Real and virtual photon structure

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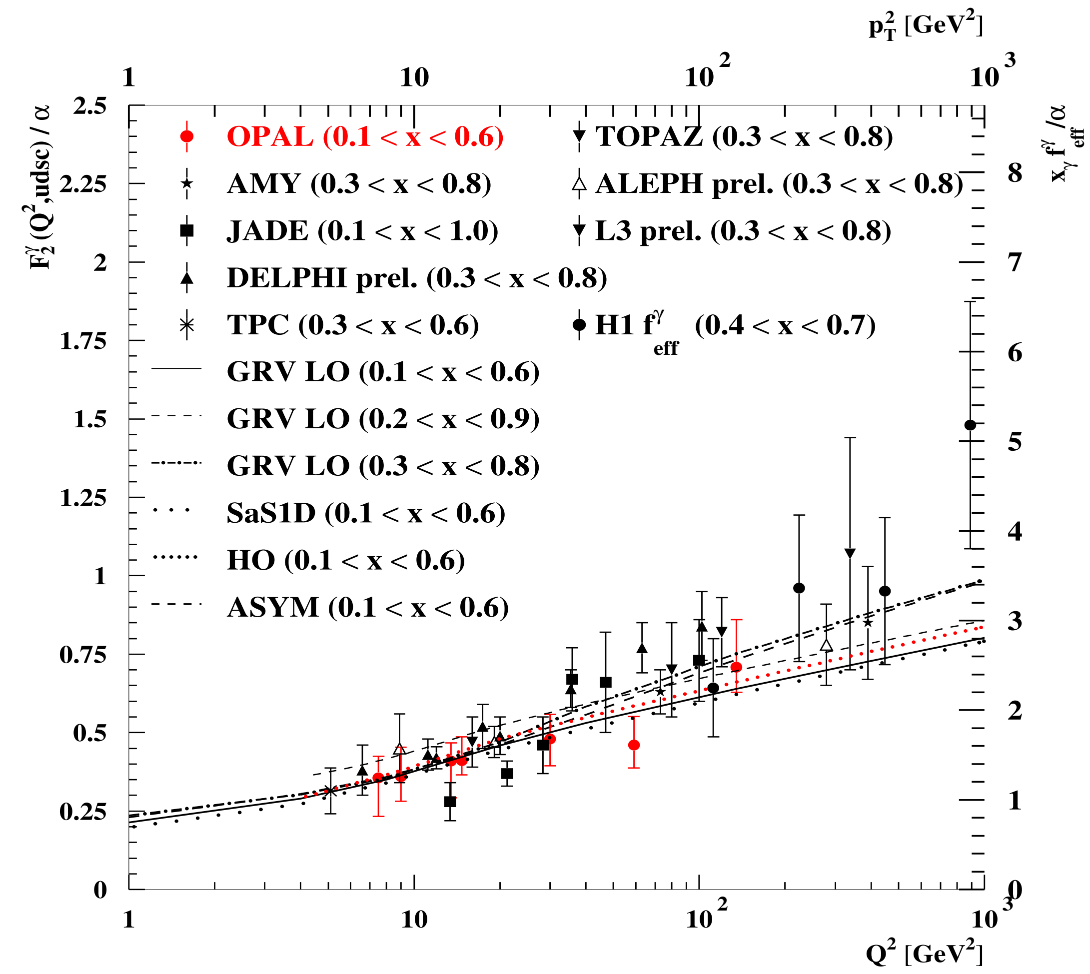
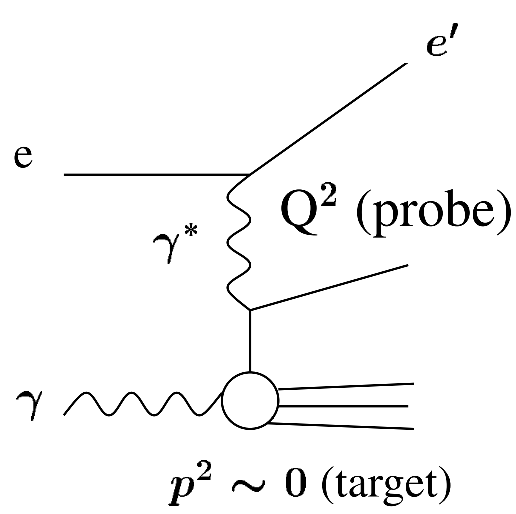
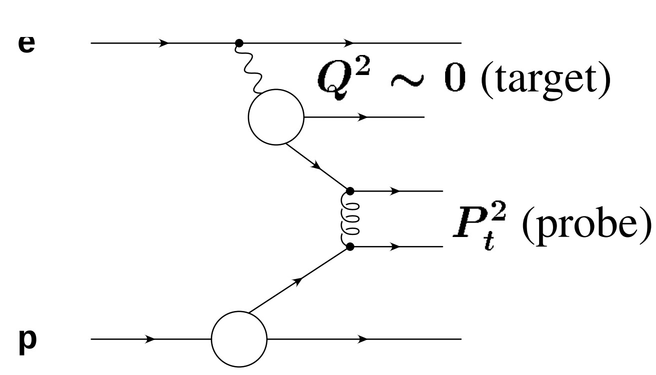
1. High p_t jets in photoproduction
2. The structure of the quasi–real photon
3. Importance of photon structure for DIS
4. Triple differential cross sections and effective parton density of the virtual photon

DIS 2000
Liverpool, April 25 – 30, 2000



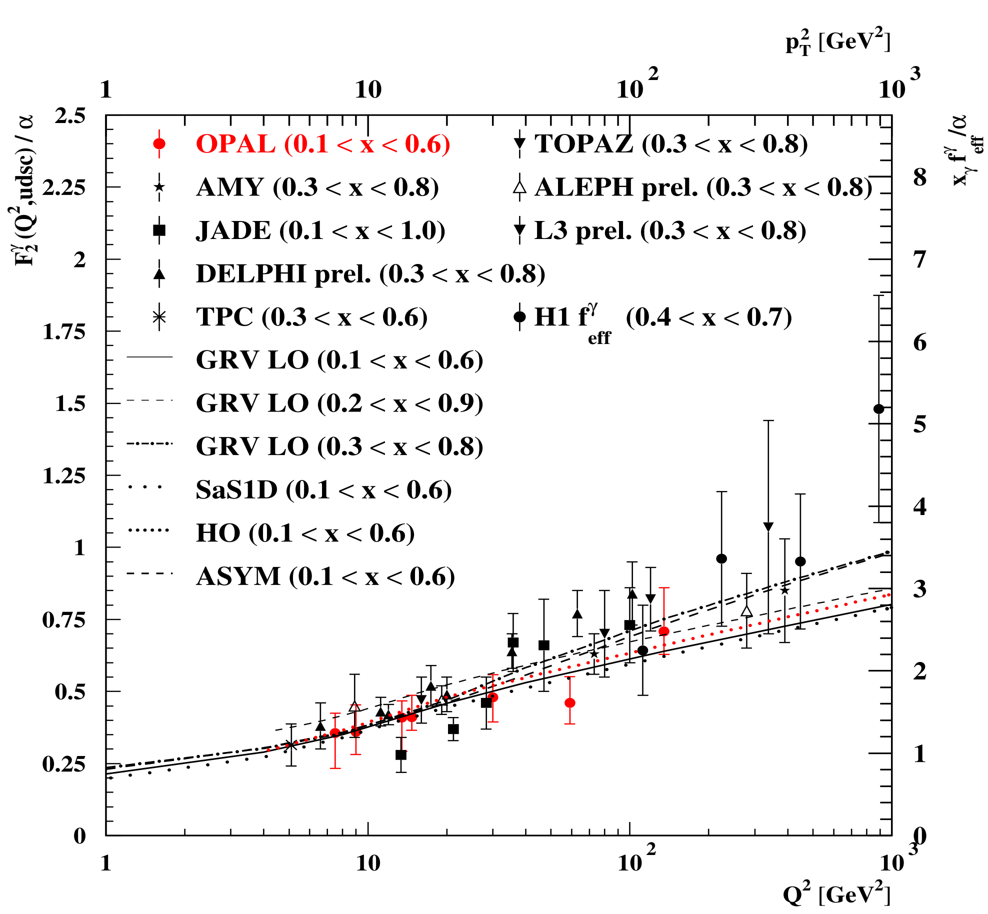
How to probe the photon structure?





- coupling to quark
- hard to access high P^2 region due to the low luminosity

- coupling to gluon and quark



Photon structure at HERA

e^+ (27.6 GeV) $\longrightarrow$ $\longleftarrow$ p (820 GeV)

- Q^2 - virtuality of γ^* and y - inelasticity
- p_t, η - transverse momentum and pseudorapidity of jets
- x_γ - fraction of γ^*'s momentum in hard subprocess

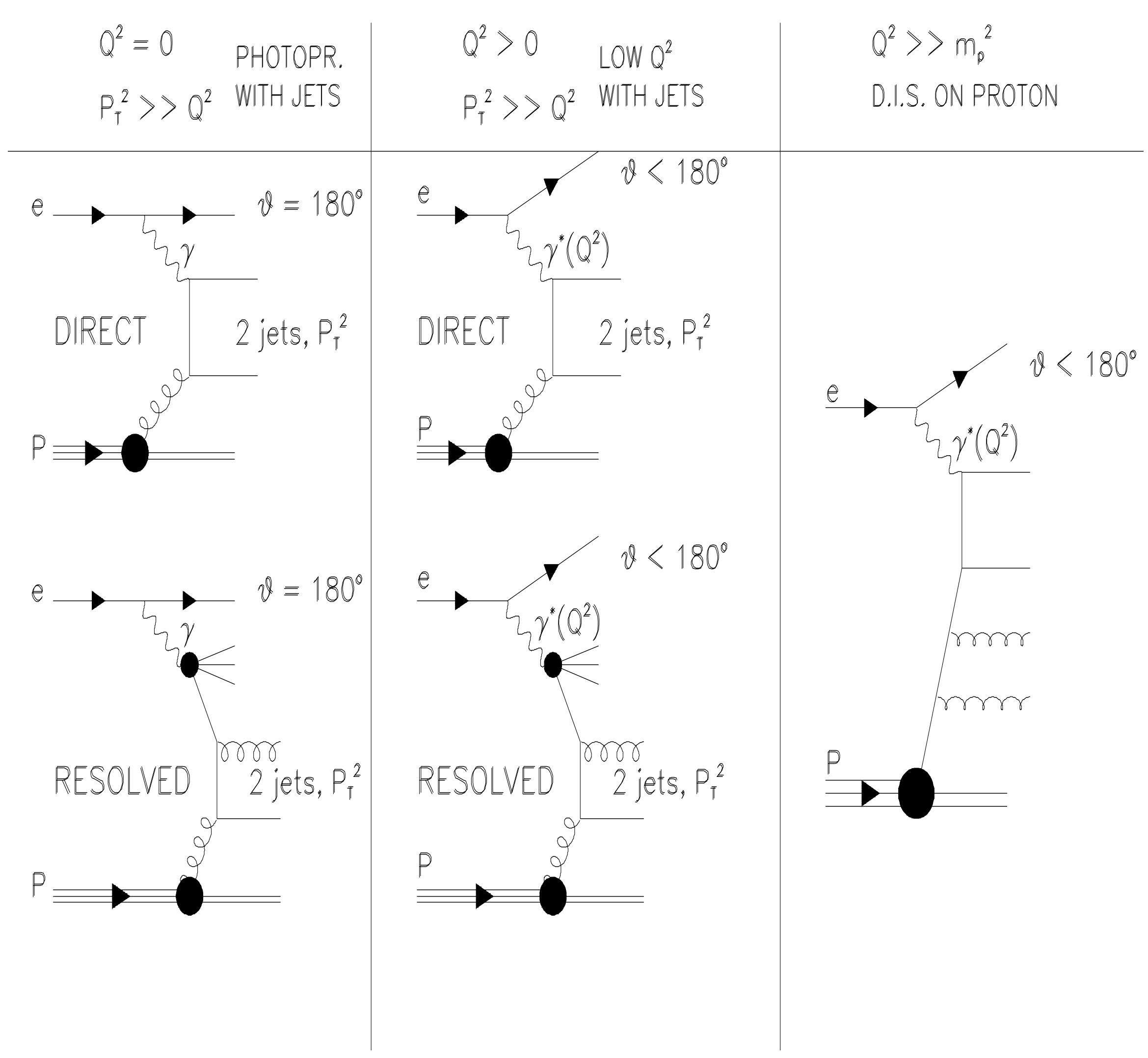
$$x_\gamma = \frac{\sum_{jets} p_{t,i} \mathrm{e}^{-\eta_i}}{2yE_e} \quad \text{or} \quad \frac{\sum_{jets}(E_i - p_{z,i})}{\sum_{had}(E_h - p_{z,h})}$$

Experimental and kinematic constraints

$$\boxed{p_{tmax}^2 = \frac{1}{4} s_{ep} y x_\gamma x_p}$$

high p_t of jets	**low p_t of jets**
large x_γ	small x_γ
direct contribution	resolved contribution
quarks in γ	gluons in γ
QCD, LO, NLO	LO, soft underlying event

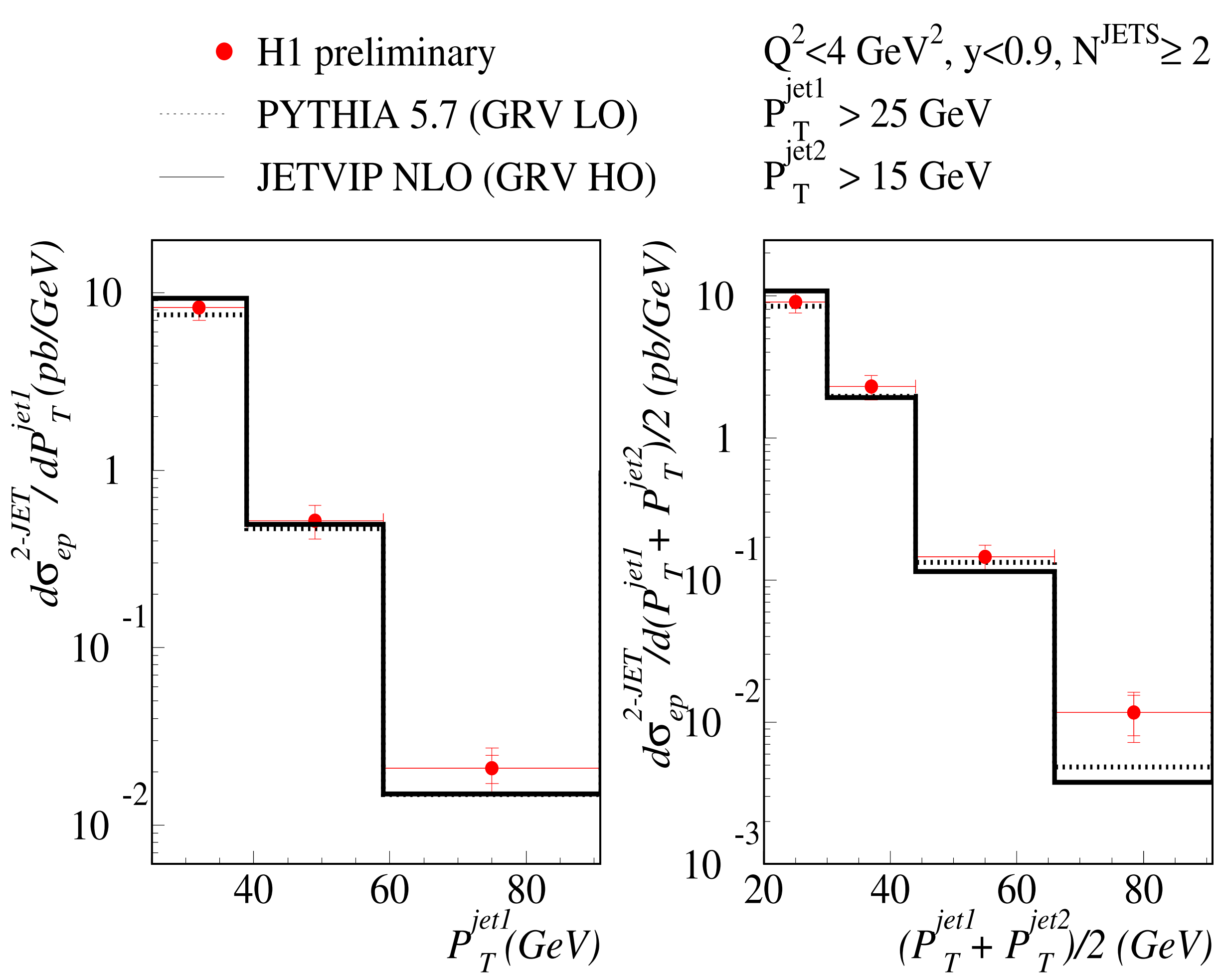
Different regimes and scales at HERA



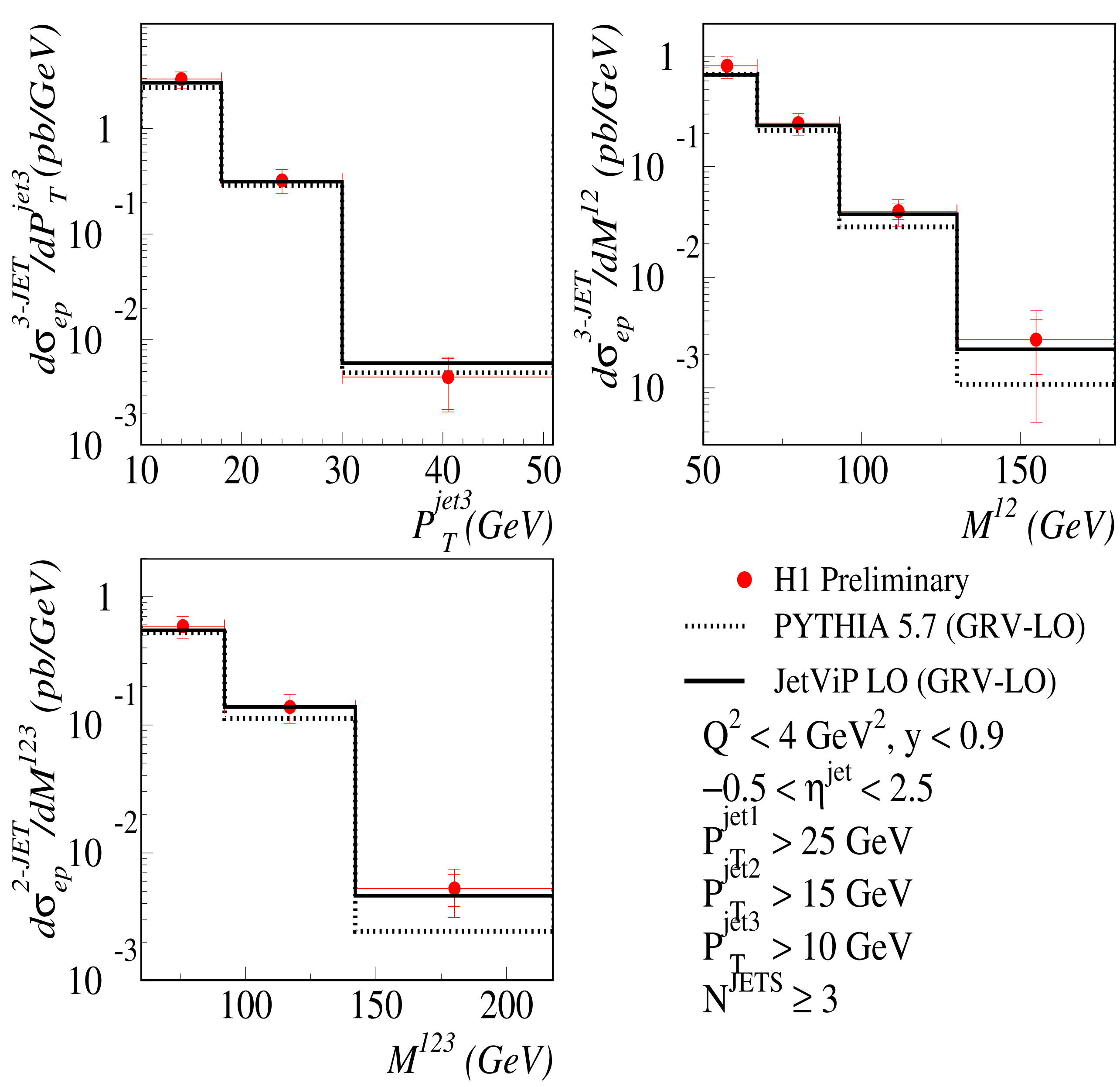
- $p_t^2 >> Q^2$ photoproduction, structure of quasi–real and virtual γ, effective pdf's (mainly anomalous component relevant, VDM dies out with Q^2)
- $p_t^2 << Q^2$ only direct contribution, standard DIS
- $p_t^2 \sim Q^2$ described by contributions of both dir+res if scale $Q^2 + p_t^2$ (or $4p_t^2$)

The high p_t jet production in photoproduction

- jets found in LAB system with inclusive k_T algorithm
- $p_t^{jet1} > p_t^{jet2} > p_t^{jet3} > ..$
- $-0.5 < \eta_{jet} <2.5$
- comparison with PYTHIA 5.7 LO (Born Level $(O(\alpha_s))$ component)
- NEW, comparison with calculations of $\rightarrow$ JETVIP. JETVIP includes 2–loop α_s, direct + resolved, 5 flavours, GRV–HO structure functions for proton and photon



- hadronization correction not important
- JETVIP NLO calculation describes 2–jet cross section and 3–jet cross sections is described by JETVIP LO



The structure function of quasi–real photon

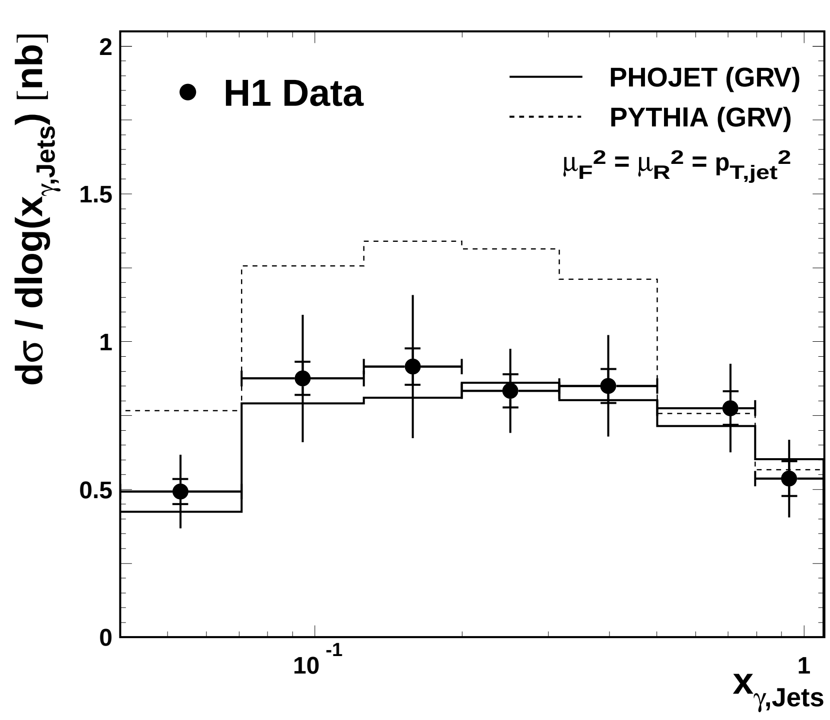
Goal of the analysis: Access to low x_γ where gluons dominate.

$p^2_{tmax} = \frac{1}{4} s_{ep} y x_\gamma x_p$ low x_γ region $\rightarrow$ low p_t jets or high y events

DESY–00–035, submitted to Phys. Lett B

Cone algorithm with $R = 0.7$, two jets in the forward lab region

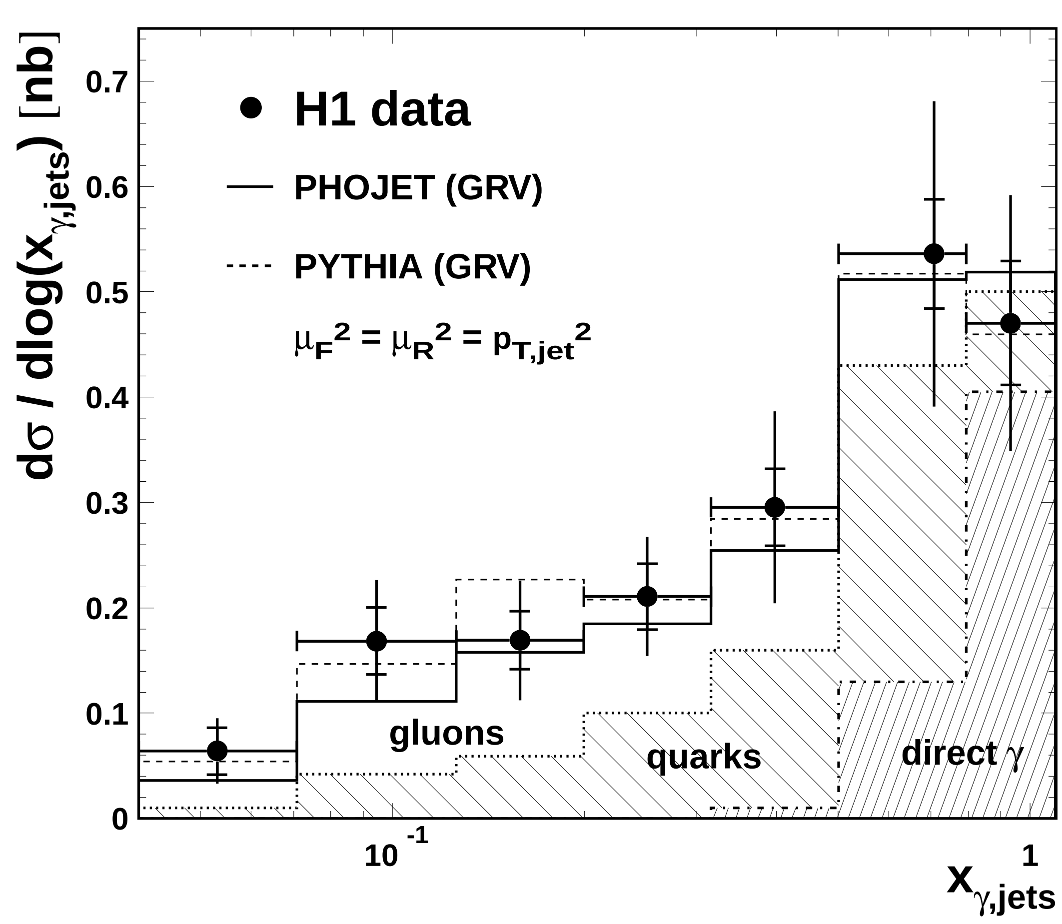
Cuts:
$p_T > 4\ GeV$, $M_{1,2} > 12$ GeV, $-0.5 < \eta_{jet} < 2.5$,
$|\eta_{jet1} - \eta_{jet2}| < 1$, $0.5 < y_e < 0.7$



- different treatment of the soft underlying event in models
- different results for PYTHIA and PHOJET

More restricted data sample dominated by hard scattering process:

- jet pedestals subtracted
- $p_t^{jet} > 6$ GeV after pedestal subtraction
- $\eta^{jet} > -0.9 - \ln(x_\gamma)$



- precise measurement down to $x_\gamma = 0.05$
- good agreement with GRV parton density within PHOJET and PYTHIA
- clear sensitivity to gluons in photon

The effective parton density of photon

Single Effective Subprocess Approach:

$$d\sigma \sim \frac{f_{\gamma/e}(y,Q^2)}{y} \sum_{i,j} \frac{f_{i/\gamma}(x_\gamma,Q^2,p_t^2)}{x_\gamma} \frac{f_{j/p}(x_p,p_t^2)}{x_p} |M_{ij}(\cos\theta^*)|^2$$

Now $M_{ij} \to M_{SES}$ and $f_{i/\gamma} \to f^{\gamma}_{eff}$ and $f_{j/p} \to f^{p}_{eff}$.

$f^a_{eff} = \sum_i^{N_f}(q_i^a + \bar{q}_i^a) + \frac{9}{4} g^a$ a = proton or photon

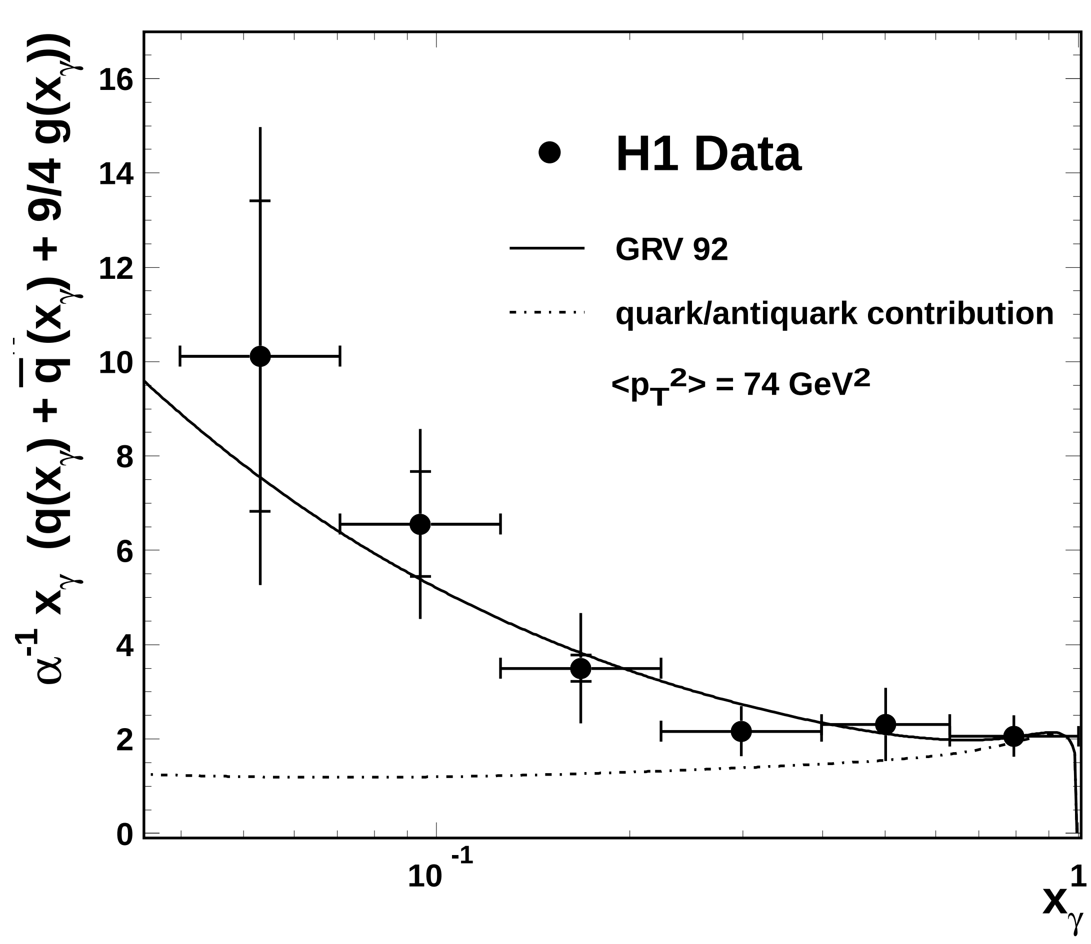
$$d\sigma \sim \frac{f_{\gamma/e}(y,Q^2)}{y} \frac{f^{\gamma}_{eff}(x_\gamma,Q^2,p_t^2)}{x_\gamma} \frac{f^{p}_{eff}(x_p,p_t^2)}{x_p} |M_{SES}(\cos\theta^*)|^2$$

effective parton density function f^{γ}_{eff} is extracted from
the comparison of parton level cross sections
in the data and MC

Single effective parton density

unfolding to the parton level in x_γ

- systematics dominated by uncertainty in hadronic E scale $\sim 30\%$ at low x_γ and MC dependence $\sim 25\%$
- here $< p_t^2 > = 74\ GeV^2$ of partons

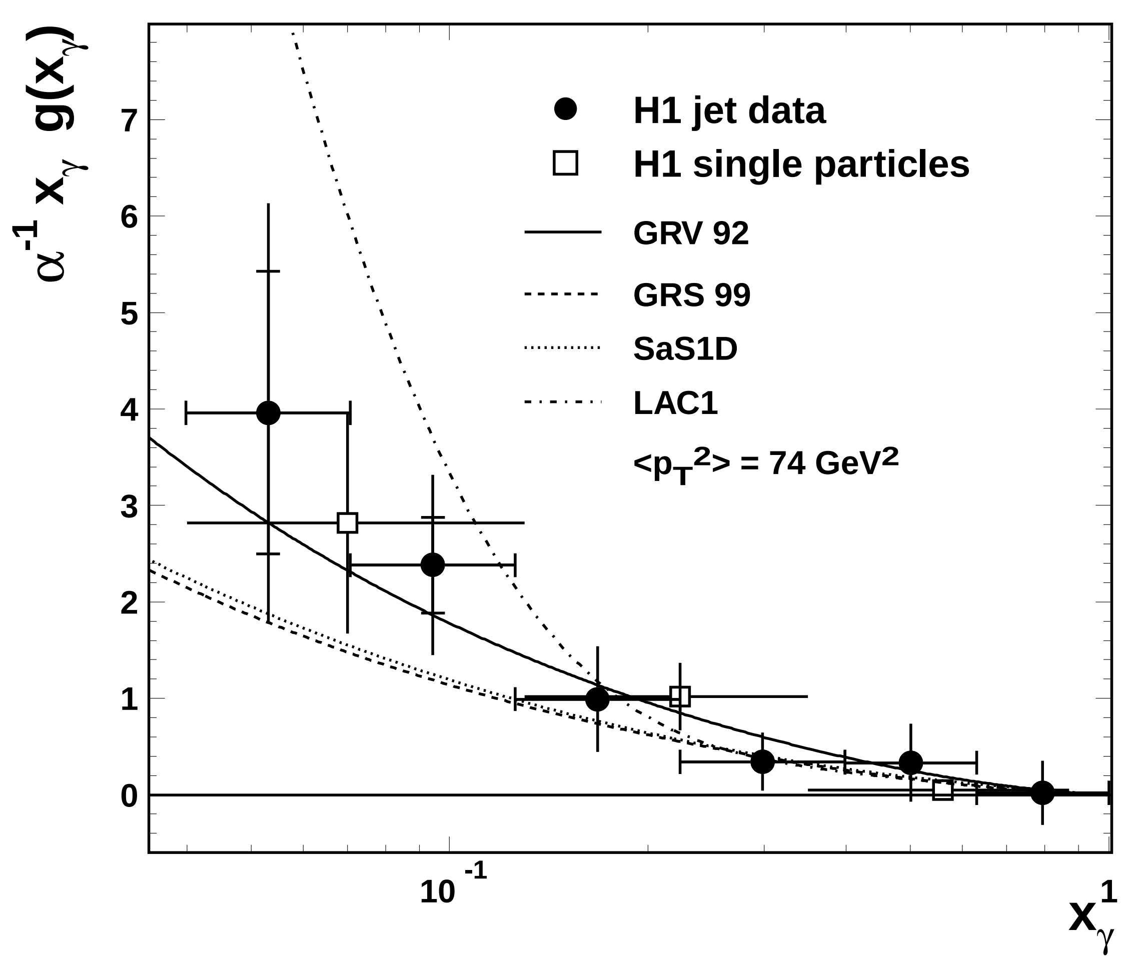


Best measurement of effective parton density so far made.

Gluon distribution of the photon

To obtain the gluon density → the quark density must be subtracted (GRV92 LO parton distributions).

1. H1 single particles, 1994
   Eur. Phys. J.C 10 (1999), 363
2. H1 jet data, 1996, this analysis



- agreement between jet and track analysis important - different systematics
- the rise of gluon density at low x_γ established

Importance of photon structure for DIS

if the relevant scale is p_t^2
$\rightarrow$ three different contributions needed for DIS

DIS =	direct γ's	+ ??	+ resolved γ's
	$p_t^2 << Q^2$	$p_t^2 \sim Q^2$	$p_t^2 >> Q^2$

A.Mueller proposal: forward jets for $Q^2 \sim p_t^2 \longrightarrow$ supressed DGLAP with respect to BFKL

- high p_t particles are correlated with emission of hard partons in QCD
- no jet algorithms needed

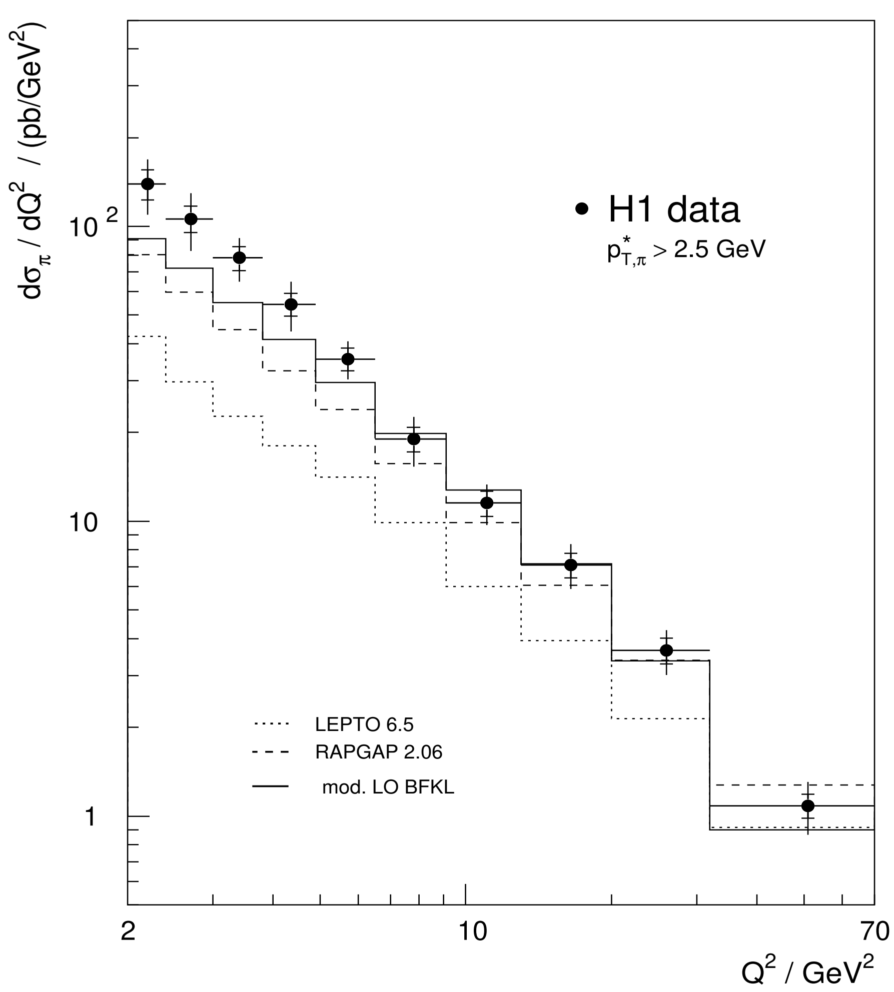
Differential cross section of forward π^0
Phys. Lett. B 462, (1999), 440

π^0 in the forward region:

$p_{T,x}$ >2.5 (3.5) GeV, $5^\circ < \theta_\pi < 25^\circ$, x=$E_\pi/E_{pr}$ >0.01

DIS 0.1< y <0.6, 2< Q^2 < 70 GeV^2

Forward π in DIS with $2 < Q^2 < 70\ GeV^2$



LEPTO, scale Q^2
DGLAP

RAPGAP, scale $Q^2 + p_t^2$
DGLAP + resolved photon

BFKL calculation
LO modif.

no one model able to describe

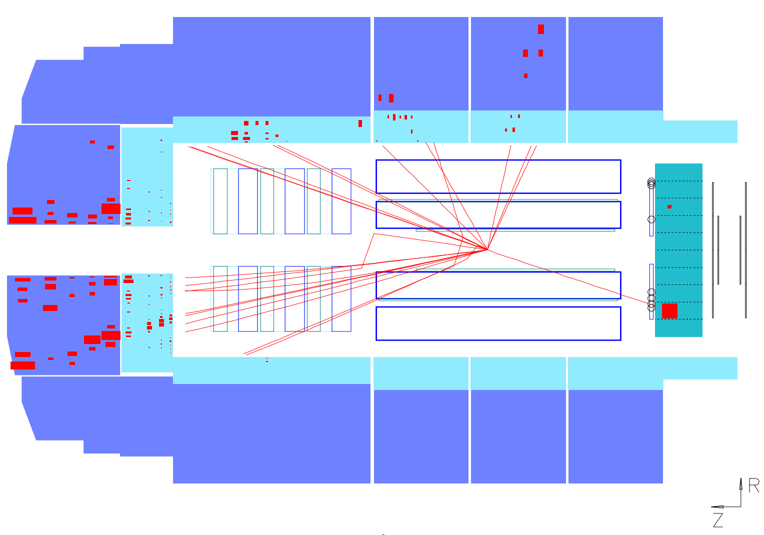
- very difficult intermediate region $p_t^2 \sim Q^2$??
- adding further contributions, double counting???

The studies of photon structure function can help to understand better also DIS region.

Very important is to study the photon structure in the region $p_t^2 > Q^2$ and $p_t^2 \sim Q^2$.

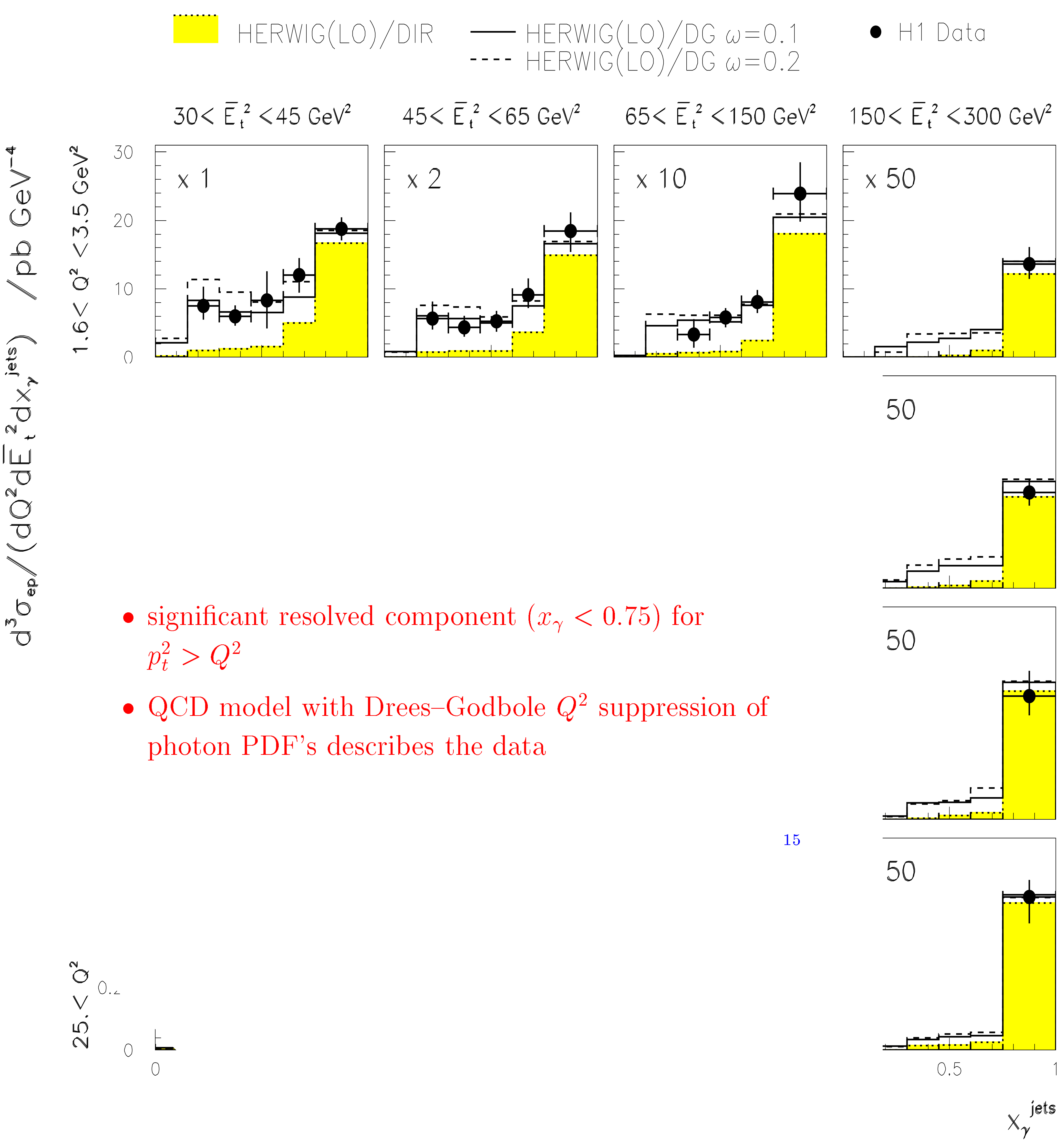
The structure of virtual photon

The region where $p_t^2 > Q^2$ and $p_t^2 \sim Q^2$



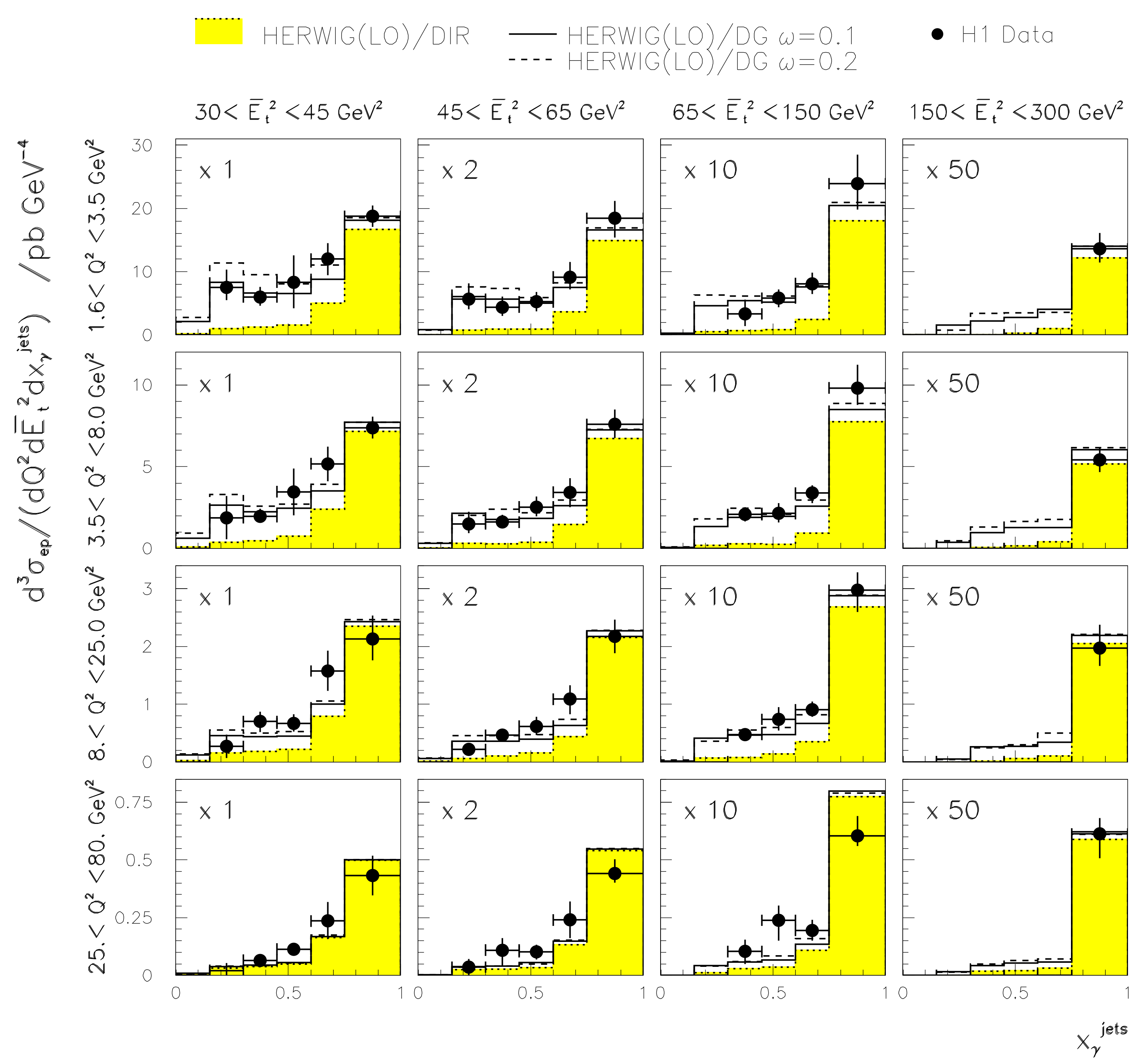
- 1996 DIS data, $\mathcal{L} \sim 6\ pb^{-1}$
- $1.6 < Q^2 < 80 GeV^2$
- $0.1 < y < 0.7$
- Jets found with inclusive K_t algorithm in $(\gamma^* p)$ frame
- ≥ 2 jets
  - ▷ $|\eta^{jet1} - \eta^{jet2}| < 1.0$
  - ▷ $-3.0 < \overline{\eta} < -0.5$
  - ▷ $\frac{|(E_t^1 - E_t^2)|}{(E_t^1 + E_t^2)} < 0.25$
  - ▷ $\overline{E}_t^2 > 30$ GeV^2

The triple differential dijet cross–section



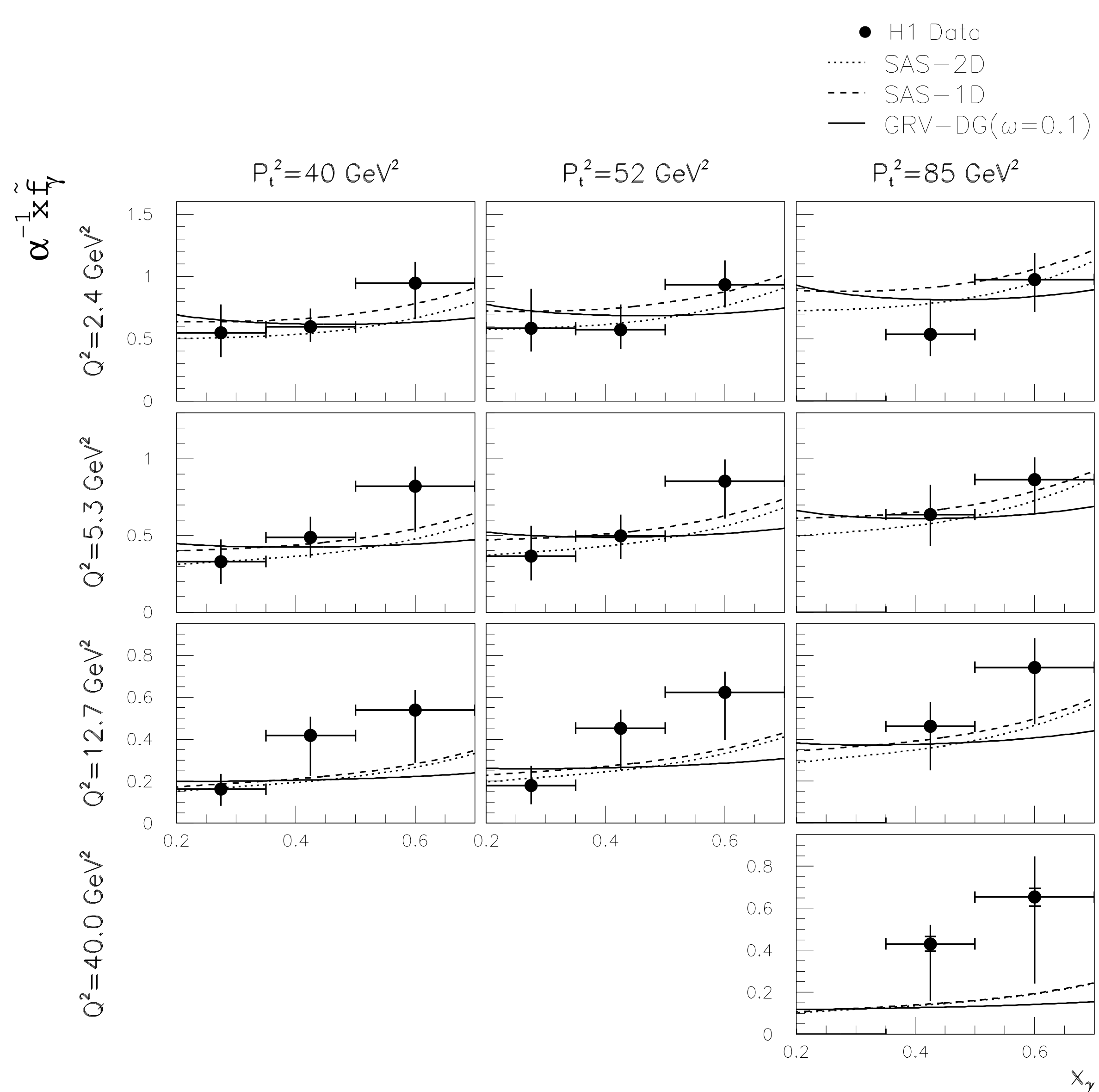
- significant resolved component ($x_\gamma < 0.75$) for $p_t^2 > Q^2$
- QCD model with Drees–Godbole Q^2 suppression of photon PDF's describes the data

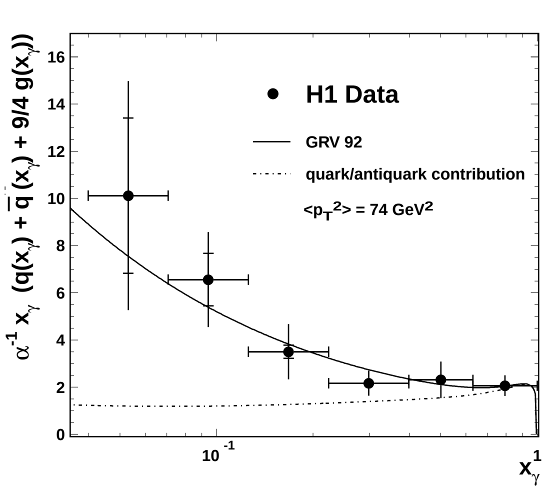
The triple differential dijet cross–section



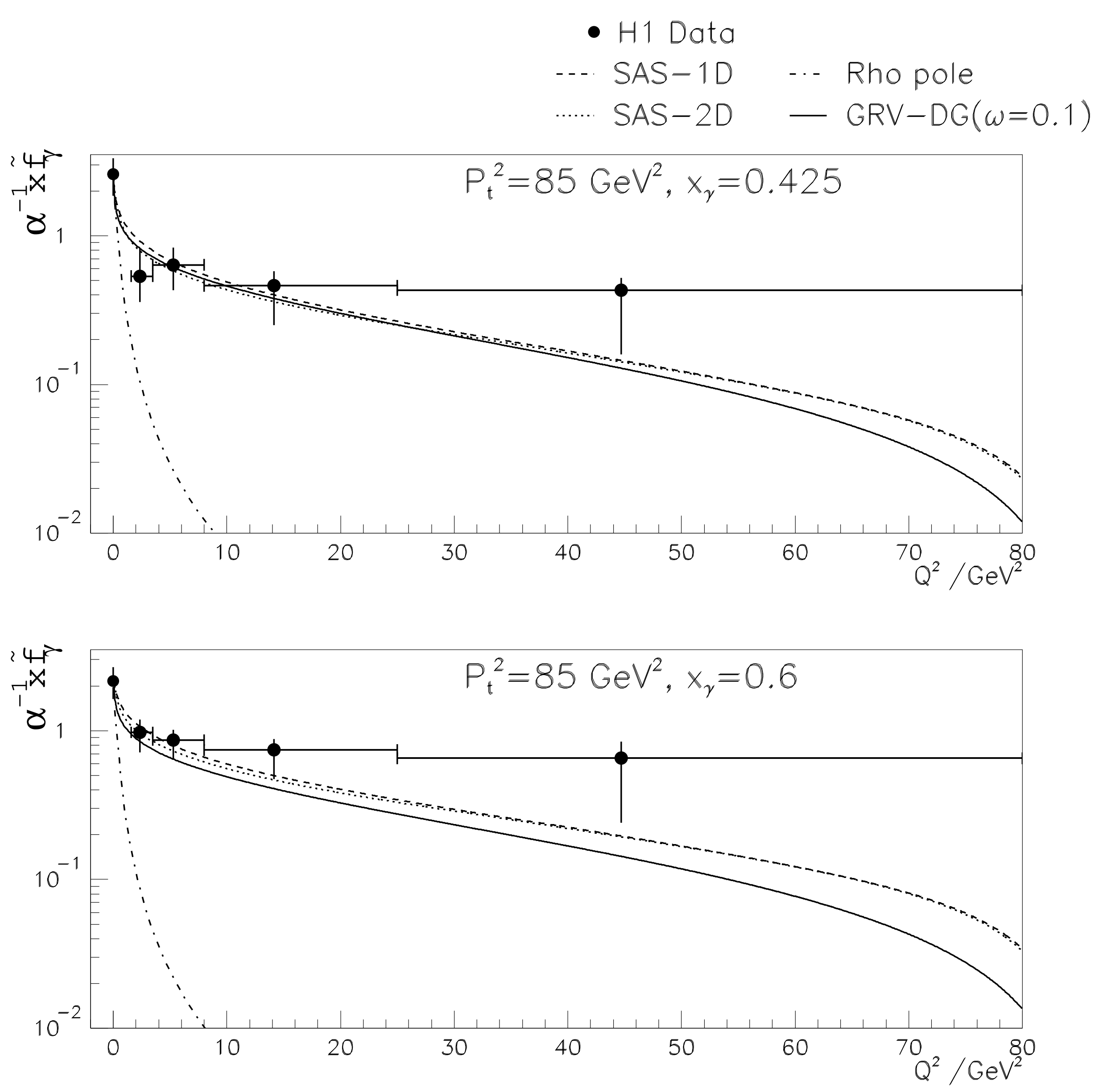
- the relative contribution of resolved component decreases with increasing Q^2

The effective parton density of the virtual photon





- rise with x_γ, within errorrs
- for quasi–real photon and similar p_t^2 range is constant



- simple ρ – pole suppresion model clearly underestimates data
- logarithmic suppresion predicted by the virtual photon models $\rightarrow$ good description below $Q^2 \sim 20\ GeV^2$
- within errors we are not able to distinguish between parametrizations

Conclusions

- At HERA, photon structure is studied in wide kinematic range, using hard processes.
- Photoproduction of 2, (3) high p_t jets described by NLO (LO) calculations of model JETVIP
- The study of the photon structure function $\rightarrow$ better understanding of DIS processes. The region $p_t^2 \sim Q^2$ most problematic.
- The rise of the gluon density in the photon at low x_γ established.
- Significant contribution of resolved processes in di–jet cross section at higher Q^2 (1.6< $Q^2 < 80\ GeV^2$) is observed. Data about the virtual photon structure consistent with the pQCD prediction.