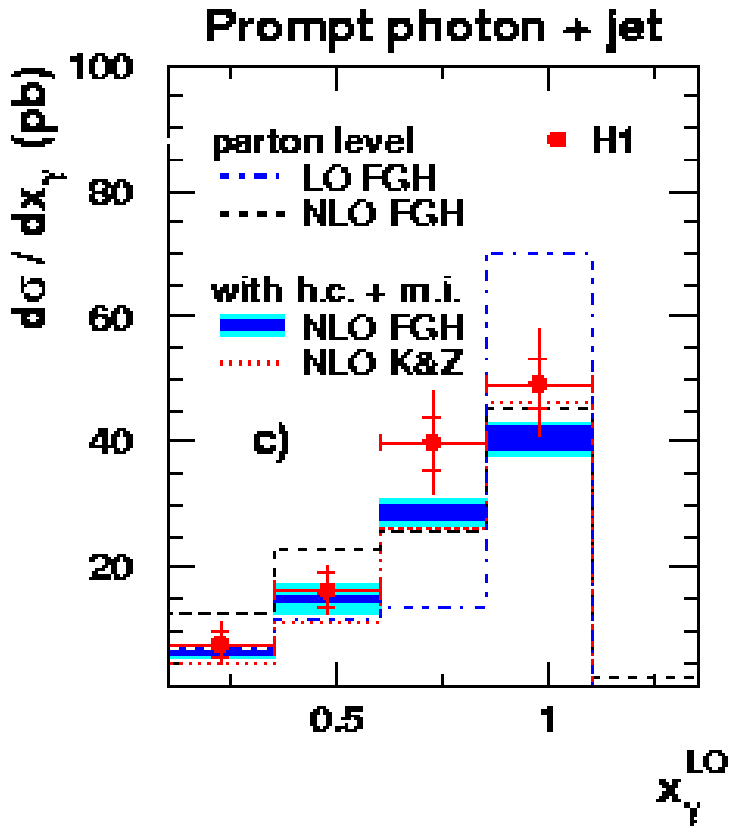


To match total cross section data, Pythia/Herwig scaled by factor 2.3/2.6

Prompt Photon + Jet, combined: x_γ



$$x_\gamma^{obs} = \sum_{\gamma,jet} \frac{E - P_z}{2E_e y}$$



$$x_\gamma^{LO} = \mathrm{E}_\mathrm{T}^\gamma(\mathrm{e}^{-\eta^{\mathrm{jet}}} + \mathrm{e}^{-\eta^\gamma})/2\mathrm{E}_\mathrm{e}\mathrm{y}$$

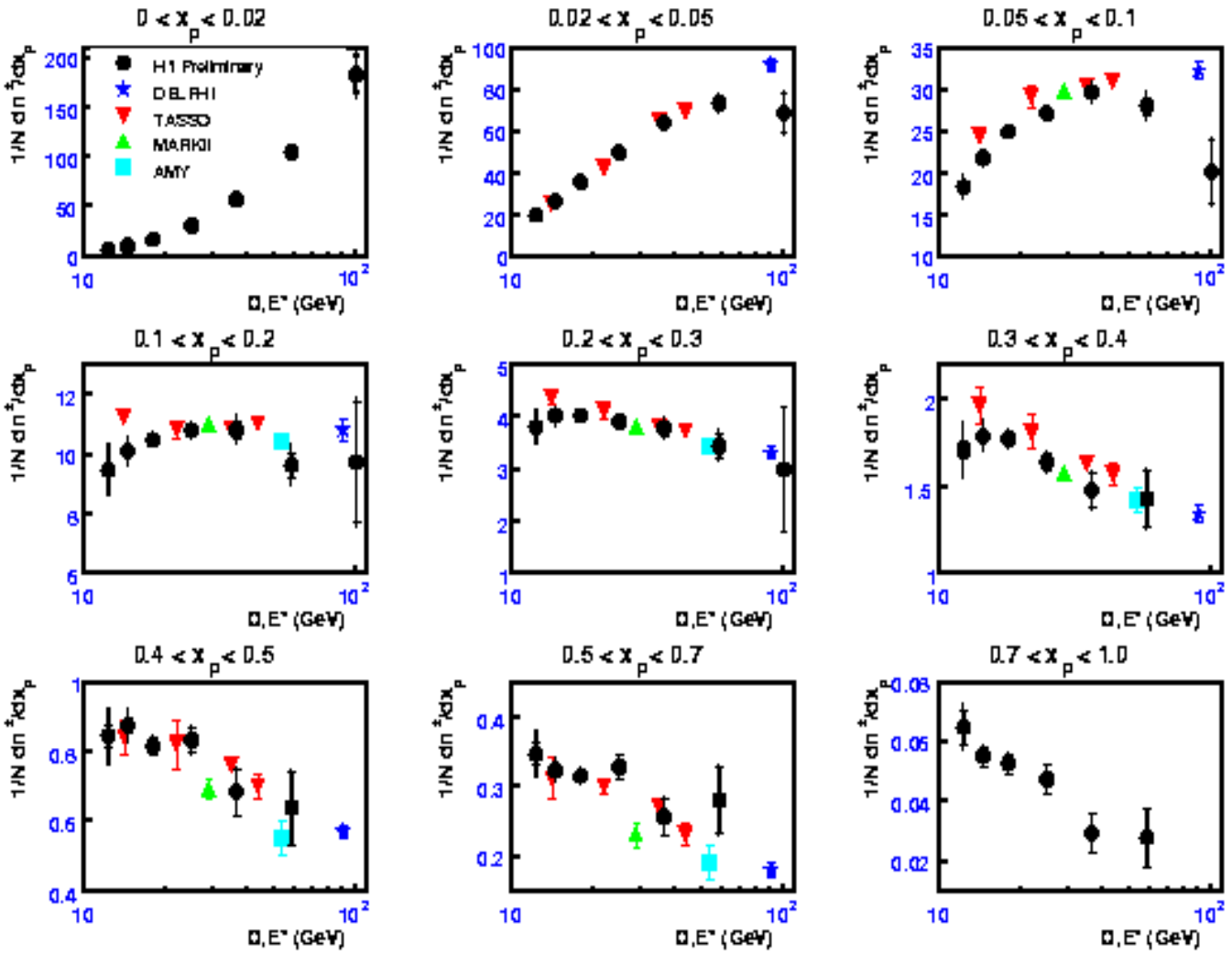
(x_γ - fraction of incoming photon energy, taking part in interaction)

FGH, KZ, LZ calculations consistent with data within errors

Strong effect of NLO corrections

HERWIG and PYTHIA: underestimate the measured cross section

$D(x_p)$ compared to e+e-



$$D(x_p)=\frac{1}{N_{event}}dn/dx_p$$

event normalised,
charged particle,
scaled momentum spectrum

$$x_p=\frac{(2P_h)}{Q}$$

scaled momentum variable

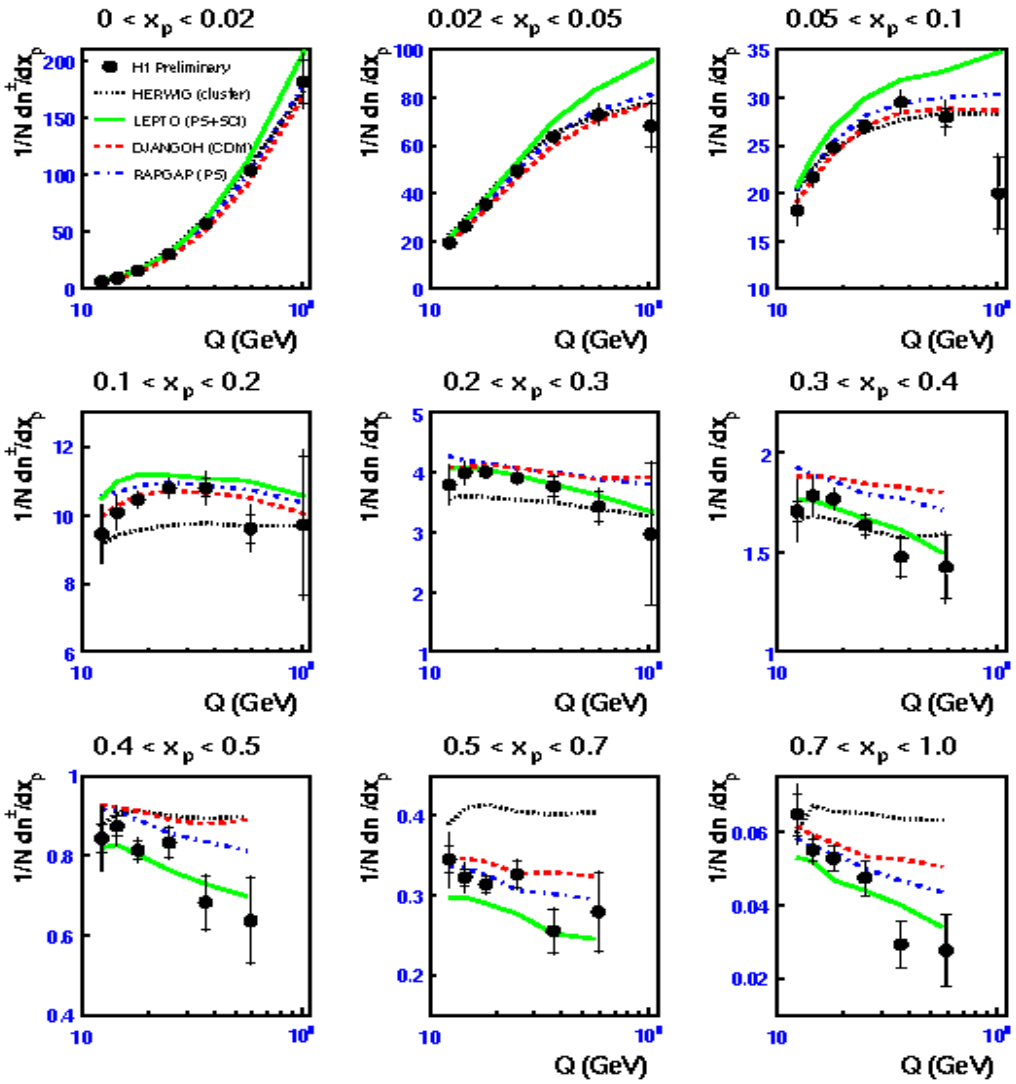
Q (E*)- scale in current region of Breit Frame (half sp.)

P_h - momentum of charged track in current region of Breit Frame

Remarkable agreement!

Good demonstration of quark fragmentation universality

$D(x_p)$: comparison with Models



Hadronisation Models:

HERWIG (6.5)

LO ME + parton shower + cluster hadr.

RAPGAP (3.1)

LO ME + parton shower + string hadr.

Parton Cascade Models:

LEPTO (6.5)

LO ME + parton shower
+ soft colour interactions
+ string hadronisation

DJANGOH (1.4)

LO ME + colour dipole model
+ string hadronisation

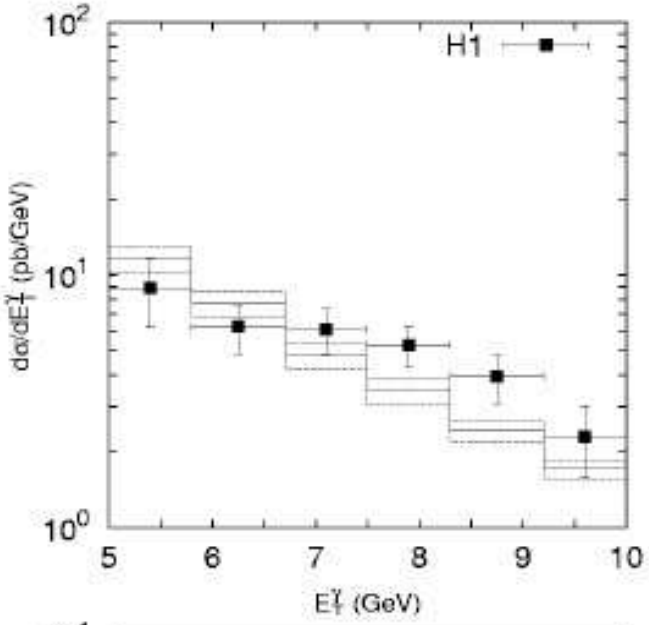
RAPGAP and DJANGOH : good description of data

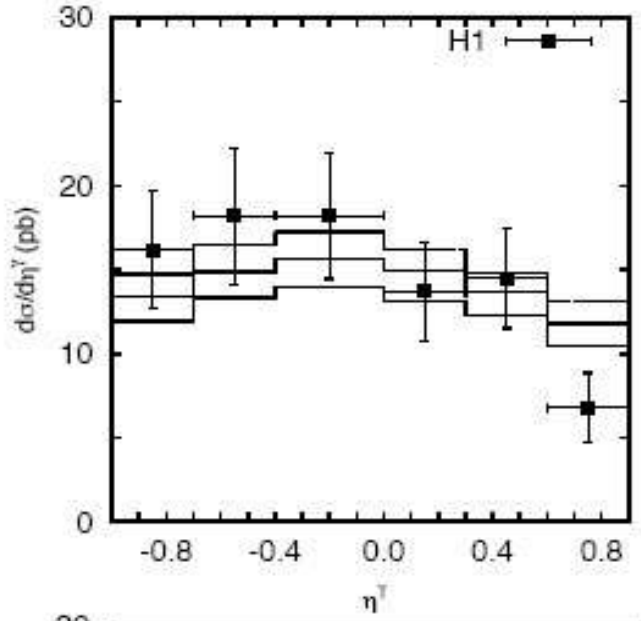
LEPTO too soft HERWIG too hard

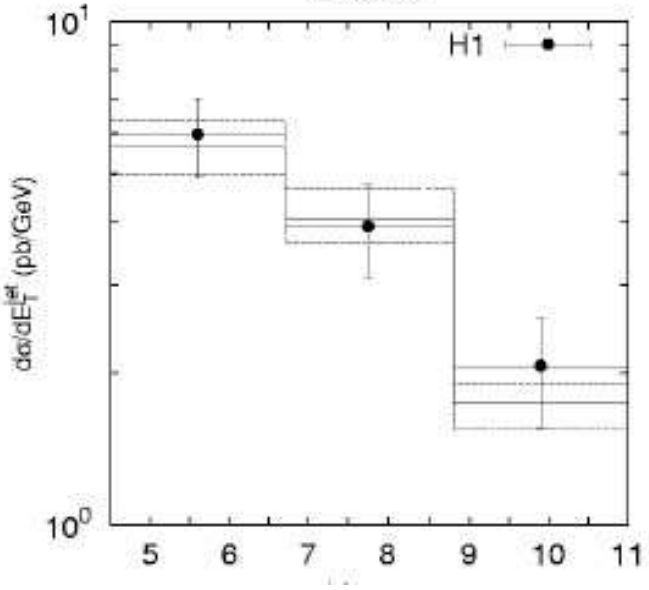
MC models tuned to e^+e^- data

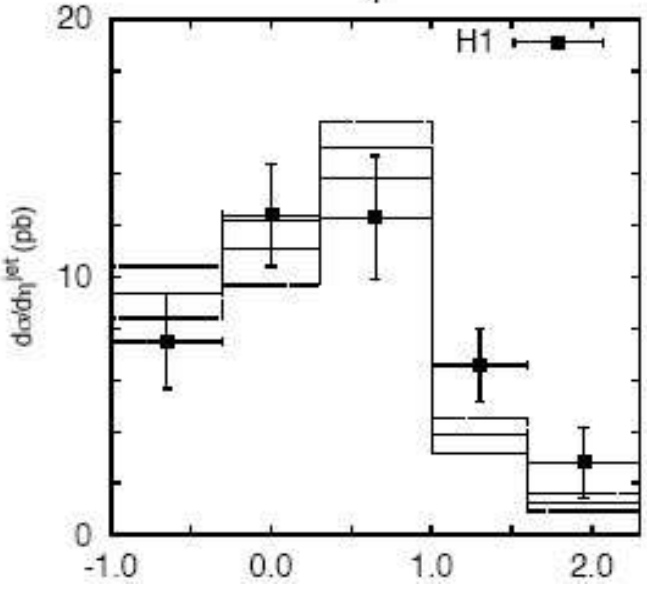
CTEQ5L PDF used

Prompt photon and jet compared with kt fact. approch (A. Lipatov, N. Zotov)









NLO pQCD calculation
Cyclops, (D. Graudenz)