Kensei Umemori
University of Tokyo, Japan

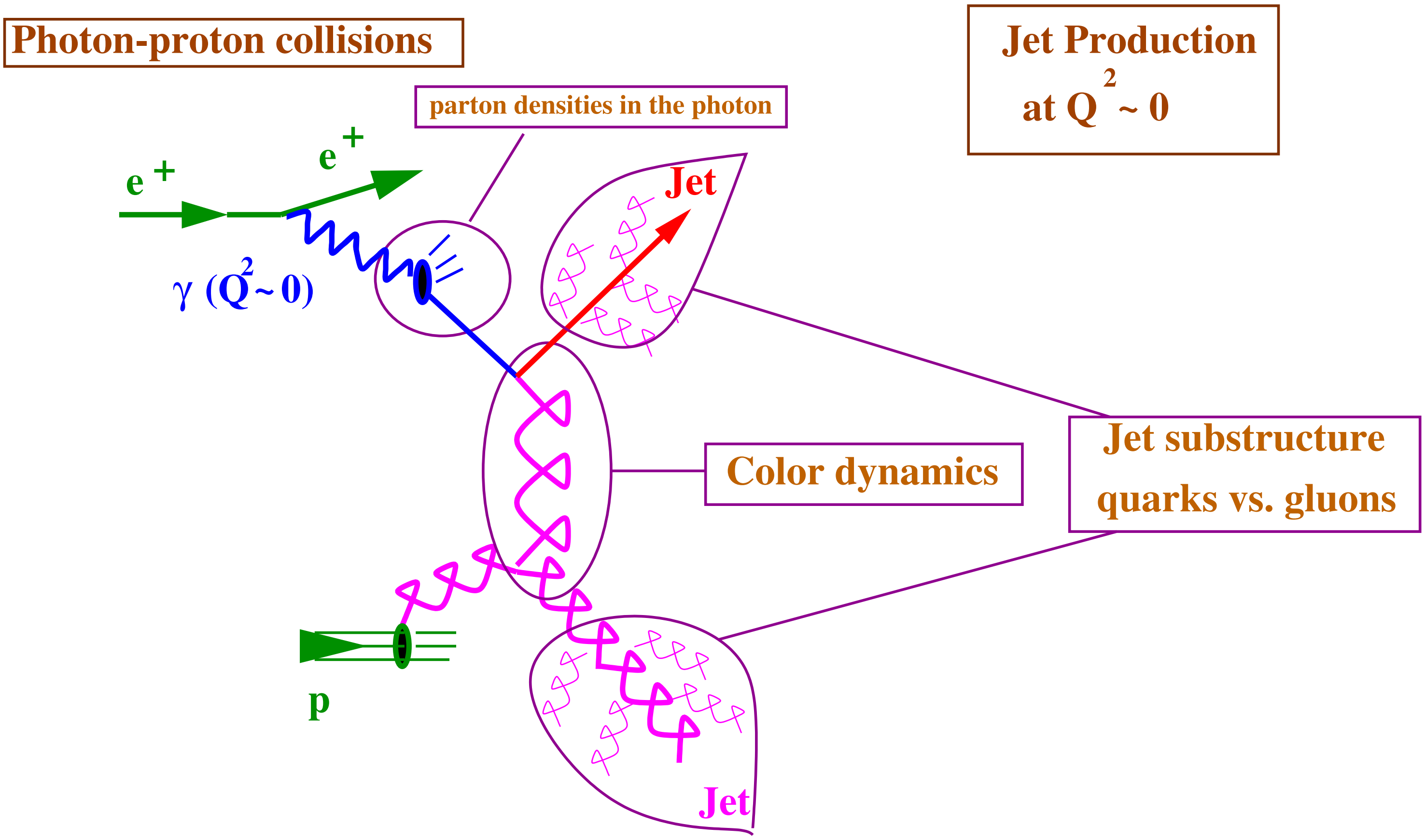
Photoproduction of Jets and Prompt Photons

from

ZEUS Collaboration

DIS99
19 - 23 April 1999
DESY Zeuthen

Jet production



Jet production is a rich source of QCD study!

Parton densities in the photon, color dynamics

- Inclusive jet cross section $\frac{d\sigma}{dE_T}$
- High mass dijet cross sections $\frac{d\sigma}{dM^{JJ}}$ $\frac{d\sigma}{d|\cos\theta^*|}$
- Prompt photon cross sections $\frac{d\sigma}{d\eta^\gamma}$ $\frac{d\sigma}{dE_T^\gamma}$

Jet substructure

- Jet shapes
- Subjet multiplicities

Inclusive jet cross section

Previous paper Eur.Phys.J.C4(1998)591-606

2.6pb^{-1}, 14 $< E_T <$ 25 GeV,
cone algorithm was applied

Kinematic region

ZEUS 95-97 data(41.3pb^{-1})

17 $< E_T^{jet} <$ 74 GeV, -0.75 $< \eta^{jet} <$ 2.5

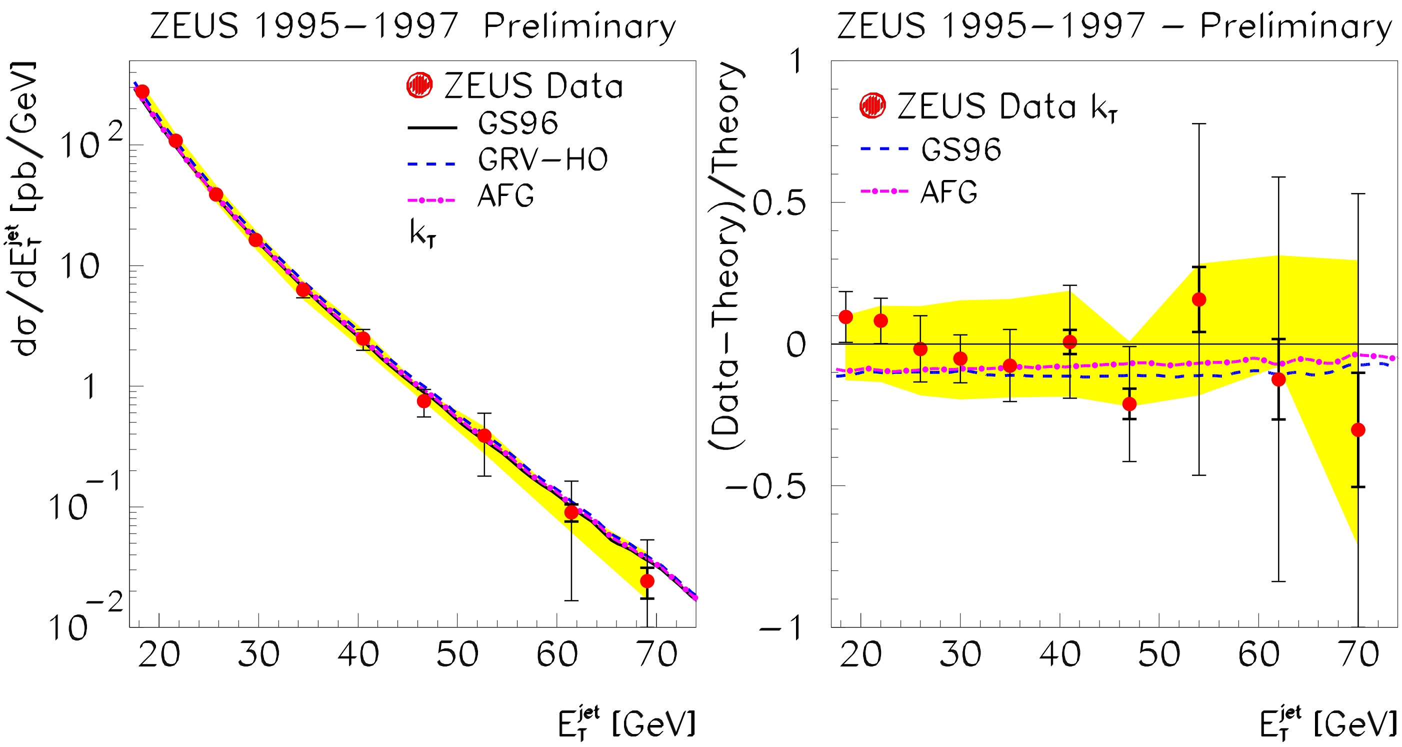
by using k_T cluster algorithm
(inclusive mode)

134 $< W <$ 277 GeV

Q^2 $\leq$ 4 GeV^2

- Higher Et jet
  $\rightarrow$ reduce the uncertainty due to the underlying events and hadronization effect
- k_T cluster algorithm
  $\rightarrow$ no merging/splitting ambiguity
  $\rightarrow$ same algorithm can be applied for both the theory and the experiment

Inclusive jet $\frac{d\sigma}{dE_T^{jet}}$



NLO QCD calculations by Harris & Owens and Klasen & Kramer

- **The NLO calculations give a reasonable description of the measured differential cross section in magnitude and shape.**

High-mass dijet cross sections

The dijet mass(M^{JJ}) distribution

The angular($\cos\theta^*$) distribution in the dijet center-of-mass system

Kinematic region

ZEUS 95-97 data(41.3pb^{-1})

At least two jets of

$E_T^{jet} > 14$ GeV, -0.75 $< \eta^{jet} <$ 2.5

by using k_T cluster algorithm

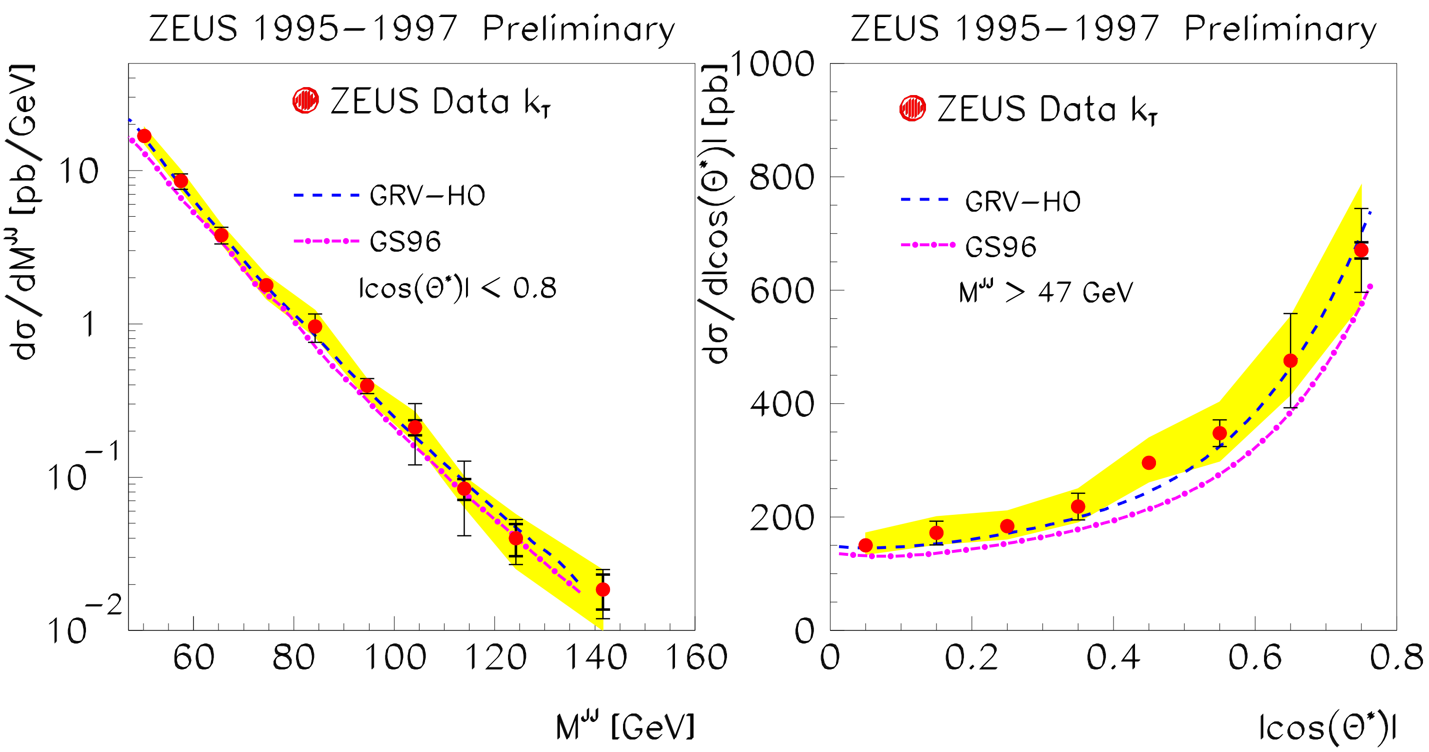
$M^{JJ} > 47$ GeV

$0 \leq |\cos\theta^*| < 0.8$

$134 < W < 277$ GeV

$Q^2 \leq 4$ GeV^2

High-mass dijet $\frac{d\sigma}{dM^{JJ}}$ and $\frac{d\sigma}{d|\cos\theta^*|}$



NLO QCD calculation: Klasen and Kramer

- The NLO calculations reasonably agree in the shape with the measured $\frac{d\sigma}{d|\cos\theta^*|}$ and $\frac{d\sigma}{dM^{JJ}}$. No significant deviations are observed.

- The predictions based on GRV-HO are closer in magnitude to the measured cross sections.

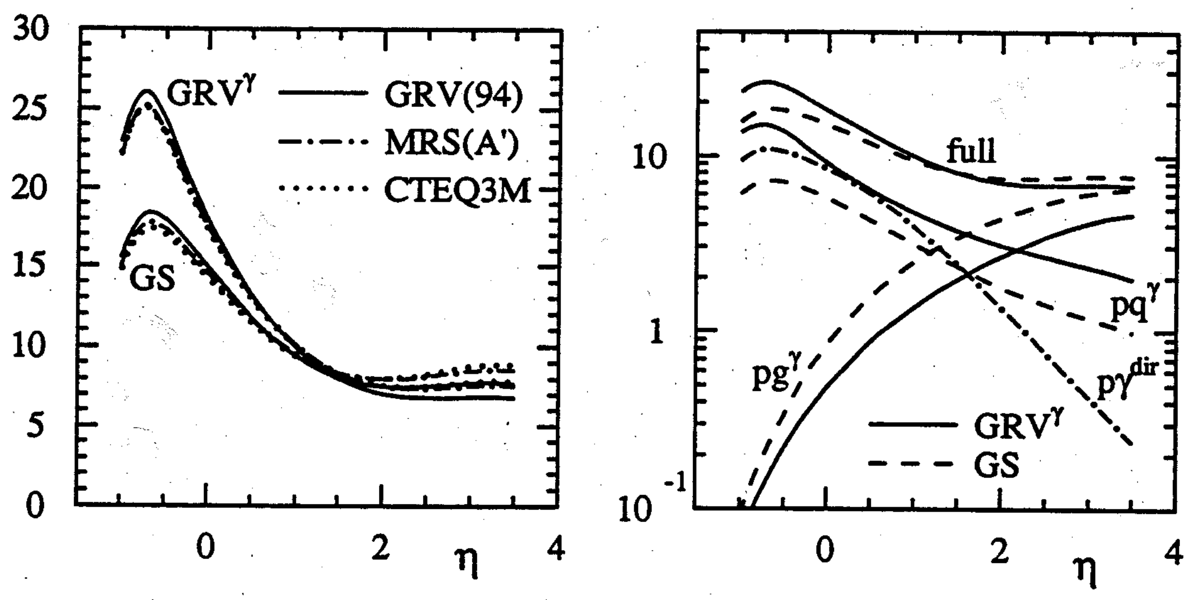
Prompt photon cross sections

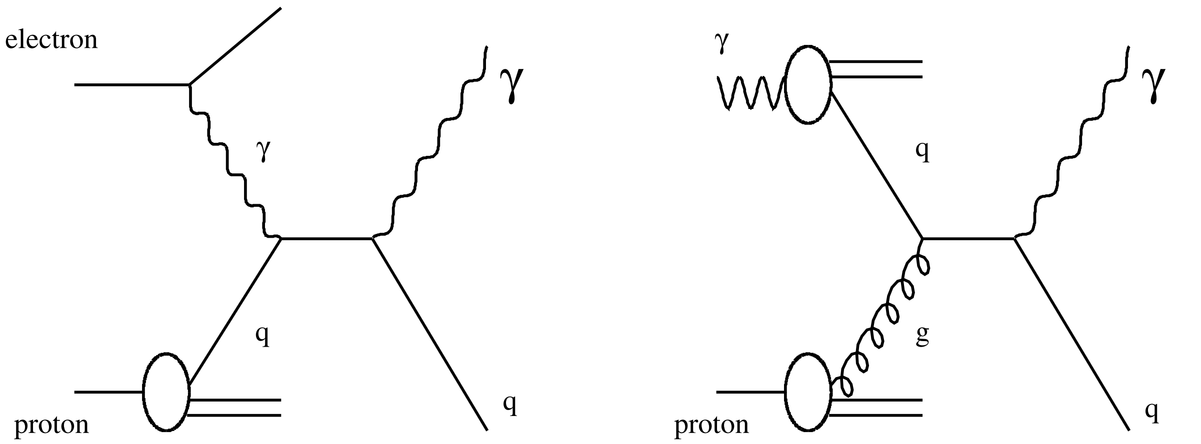
- parton densities in photon

  (sensitive to quark densities)

NLO QCD prediction

by L.Gordon and W.Vogelsang





Direct process Resolved process

Hadronization effect is much suppressed!

Previous paper

Phys.Lett.B413(1997)201-216

6.4pb^{-1}, prompt photon+jet events

Kinematic region

ZEUS 96-97 data(37pb^{-1})

Inclusive prompt photon

$5 < E_T^\gamma < 10(15)$ GeV for $\frac{d\sigma}{d\eta^\gamma}$ ($\frac{d\sigma}{dE_T^\gamma}$)

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

$\Sigma E_T < 0.1 E_T^\gamma$ (Isolation requirement)

$120 < W <$ 270 GeV

$Q^2 < 1$ GeV^2

Prompt photon + jet

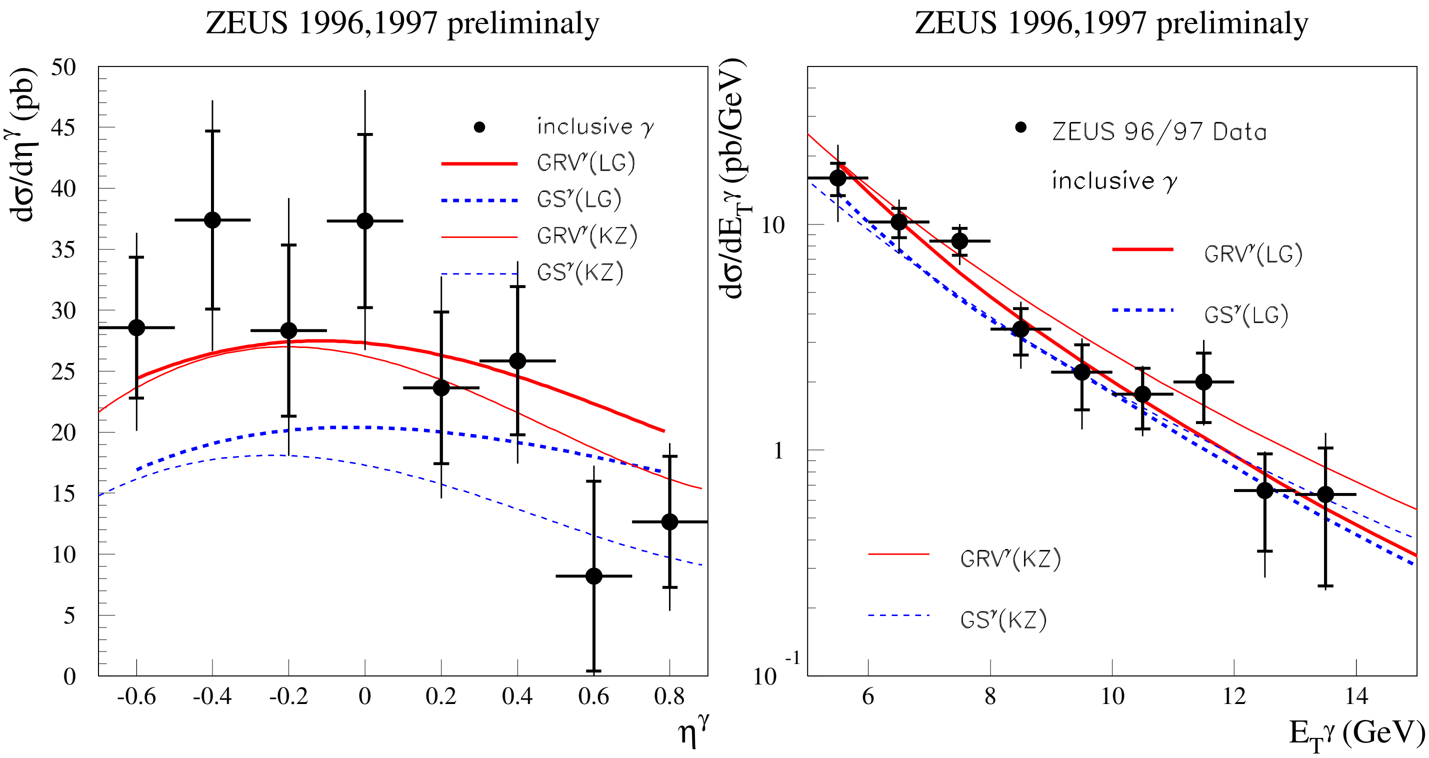
All above requirements

&

$E_T^{jet} > 5$ GeV and $-1.5 < \eta^{jet} <$ 1.8

- First measurement of $\frac{d\sigma}{d\eta^\gamma}$ $\frac{d\sigma}{dE_T^\gamma}$ at HERA

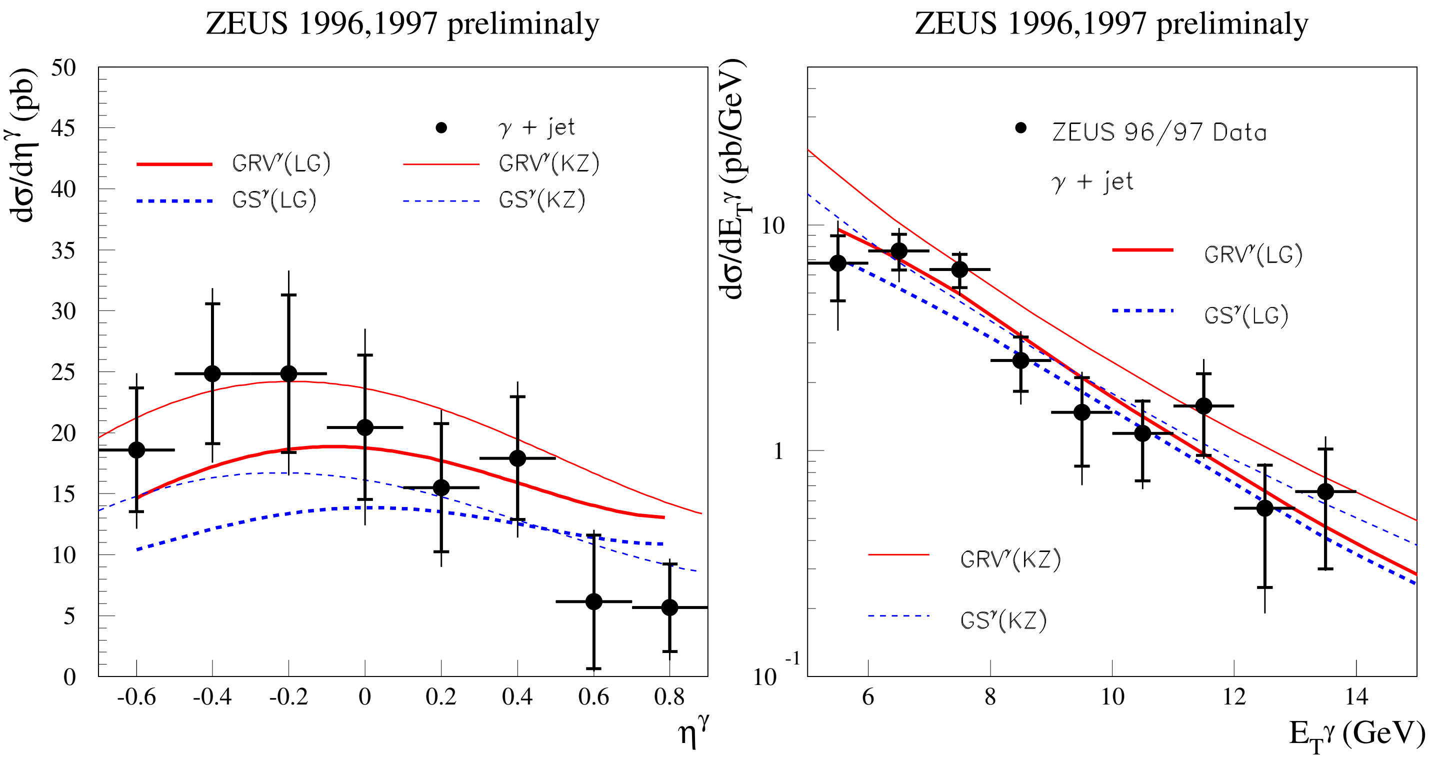
Inclusive prompt photon $\frac{d\sigma}{d\eta^\gamma}$ and $\frac{d\sigma}{dE_T^\gamma}$



QCD prediction LG: L.Gordon
KZ: Krawczyk and Zembrzuski

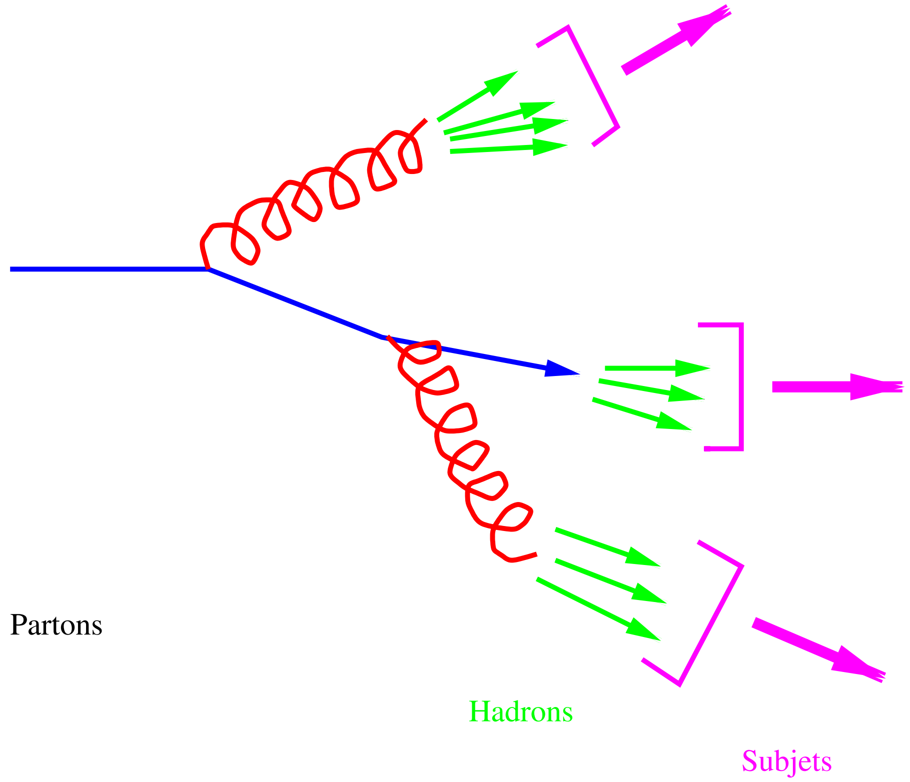
- Measured cross sections are generally described by NLO QCD calculations
- Away from the most forward direction, GRV gives better description of data than GS

Prompt photon + jet $\frac{d\sigma}{d\eta^\gamma}$ and $\frac{d\sigma}{dE_T^\gamma}$



- Measured cross sections are generally described by NLO QCD calculations

Jet internal structure



Study the transition between a primary parton to hadrons

jet shapes

Inclusive Et flow of hadrons in a jet

subjet multiplicities

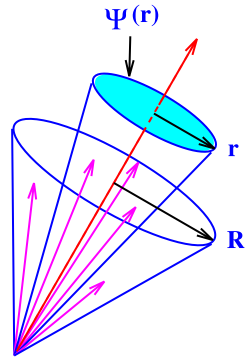
Multiplicity of the local objects in a jet

Both observables are sensitive to the difference of the quark and gluon jets

Jet shapes

- **Integrated jet shape ($\psi(r)$)**

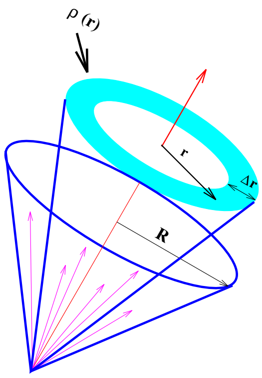
$$\boxed{\psi(r) = \frac{1}{N_{jets}} \sum_{jets} \frac{E_T(0,r)}{E_T(0,1)}}$$



average fraction of the jet's transverse energy inside an inner cone $r < R$ around the jet axis.

- **Differential jet shape ($\rho(r)$)**

$$\boxed{\rho(r) = \frac{1}{N_{jets}\Delta r} \sum_{jets} \frac{E_T(r - \frac{\Delta r}{2}, r + \frac{\Delta r}{2})}{E_T(0,1)}}$$



average fraction of the jet transverse energy which lies in the ring with radius r around the jet axis.

Jet shapes

Previous paper Eur.Phys.J.C2(1998)61-75
2.65pb^{-1}, $E_T > 14$ GeV,
cone algorithm was applied

Kinematic region

ZEUS 95 data(6.3 pb^{-1})
$E_T^{jet} > 17$ GeV, $-1 < \eta^{jet} < 2$
by using k_T cluster algorithm
$134 < W < 277$ GeV
$Q^2 \leq 1$ GeV^2

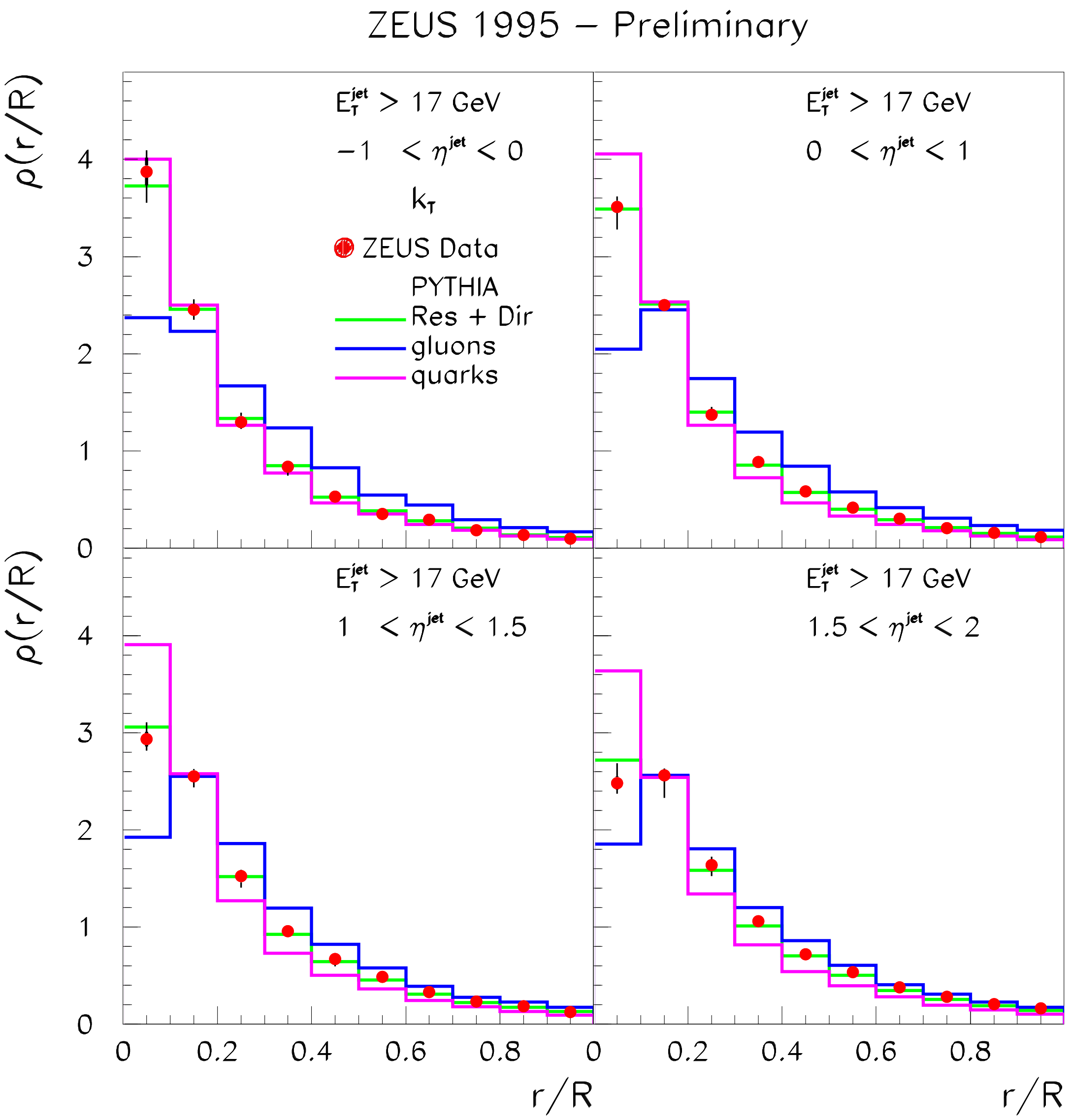
Measured jet shapes have been corrected to the hadron level
$\rightarrow$ compared with PYTHIA predictions
NLO calculations for k_T cluster algorithm are not yet available

Higher Et jet
$\rightarrow$ jet shapes are less sensitive to the hadronization effect.

QCD prediction

Gluon jets are broader than quark jets

Differential jet shapes: η^{jet} dependence

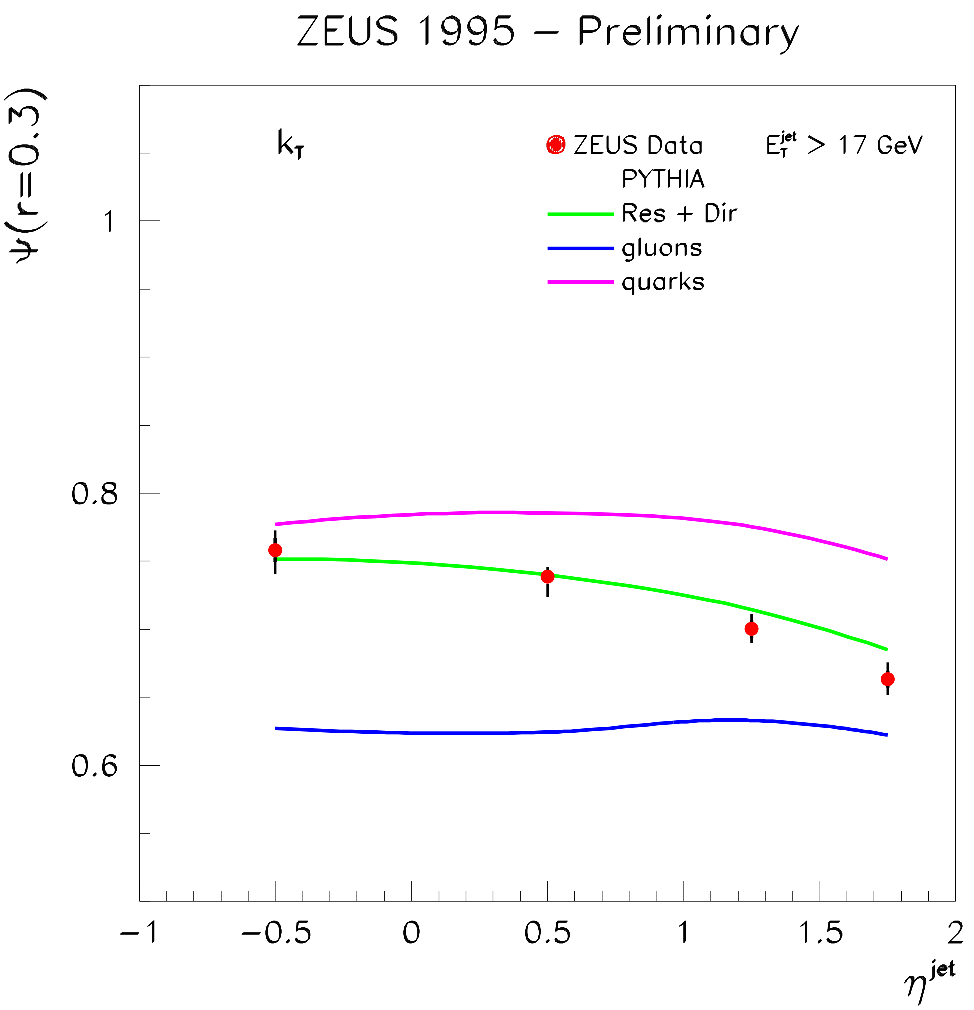


- Jets become broader as η^{jet} increases.
- PYTHIA gives good description of the data.
- The measured jets are

$\rightarrow$ quark-like for $-1 < \eta^{jet} < 0$

$\rightarrow$ more gluon-like for $1.5 < \eta^{jet} < 2$.

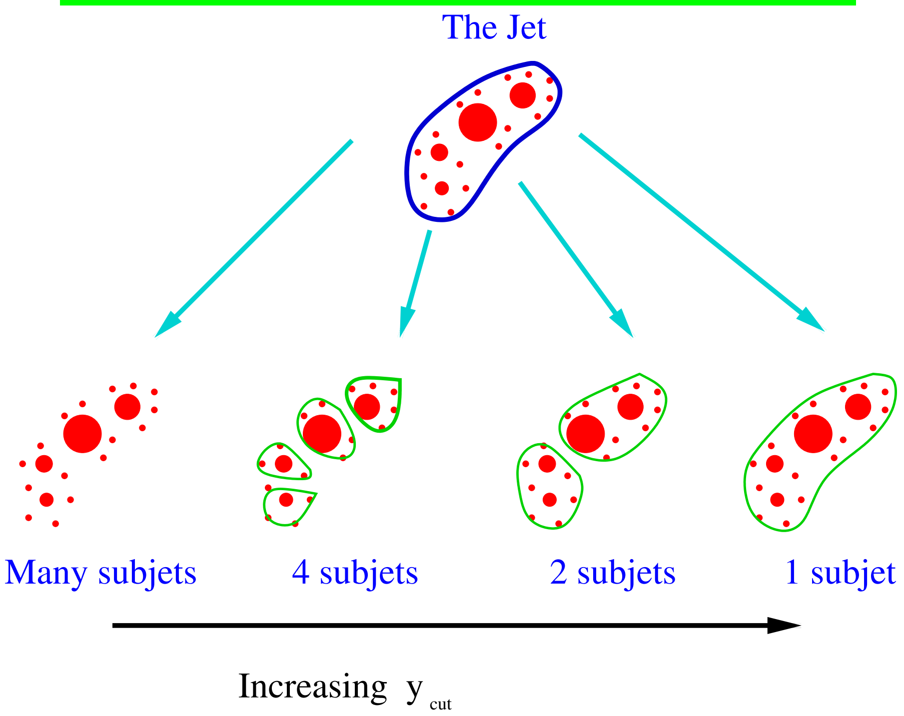
Integrated jet shapes: η^{jet} dependence at fixed r



- The measured jet shape $\psi(r = 0.3)$ decreases with η^{jet}: the jets become broader as η^{jet} increases.

$\rightarrow$ consistent with an increasing fraction of gluon jets as η^{jet} increases.

Subjet multiplicities



Subjet finding procedure

(1) Jet finding

running k_T-cluster algorithm at inclusive mode

(2) Subjet finding

re-running k_T-cluster algorithm for the objects inside the jet.

when all the closeness

$$d_{ij}=\min(E_T^i, E_T^j)^2 \times (\Delta\eta_{ij}^2 + \Delta\phi_{ij}^2)$$

are above

$$d_{cut} = y_{cut} \times (E_T^{jet})^2$$

the clustering is stopped.

Then remaining objects = subjets

$\Rightarrow$ Counting subjet multiplicities, $\langle n_{subjet} \rangle$, as a function of y_{cut}

Subjet multiplicities

- Theoretical advantages

  resummed calculation is possible

  (not yet available)

  small hadronization corrections

  (for not too low y_{cut})

Kinematic region

ZEUS 95 data(6.3 pb^{-1})

$E_T^{jet} > 15$ GeV, $-1 < \eta^{jet} < 2$

by using k_T cluster algorithm

$134 < W < 277$ GeV

$Q^2 \leq 1$ GeV^2

$\langle n_{subjet} \rangle$ have been measured at

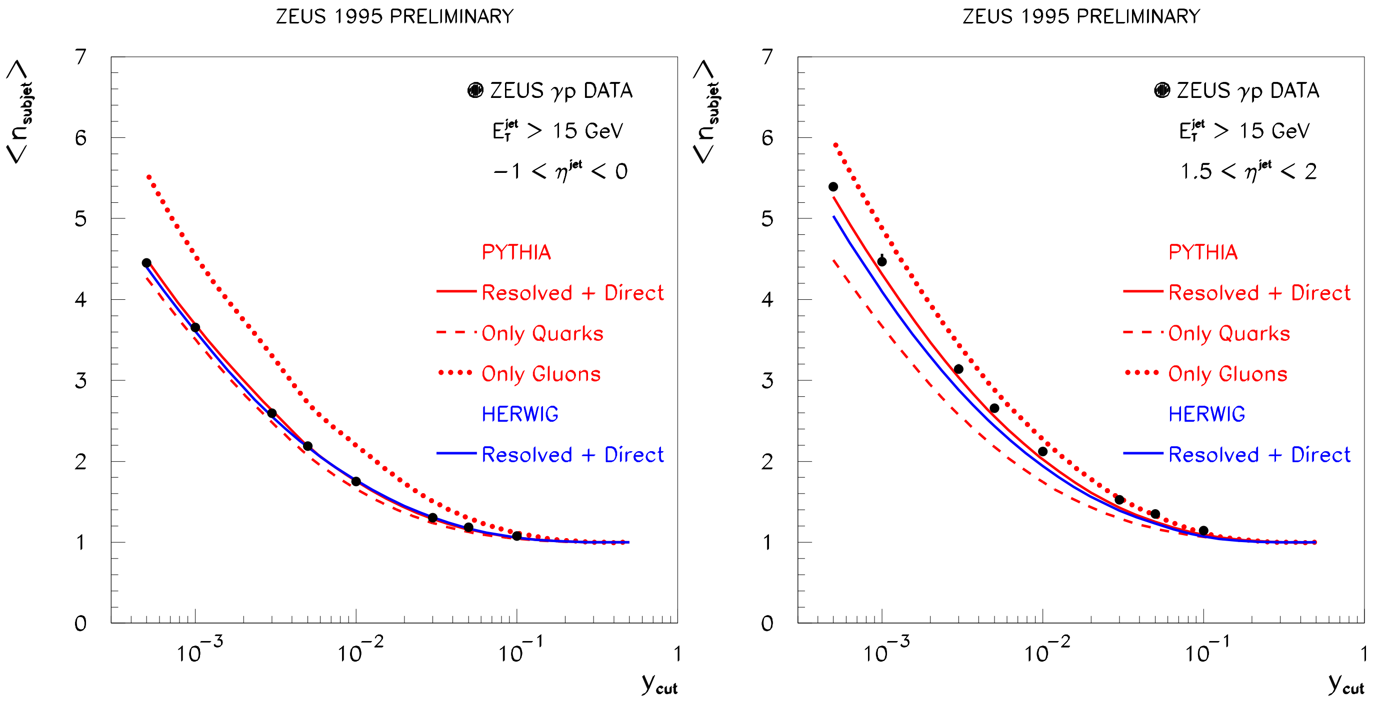
$$5 \times 10^{-4} < y_{cut} < 10^{-1}$$

Measured $\langle n_{subjet} \rangle$ have been corrected to the hadron level

QCD prediction

Gluon jets have larger subjet multiplicities

$\langle n_{subjet} \rangle$: y_{cut} dependence

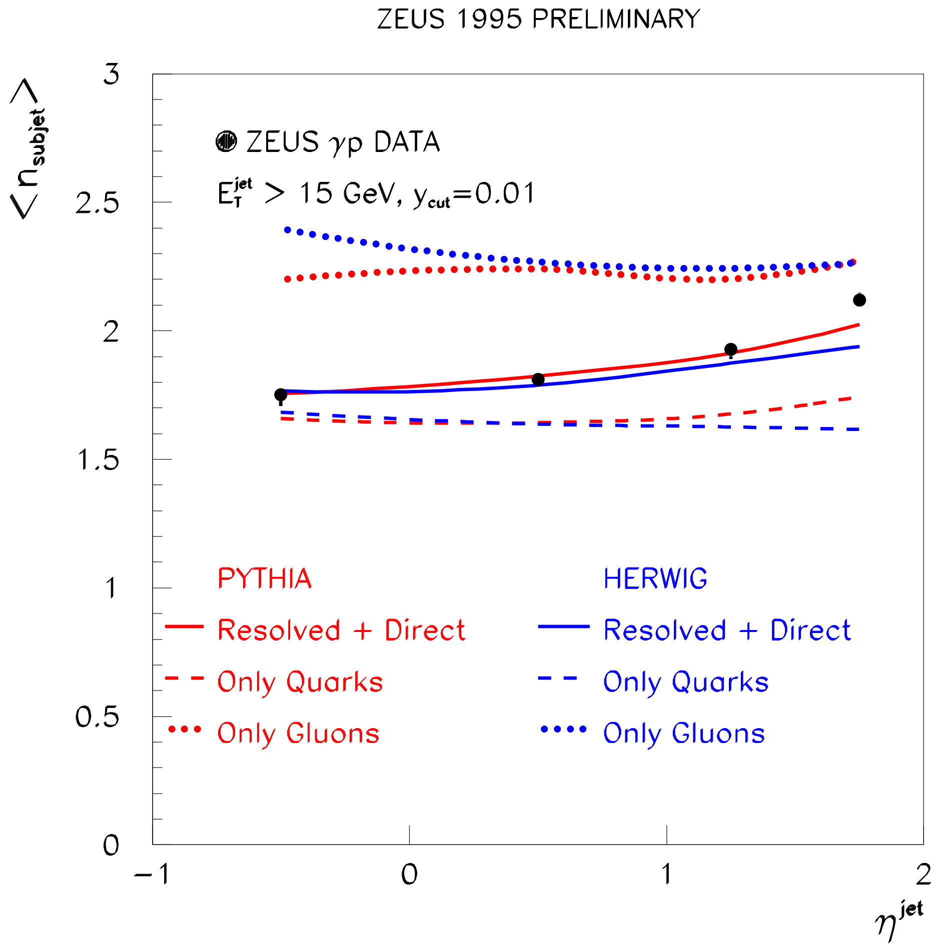


- $\langle n_{subjet} \rangle$ is reasonably described by PYTHIA and HERWIG
- The measured jets are

$\rightarrow$ quark-like for $-1 < \eta^{jet} < 0$

$\rightarrow$ more gluon-like for $1.5 < \eta^{jet} < 2$.

$\langle n_{subjet} \rangle$: η^{jet} dependence at $y_{cut} = 10^{-2}$



- **The measured subjet multiplicities increase with η^{jet}**

→ consistent with an increasing fraction of gluon jets as η^{jet} increases.

Summary

Inclusive jet, high-mass dijet and prompt photon cross sections have been measured.
Measured cross sections are reasonably described by NLO QCD calculations.
The predictions based on GRV give better description of the data than those based on GS.

Jet shapes and subjet multiplicities have been measured by using k_T cluster algorithm.
The jet shapes become broader and subjet multiplicities become larger as η^{jet} increases.
Those behaviour are consistent with an increasing fraction of gluon jets as η^{jet} increases.