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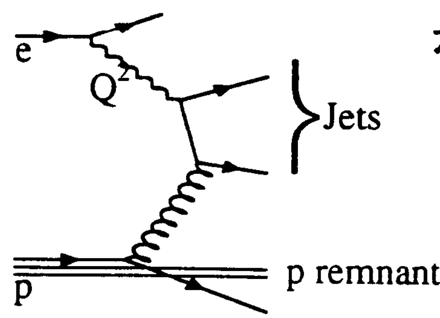
Measurement of the Di-Jet Cross-Section and the Effective Parton Density Function of the Photon at HERA

- Introduction to Photoproduction at HERA
- Di-jet Cross-Section
- Extraction of effective parton density function of photon.
- Conclusions

Introduction

- Photoproduction of high p_t jets is sensitive to photon and proton structure.

DIRECT

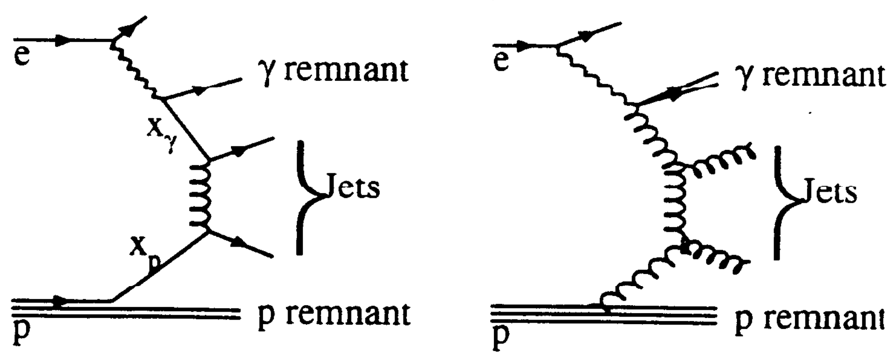


$x_\gamma = 1$

$$x_\gamma^{jets} = \frac{E_T^{j1} e^{-\eta_{j1}} + E_T^{j2} e^{-\eta_{j2}}}{2yE_e}$$

RESOLVED

$x_\gamma < 1$



- Probability of finding quark with energy fraction x_γ in photon predicted by pQCD:

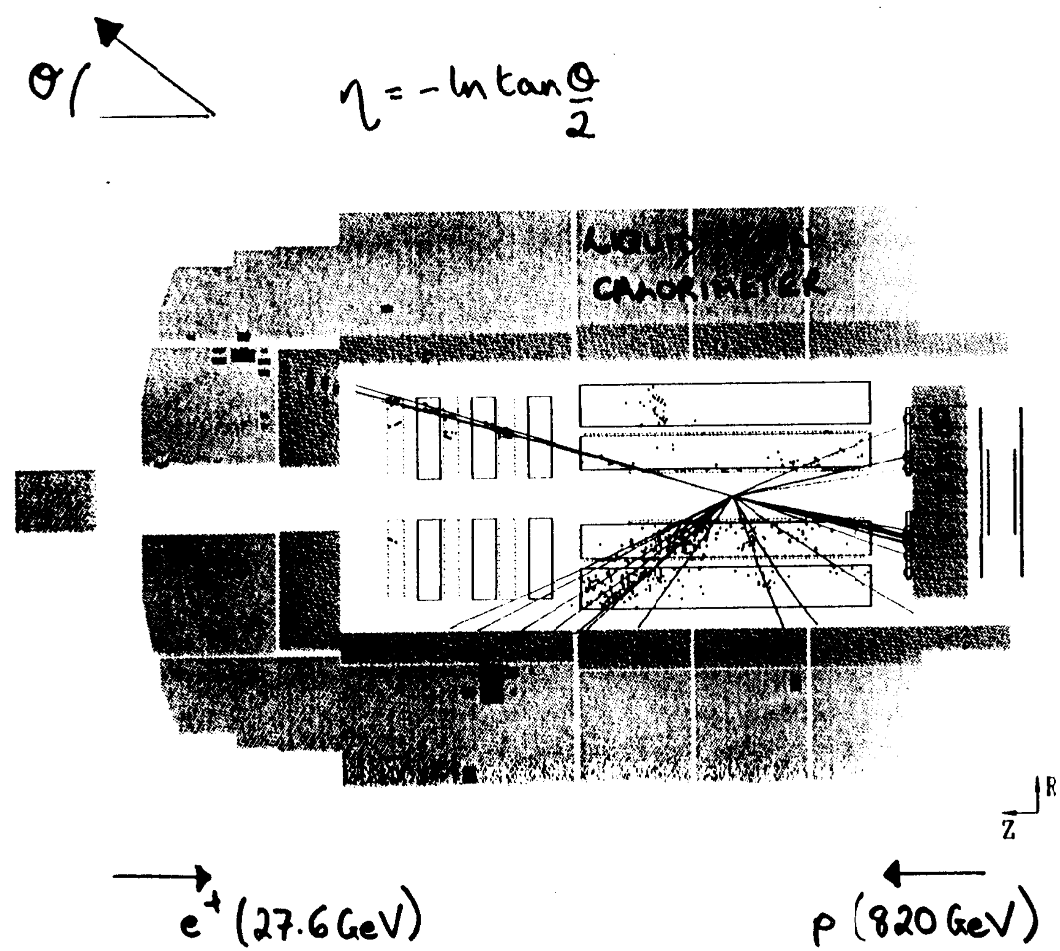
ANOMALOUS COMPONENT OF PHOTON.

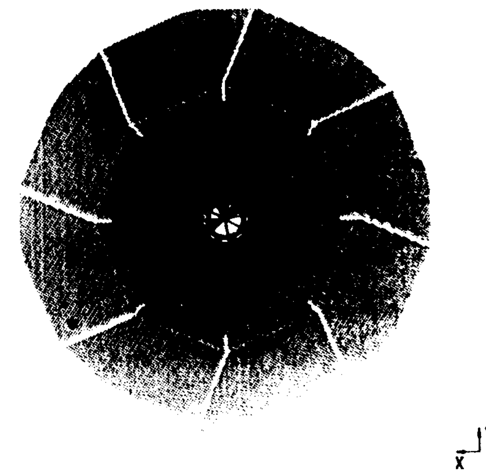
$* \; f_{q/\gamma} \sim \ln \mu_f^2 \; *$

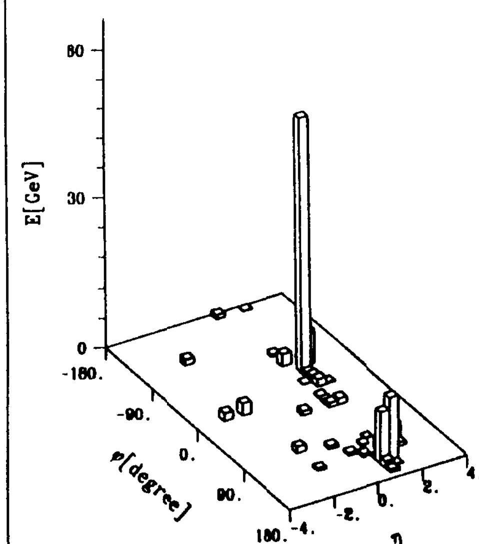
$$f_{q/\gamma} = e_q^2 \frac{\alpha}{\pi} \ln \frac{\mu_f^2}{\Lambda_{QCD}^2} (x_\gamma^2 + (1 - x_\gamma)^2)$$

Run 63286 Event 15437 Class:

2 - jet photoproduction + gamma remnant

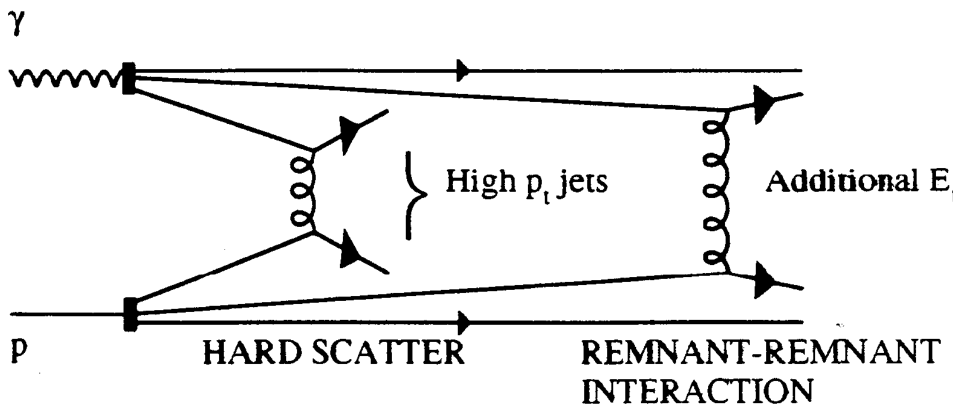




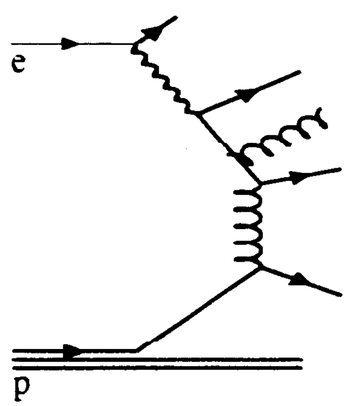


Complications

- **Multiple parton-parton interactions in resolved events**

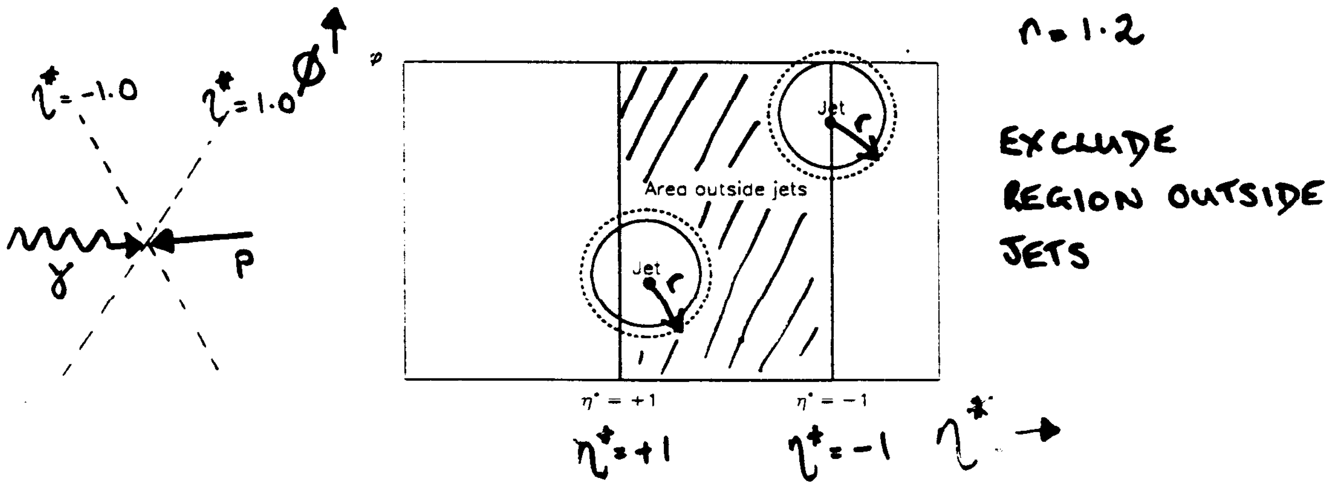


- QCD radiation (parton showers), higher order processes
  Imbalance in p_t between jets, or more than 2 jets.

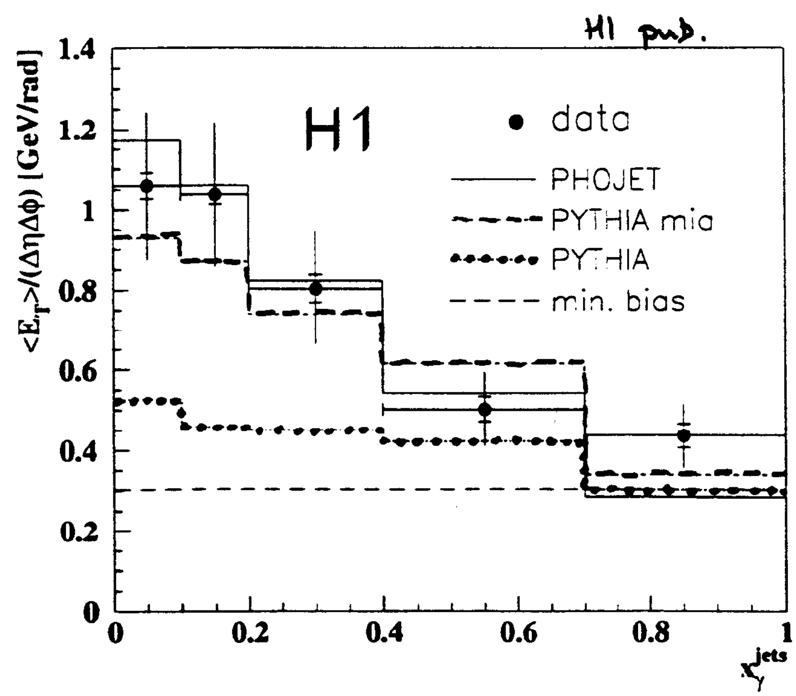


- These effects are modelled in LO Monte Carlo generators, eg PYTHIA.

Evidence for Multiple Interactions

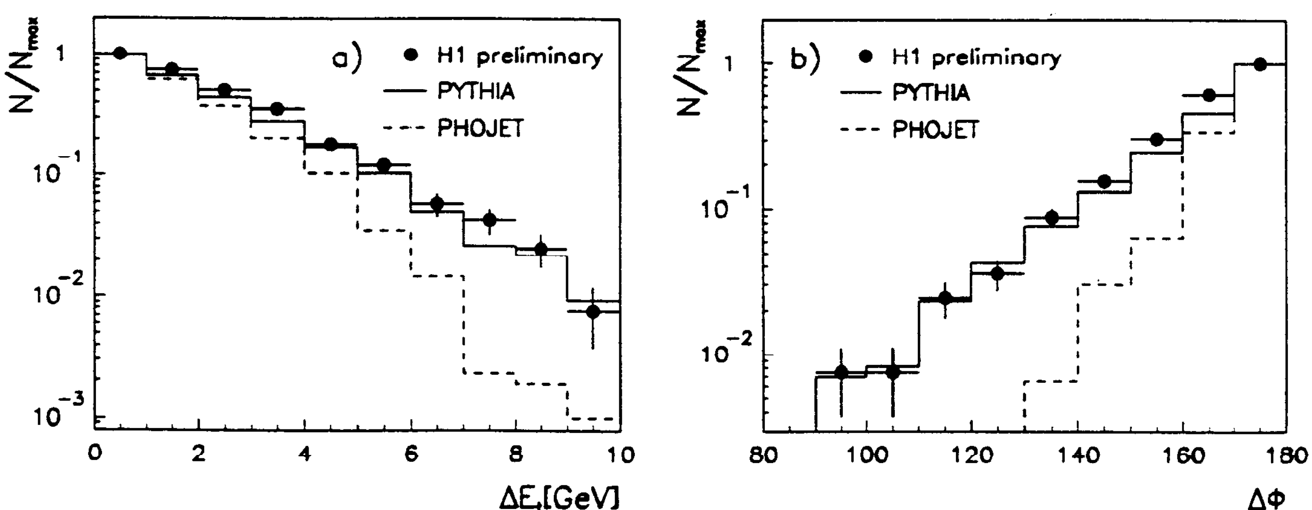


- $\sum E_t$/Area outside jets in region $-1.0 < \eta^* < 1.0$ in γp centre of mass frame.



Evidence for QCD Radiation

- Consider di-jet events.
- PYTHIA includes initial state QCD radiation, PHOJET does not.
- QCD radiation needed to describe ΔE_t and $\Delta\phi$ between the jets.



$$|E_T^{JET1} - E_T^{JET2}| = \Delta E_T$$

$$\phi^{JET1} - \phi^{JET2} = \Delta\phi$$

Data Selection

- Analysis based on 1994 H1 data (2pb^{-1})
- Scattered positron not detected ("untagged events") $\Rightarrow Q^2 < 4\,\text{GeV}^2$, 80% of events have $Q^2 < 0.1\text{GeV}^2$.
- y reconstructed from hadronic final state:

$$y_{jb} = \frac{1}{2E_e} \sum_h E_t^h e^{-\eta^h}$$

- Photon energy restricted to $0.2 < y < 0.83$.

Jet reconstruction:

- Jets found with a cone algorithm ($R = 0.7$)
- $E_t^{jet} > 8\,\text{GeV}$
- $-0.5 < \eta^{jet} < 2.5$
- $\Delta\eta < 1$ ($\equiv \cos\theta^* < 0.46$)

Di-jet Cross-Section

- In LO the di-jet cross-section is:

$$\frac{d^4\sigma}{dy\,dx_\gamma\,dx_p\,d\cos\theta^*} \sim \sum_{ij} \frac{f_{\gamma/e}}{y} \frac{f_{i/\gamma}}{x_\gamma} \frac{f_{j/p}}{x_p} \mid M_{ij}(\cos\theta^*) \mid^2$$

where:

- $f_{\gamma/e}$ = probability of finding photon with energy yE_e in electron
- $f_{i/\gamma}$ = probability of finding parton with energy $x_\gamma E_\gamma$ in photon
- $f_{j/p}$ = probability of finding parton with energy $x_p E_p$ in proton
- $M_{ij}(\cos\theta^*)$ = QCD Matrix Element (scattering angle in the parton-parton cms frame = θ^*)

- Conventionally, $\mu_r=\mu_f=p_t$ (p_t = transverse momentum of the scattered partons, in LO $p_t^2 = \frac{1}{4}s_{ep}yx_\gamma x_p \sin^2\theta^*$)

- Differential cross-sections are integrated over y and θ^* and presented as function of x_γ^{jets} and E_t^{jet} (E_t^{jet} defined as E_t of second highest E_t jet)

Measurement of Di-jet Cross-Section

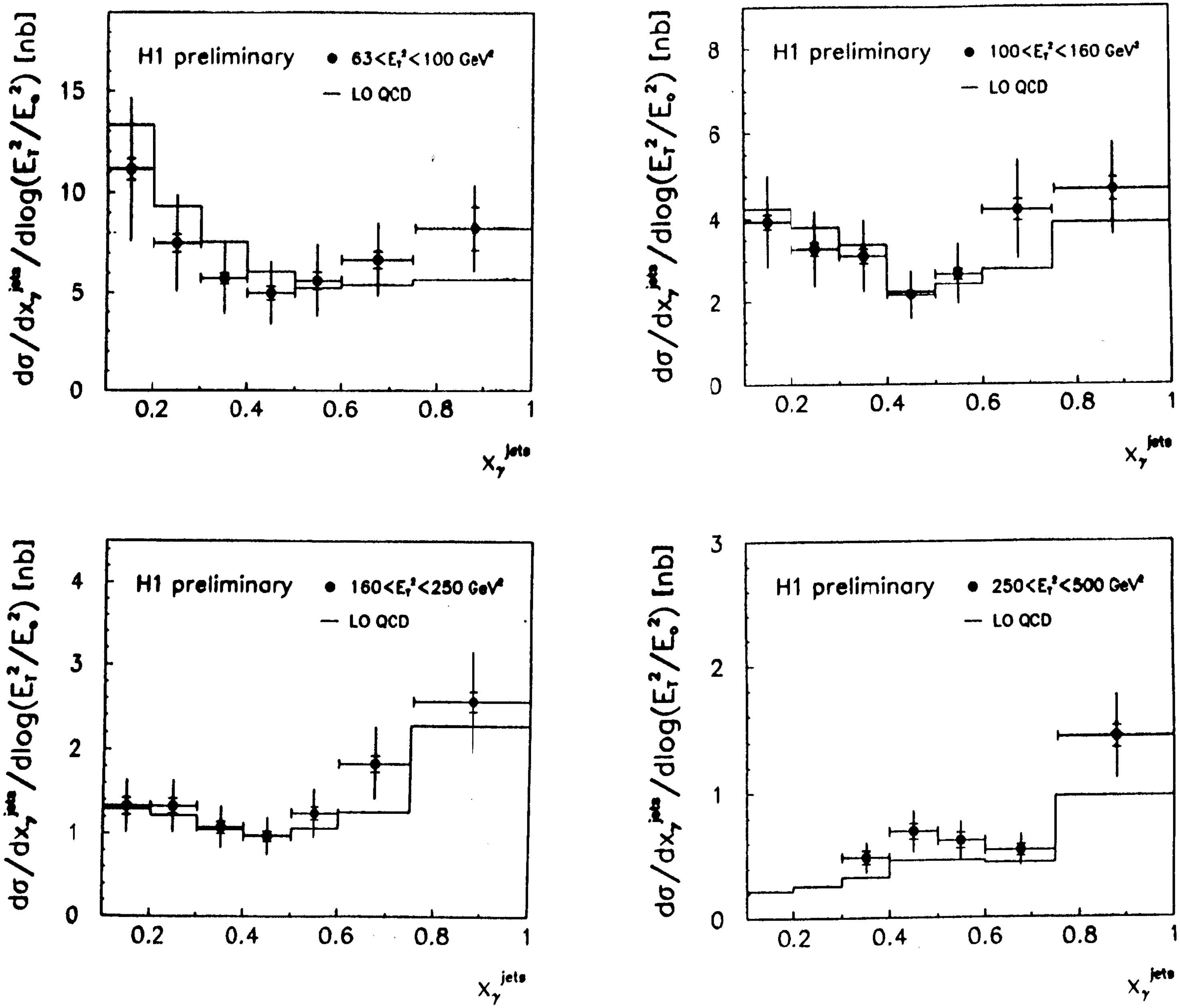
- x_γ^{jets} reconstructed from two highest E_t jets:

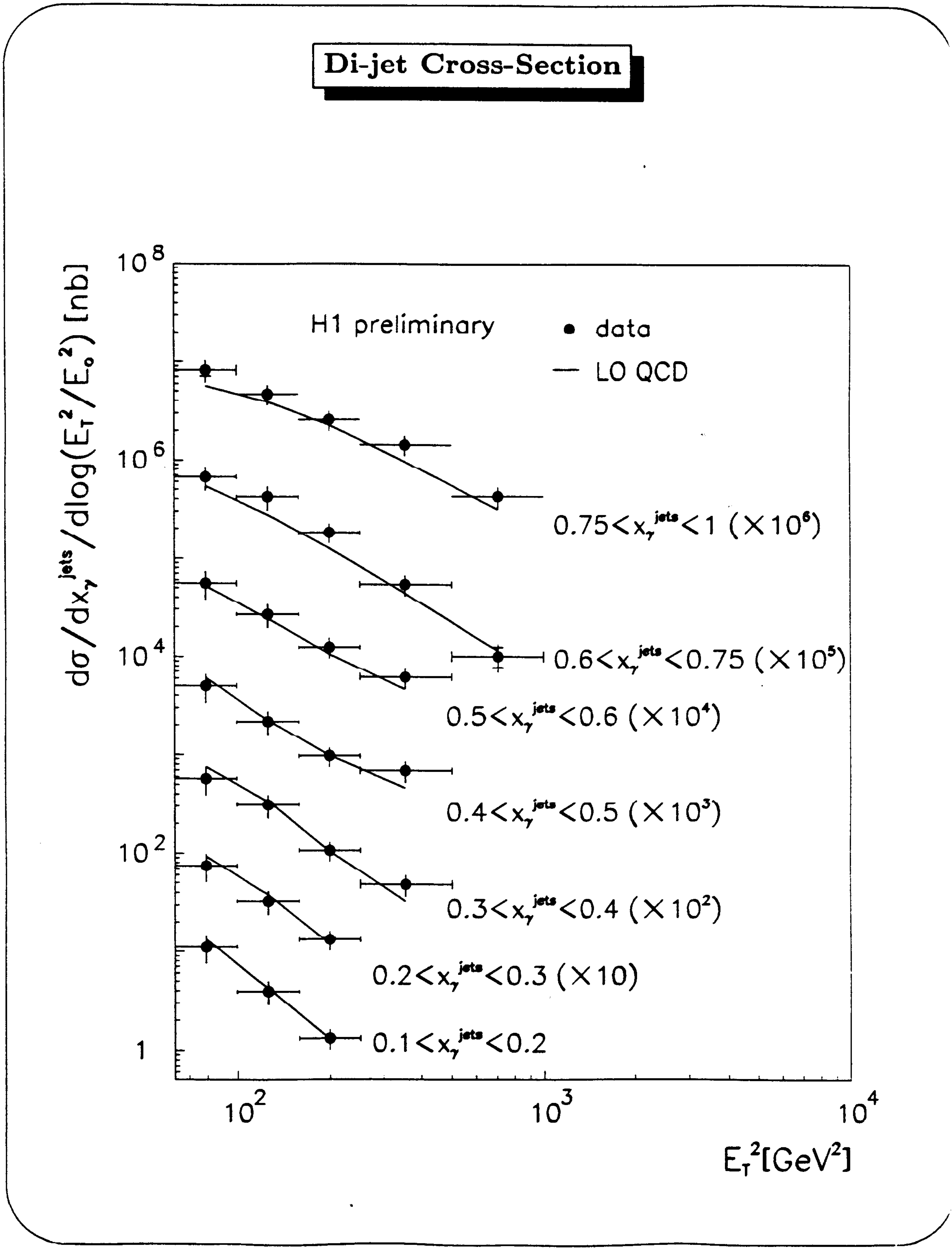
$$x_\gamma^{jets} = \frac{E_t^{jet1} e^{-\eta^{jet1}} + E_t^{jet2} e^{-\eta^{jet2}}}{2 y_{jb} E_e}$$

- Cross-section corrected for detector effects by an unfolding procedure.
- No corrections for underlying event energy made.
- Largest source of systematic error is uncertainty in the calorimeter energy scale.
- Comparison with PYTHIA, using GRV-LO parton densities for photon and proton.

Double differential di-jet cross sections

$\ldots < y < 0.65$, $Q^2 < 1$ GeV
$-0.5 < \eta_{jet} < 2.5$
$|\Delta\eta_{jet}| < 1$

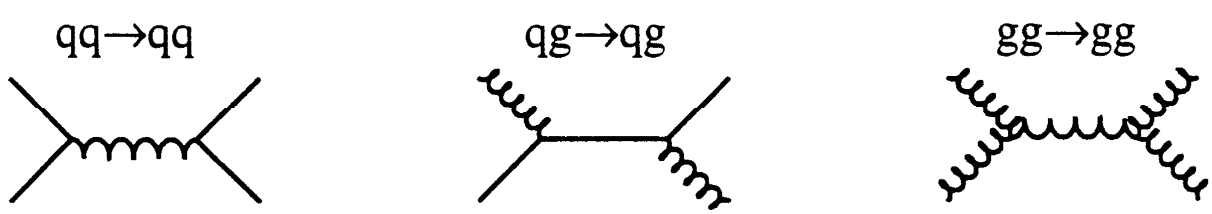



Di-jet Cross-Section
H1 preliminary
data
LO QCD
0.75<x_γ^jets<1 (×10^6)
0.6<x_γ^jets<0.75 (×10^5)
0.5<x_γ^jets<0.6 (×10^4)
0.4<x_γ^jets<0.5 (×10^3)
0.3<x_γ^jets<0.4 (×10^2)
0.2<x_γ^jets<0.3 (×10)
0.1<x_γ^jets<0.2
dσ/dx_γ^jets/dlog(E_T^2/E_o^2) [nb]
E_T^2[GeV^2]
10^8
10^6
10^4
10^2
1
10^2
10^3
10^4

Single Effective Subprocess Approximation

((Cambridge + Maxwell, 1983).

- Dominant contributions to dijet cross-section:



- Shape of these matrix elements is similar:

$$| M_{qq} |^2 : | M_{qg} |^2 : | M_{gg} |^2 \approx 1 : \frac{9}{4} : (\frac{9}{4})^2$$

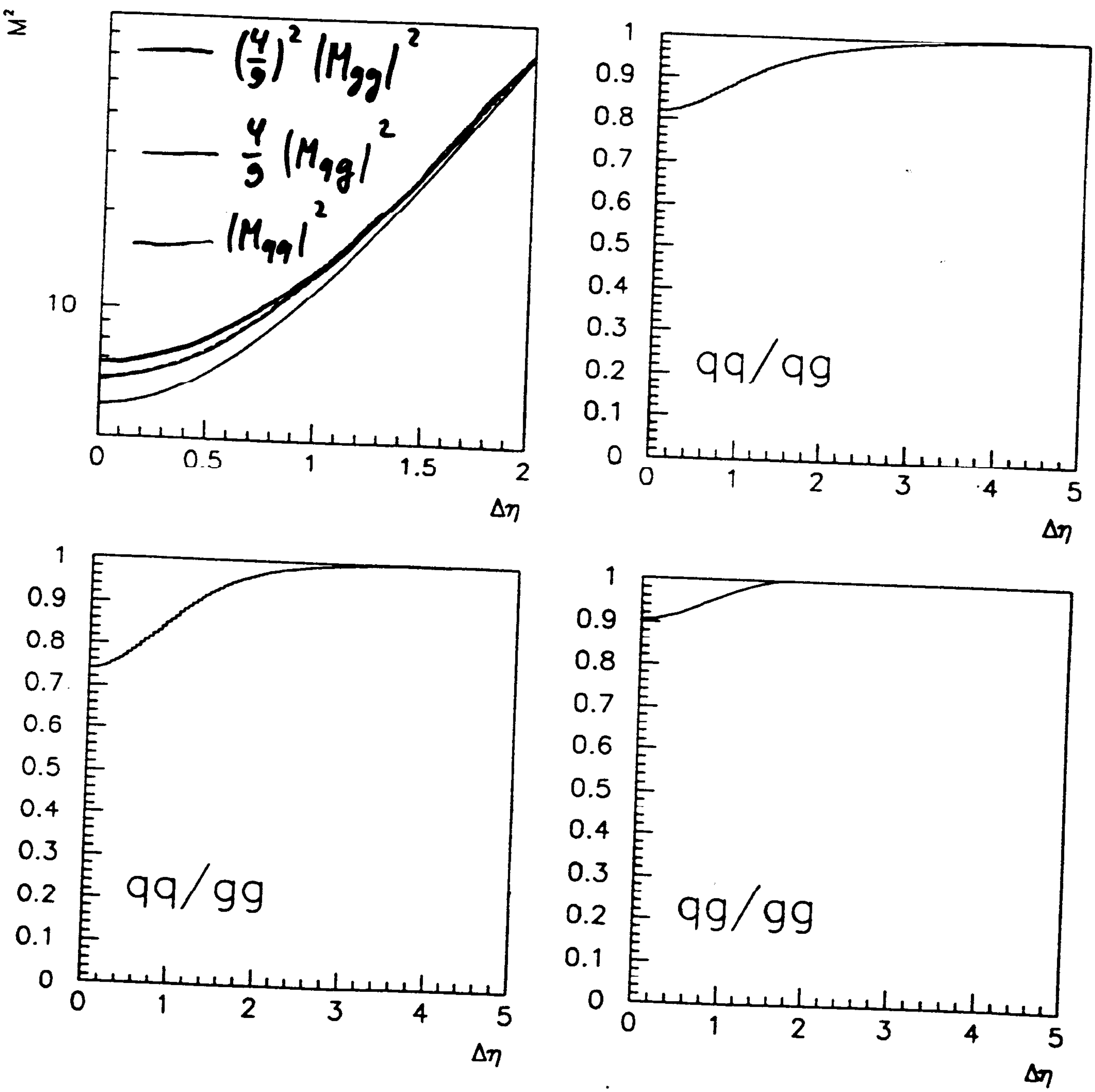
- Use a single effective subprocess (SES) where $| M_{SES} |^2 \approx | M_{qq} |^2$ and define effective parton distribution functions:

$$\tilde{f}(x) = \sum_q (q(x) + \bar{q}(x)) + \frac{9}{4} g(x)$$

- Differential di-jet cross-section becomes:

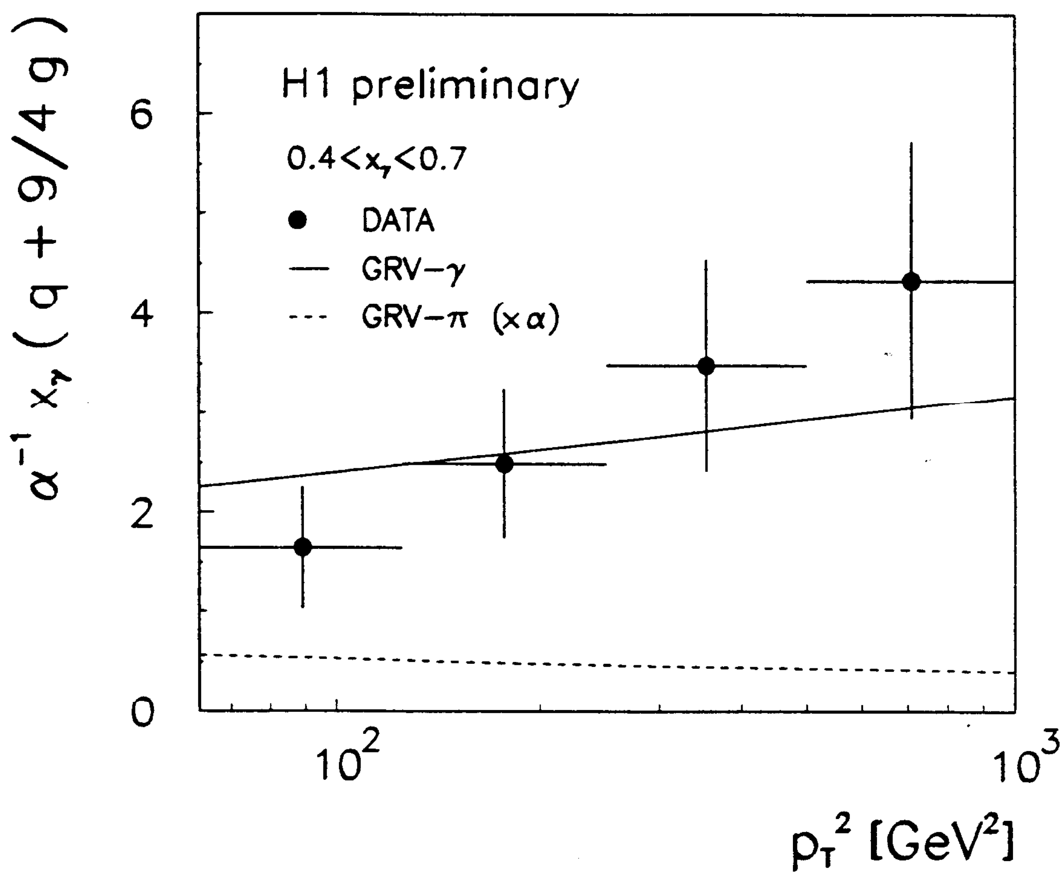
$$\frac{\mathrm{d}^4\sigma}{\mathrm{d}y\,\mathrm{d}x_\gamma\,\mathrm{d}x_p\,\mathrm{d}\cos\theta^*} \sim \frac{f_{\gamma/e}}{y} \frac{\tilde{f}_\gamma}{x_\gamma} \frac{\tilde{f}_p}{x_p} | M_{SES}(\cos\theta^*) |^2$$

Shape comparison of the resolved matrix elements



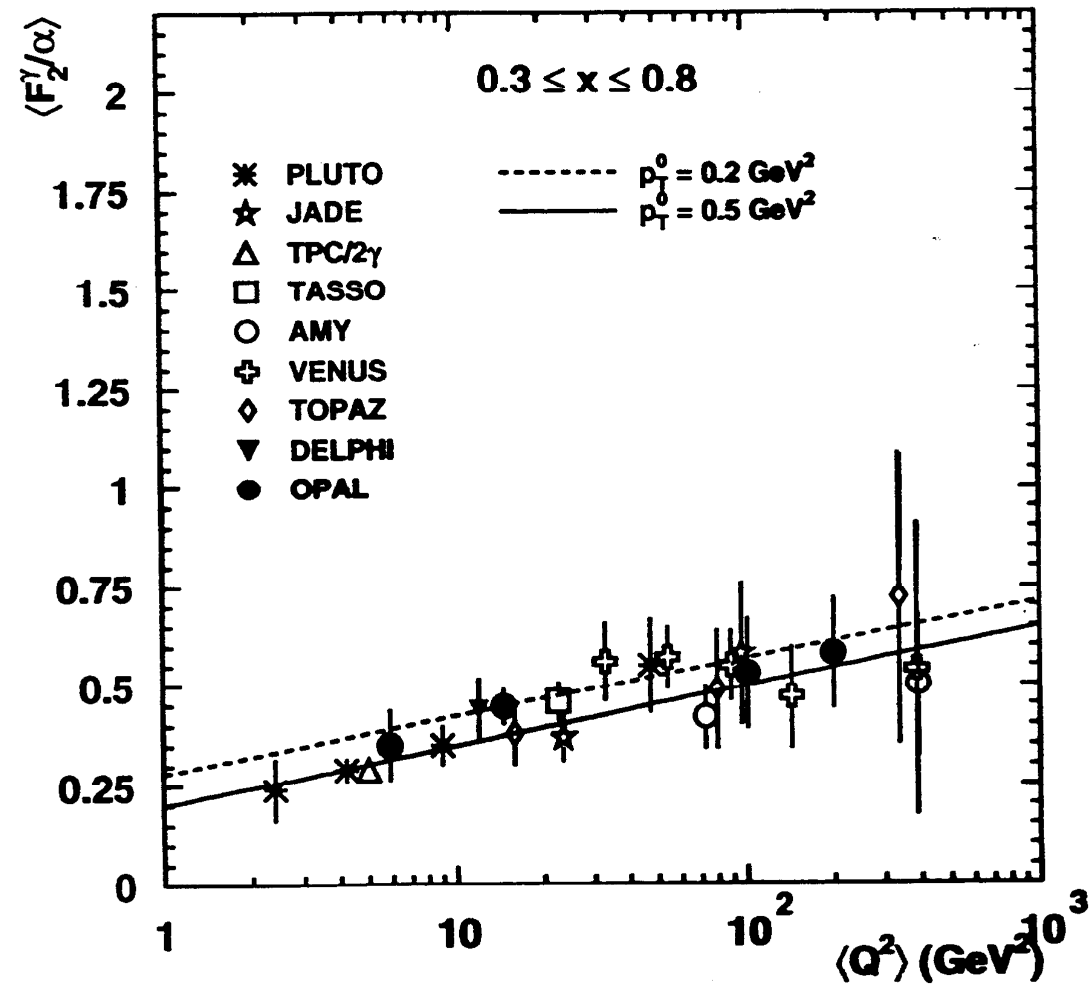
Measuring Effective Parton Density Function of γ

- Assume proton structure function well-measured, and use di-jet cross-section to measure photon structure.
- Di-jet cross-section corrected to leading order di-parton cross-section by an unfolding procedure,
ie corrections made for underlying event, fragmentation and parton showers.
- Jet-parton correlations calculated from PYTHIA.
- Differential parton cross-sections measured in the data compared to LO calculation from PYTHIA to give effective parton density function of photon.
- Data corresponds to range $0.4 < x_\gamma < 0.7$.
- Uncertainty in knowledge of underlying event energy is included in systematic error, by varying multiple interaction parameters in PYTHIA.



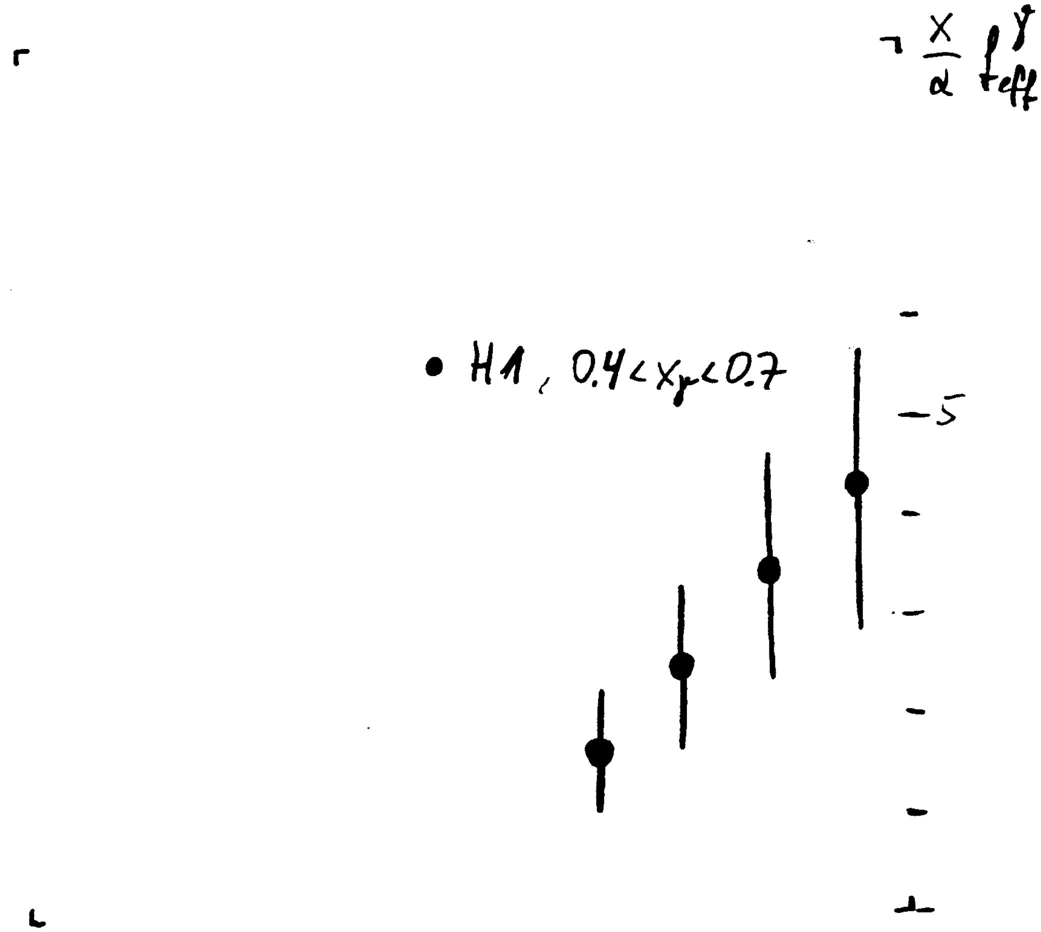
- Data shows increase with p_t^2 compatible to the logarithmic increase predicted by pQCD from the anomalous component of the photon. $(\text{c.f } f_{q/\gamma} \sim \ln \mu_F^2)$
- Different to behaviour of other hadrons eg π.
- In GRV parameterisation, quark contribution to the effective photon pdf is 80% for $0.4 < x_\gamma < 0.7$.

$F_2^\gamma(Q^2)$, measured at e^+e^- experiments



Electromagnetic pointlike ["anomalous"] coupling of the photon to $q\bar{q}$ pairs causes the photon structure function to rise with Q^2

$\Rightarrow$ Photon is not (only) a hadron.


x/α f_eff^γ
H1, 0.4<x_γ<0.7
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Conclusions

- First measurement of the double differential di-jet cross-section as a function of x_γ^{jets} and E_t^{jet}.
- The effective parton density function of the photon has been extracted from the data.
- The observed scale dependence shows an increase with p_t^2 compatible with the logarithmic increase predicted by pQCD from the anomalous component of the photon.