The structure of real and virtual photons at HERA

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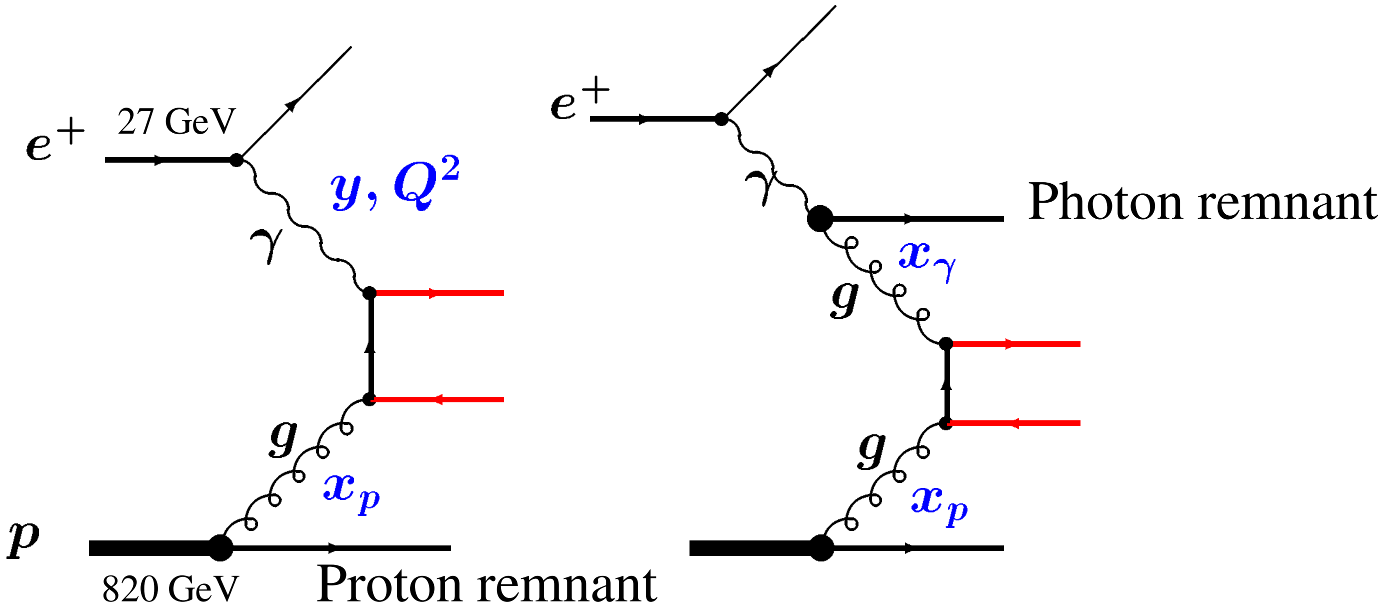
- **Di-jets in γp** (Abstract 268, 657))
  - Di-jet cross section
  - parton distribution of the photon
  - Q^2 dependence of resolved contribution
- **High p_t charged particles in γp** (Abstract 270)
  - gluon in the photon
- **Prompt photons** (Abstract 265, 656)
  - x_γ and x_p distribution from prompt photons
  - cross section
- **Summary**

Photoproduction at HERA:

interaction with a quasi-real photon ($Q^2 \simeq 0$)
center of mass energy $\sqrt{s}$= 300 GeV



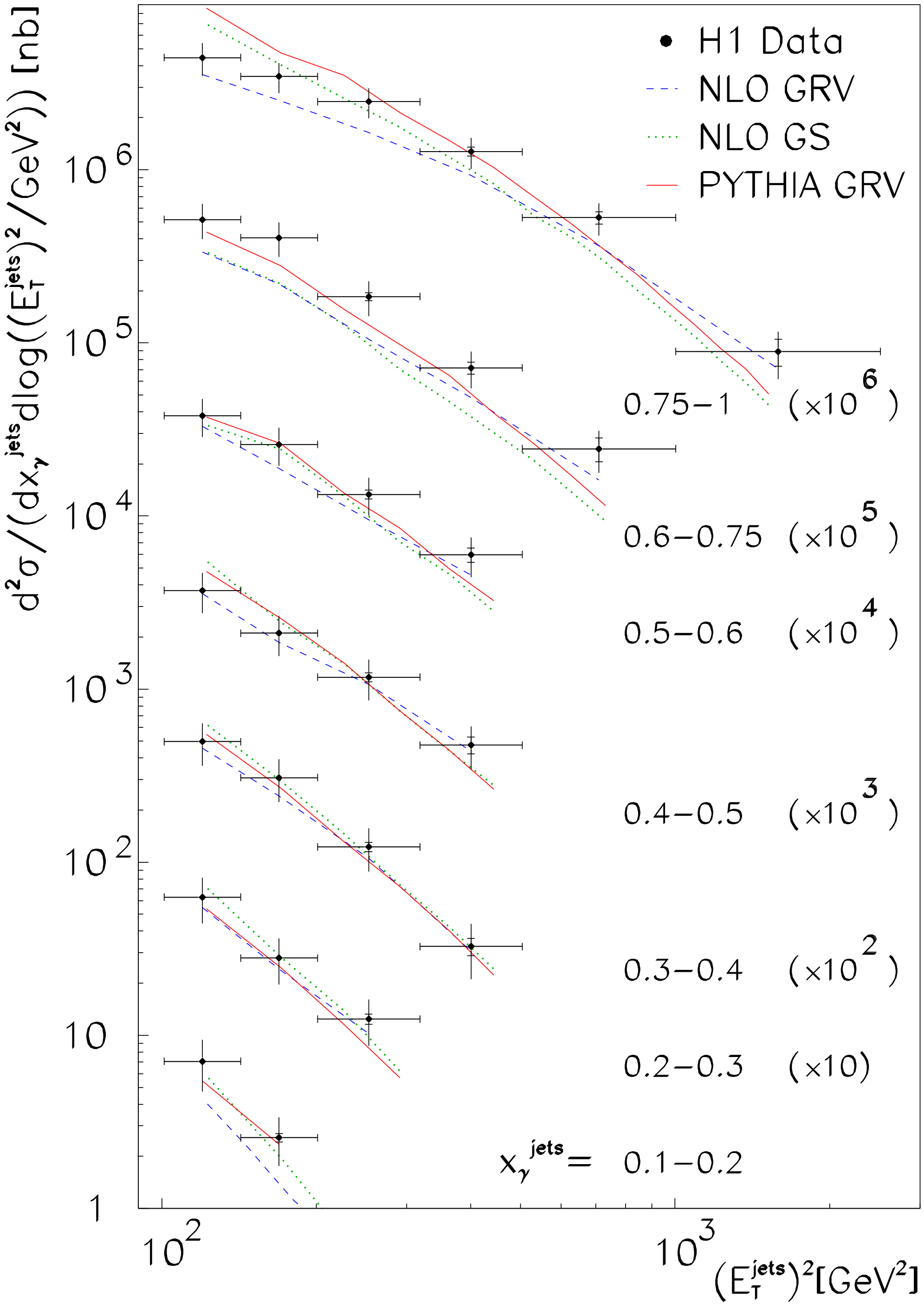
Direct $x_\gamma = 1$ Resolved $x_\gamma < 1$

- y : fraction of positron momentum in photon
- x_γ : fraction of photon momentum in parton from photon
- x_p : fraction of proton momentum in parton from proton

→ Structure of proton and real and virtual photons
di-jets and prompt photon events

Differential di-jet ep-cross section

in bins of $x_\gamma$and $(\mathrm{E}_T^{Jets})^2$ (average transverse energy of jets)



Q^2 <4 GeV^2

0.2<y<0.83

$0<\bar{\eta}_{Jets}<2$

$\Delta\eta_{Jets}<1$

$\Delta E_{Jets}<0.5\bar{E}_{Jets}$

Main systematic errors elmgn. energy scale 4%, unfolding procedure $<$ 10%

- Satisfactory overall description except for $x_\gamma>$ 0.6
- GRV and GS: good description of data

$\rightarrow$ universality of photon parton distributions

Di-Jets: Parton distributions of photon

define effective parton densities

Idea: B. L. Cambridge, B. J. Maxwell, Nucl.Phys. B239 (1984) 429.

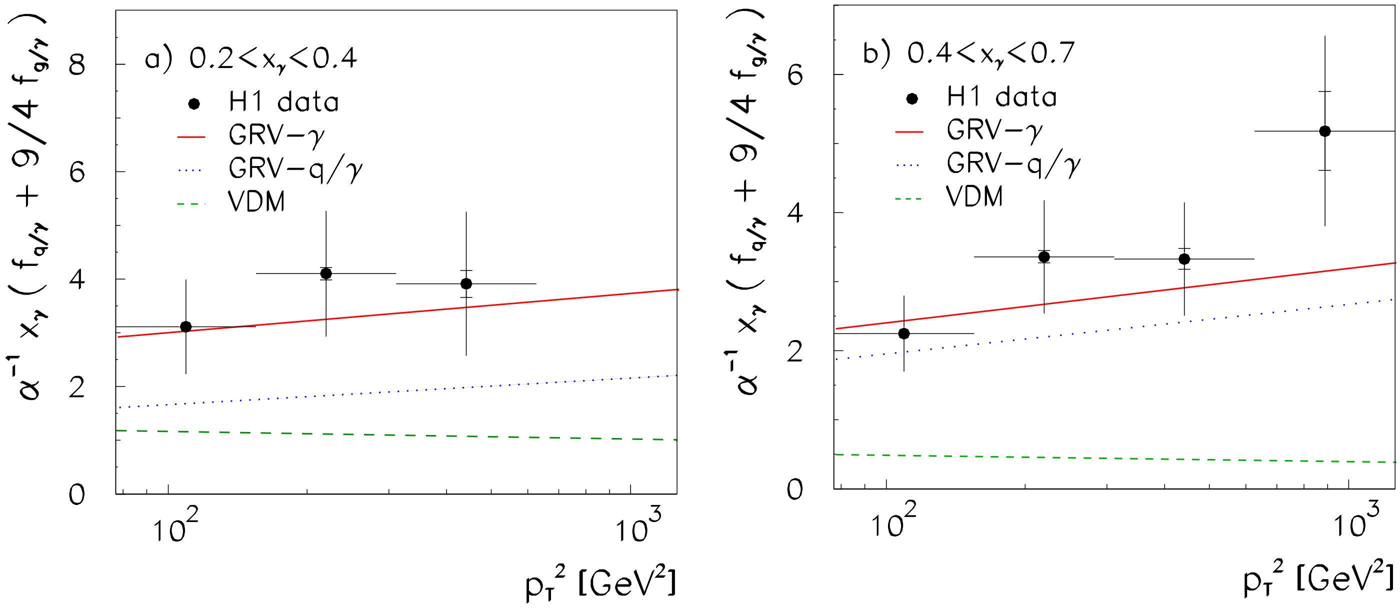
$$f_{eff}(x,p_t^2) = \Sigma_q(q(x,p_t^2) + \bar{q}(x,p_t^2)) + \frac{9}{4}\cdot g(x,p_t^2)$$

$\rightarrow$ cross section factorises

$$\frac{d^4\sigma}{dy\,dx_\gamma dx_p d\cos\theta^\star} = \frac{1}{32\pi s}\frac{f_{\gamma/e}}{y}\frac{f^\gamma_{eff}}{x_\gamma}\frac{f^p_{eff}}{x_p}|M_{SES}|^2$$

effective parton distribution

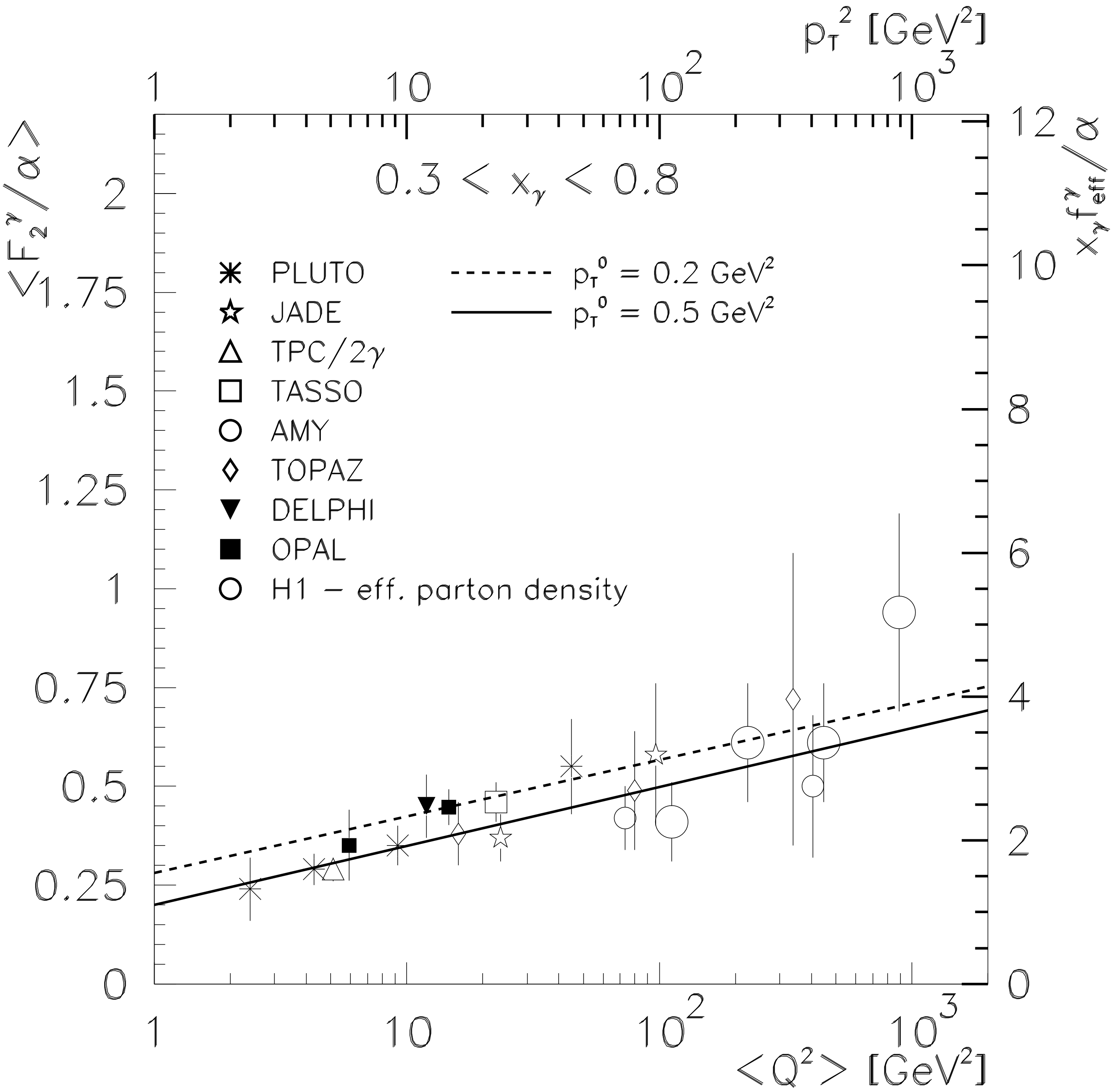
low x_γ high x_γ



- F_2^γ rises with p_t^2
- described by GRV_LO parametrization
- VDM very different $\rightarrow$ no pure hadronic parton distribution
- anomalous component of photon

F_2^γ: comparison with e^+e^-

GRV: at $x_\gamma \simeq 0.5$: quark contribution dominating ($\simeq$ 80%)
$\rightarrow$ allows comparison with e^+e^-

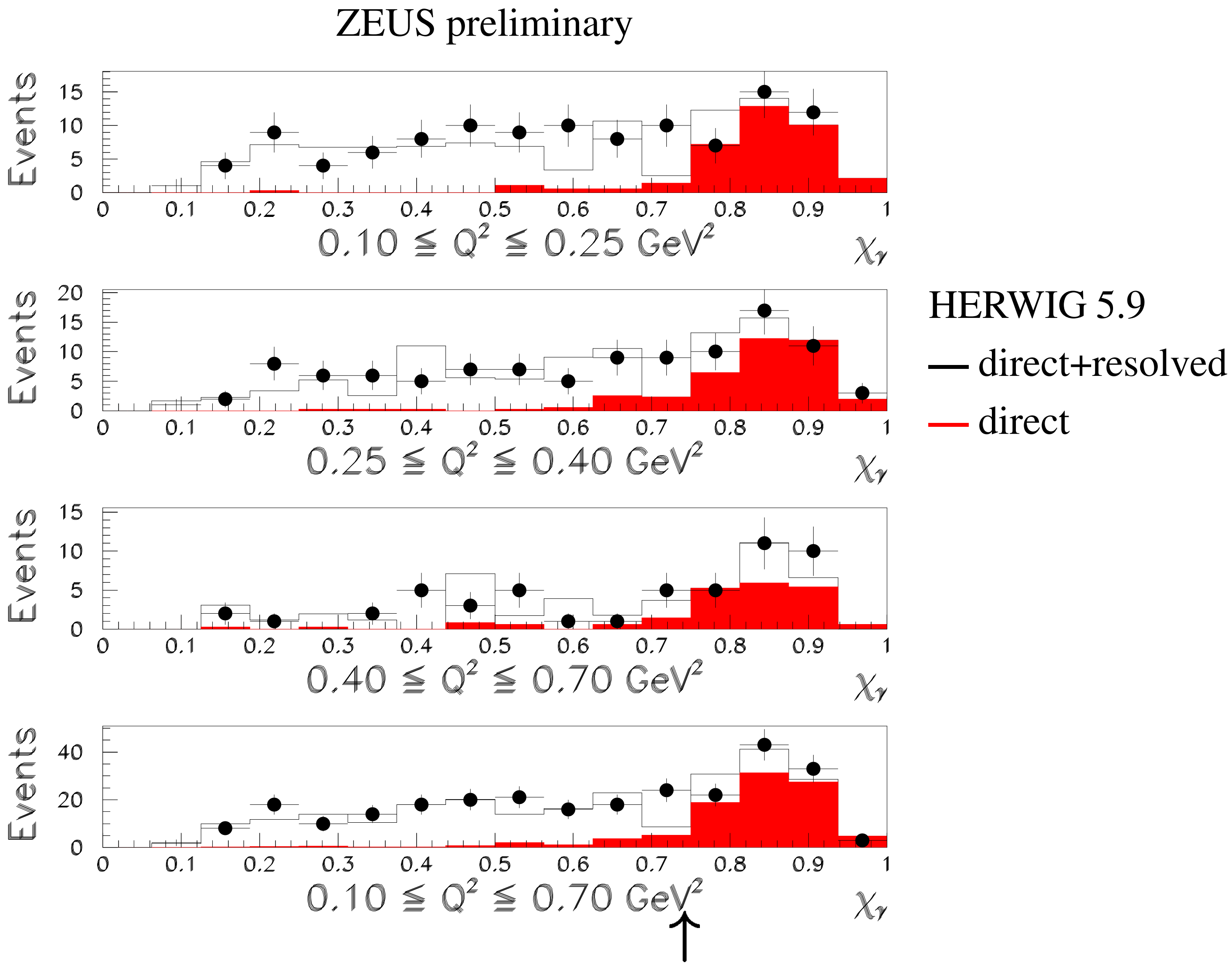


- systematic errors comparable
- measurement at higher scale $p_T^2 > 1000$ GeV^2

Q^2 dependence of x_γ from di-jet events

$$x_\gamma = \Sigma(E_{TJet} \cdot e^{-\eta_{Jet}})/2yE_e$$

$E_T^{Jet} > 6.5$ GeV, $-1.125 < \eta_{Jet} < 1.875$, $0.2 < y < 0.55$
$Q^2 > 0$: electron measured in beampipe calorimeter



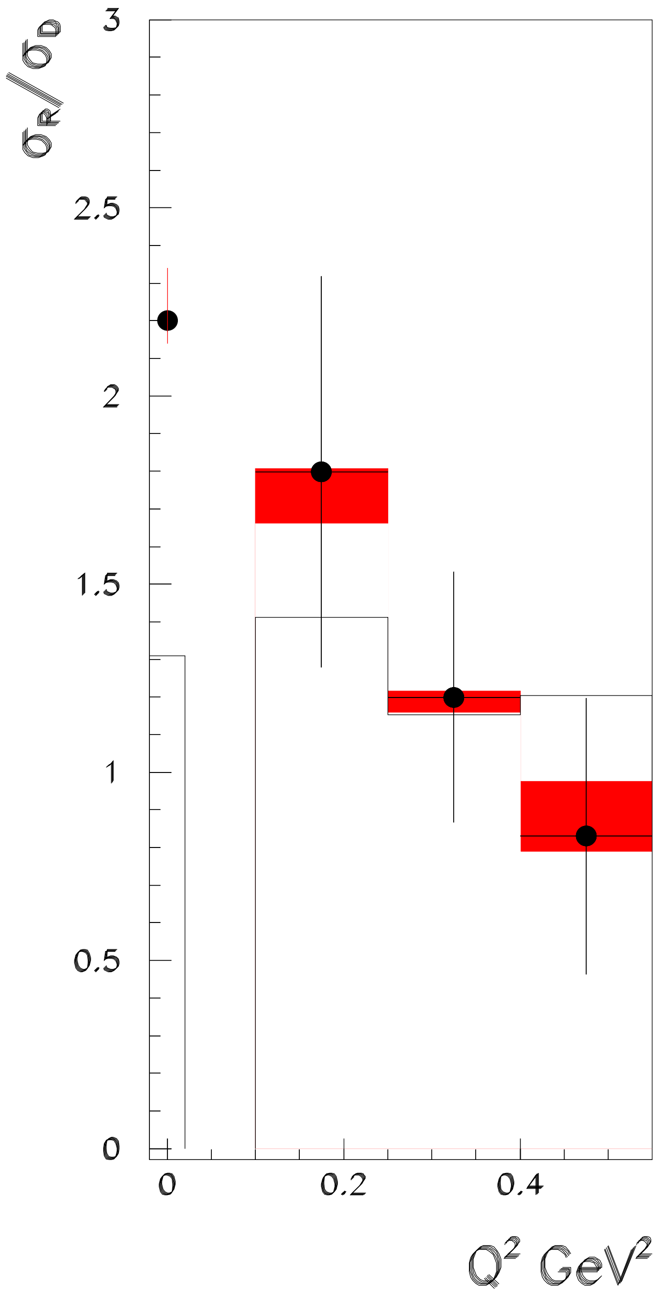
separation in 'resolved' and 'direct' signal:
resolved: x_γ<0.75, direct: x_γ>0.75

resolved signal visible up to $Q^2 \leq 0.7$ GeV^2

Q^2 dependence of resolved/direct signal

Comparison with HERWIG wo Q^2 suppression of resolved part

ZEUS preliminary



ZEUS preliminary data
with statistical errors only

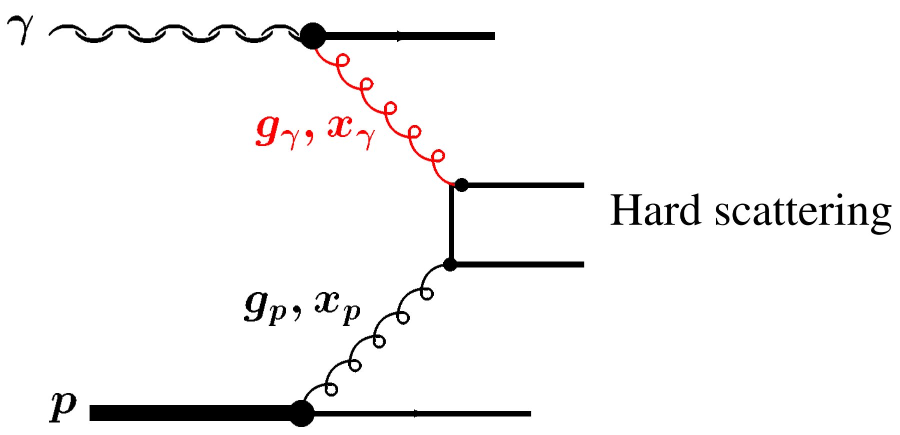
— e-scale error

5% normalisation uncertainty
not included

— HERWIG 5.9 wo Q^2 suppression

$E_T^{Jet} > 6.5$ GeV
$-1.125 < \eta_{Jet} < 1.875$
$0.2 < y < 0.55$

- Q^2 increase $\rightarrow$ decrease of relative contribution from resolved processes
- HERWIG 5.9 wo Q^2 suppression is flat
- Resolved contribution still evident for $Q^2 < 0.7$ GeV^2



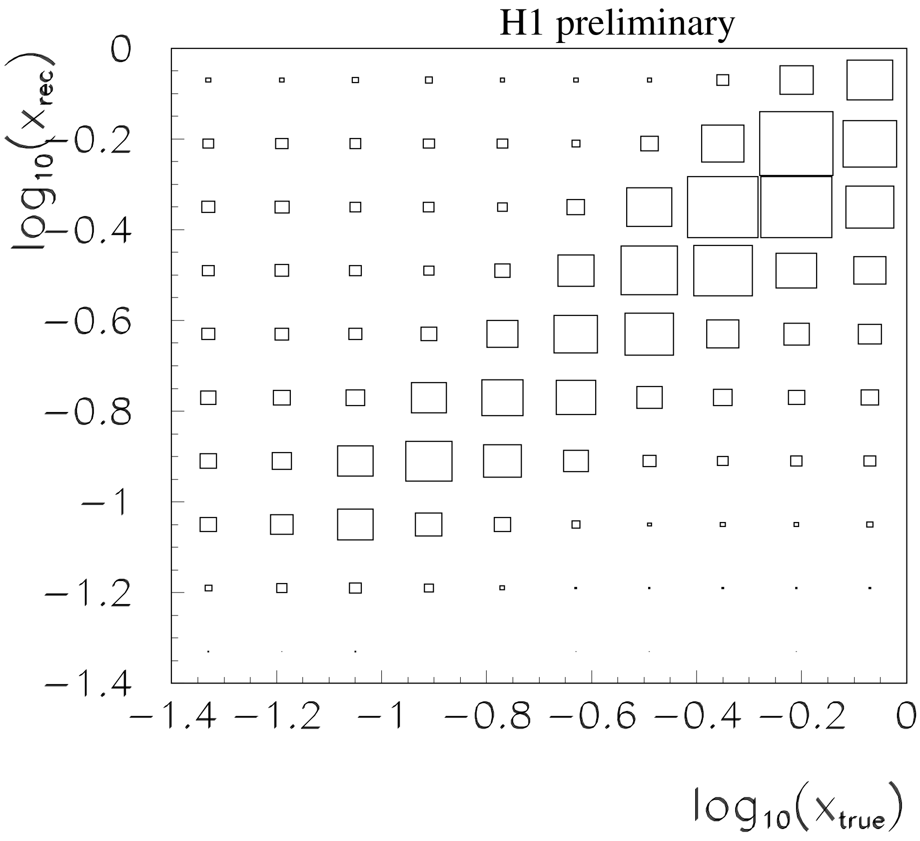
Extraction of x_γ using high p_t charged particles instead of di-jet events.

$$x_\gamma^{rec} = \frac{\Sigma_N p_z e^{-\eta}}{E_\gamma}$$

$\rightarrow$ use unfolding to get x_γ

Good correlation with x_γ: compare $x_\gamma{}^{true}$ and $x_\gamma{}^{rec}$

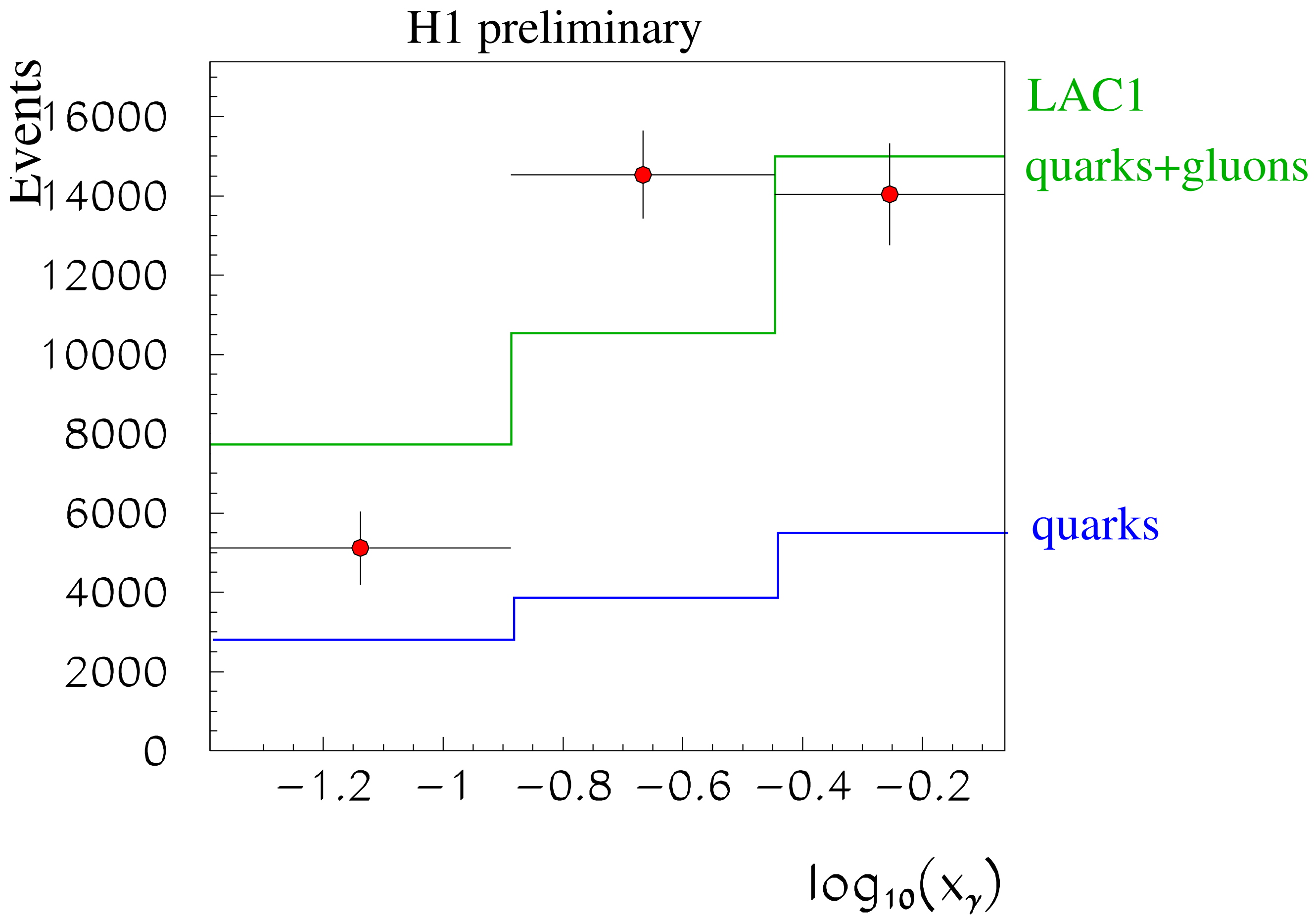
- $p_T > 2.6$ GeV
- $|\eta| < 1$
- $0.3 < y < 0.7$



x_γ from charged particled

Determine x_γ with unfolding procedure

$$x_\gamma^{rec} = \frac{\Sigma_N p_z e^{-\eta}}{E_\gamma}$$

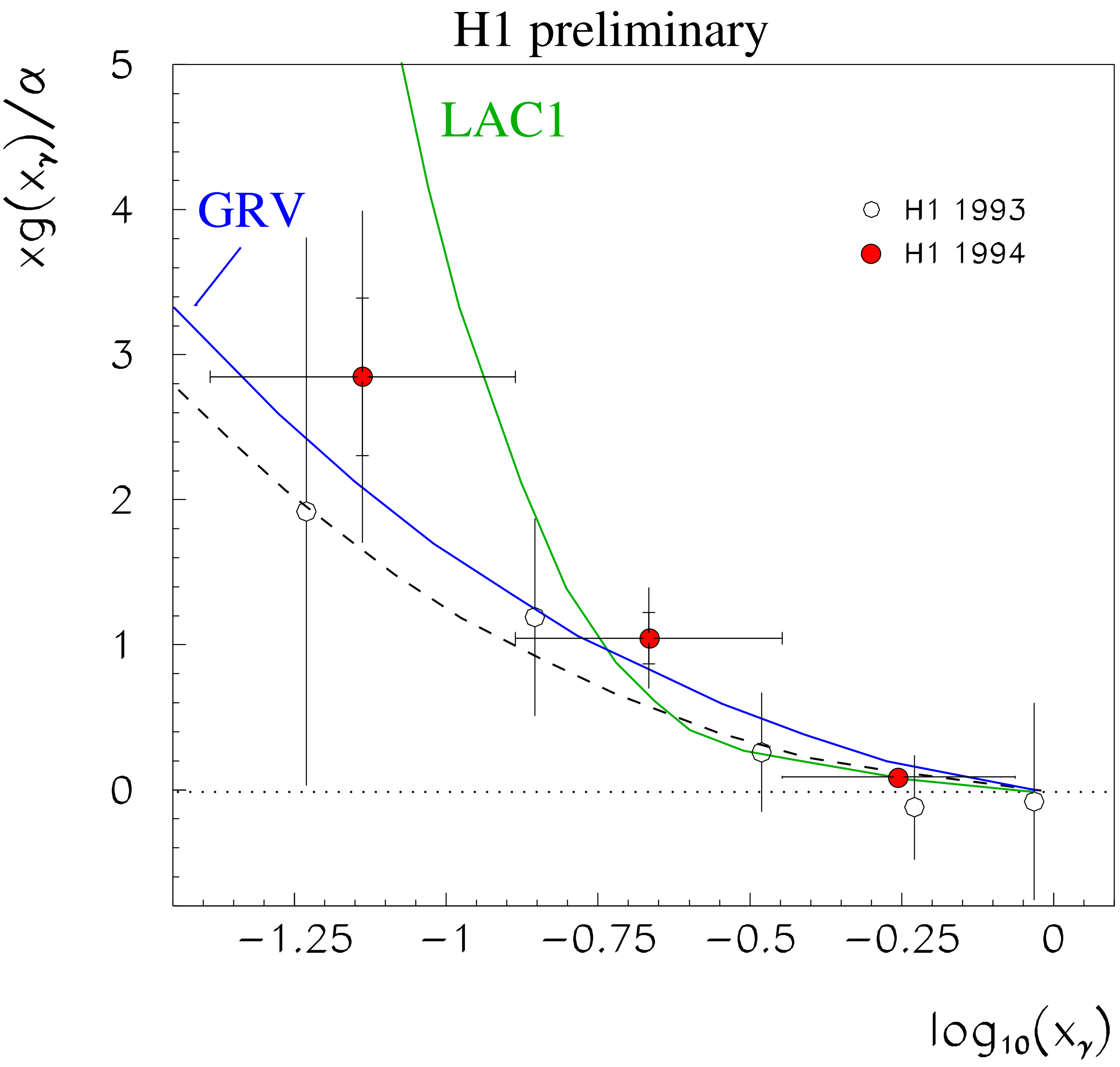


Systematical errors

- uncertainty in the quark distributions (LAC1-GRV) 15%
- unfolding procedure 10%
- stability of unfolding 20%
- Track reconstruction

Gluon density in the photon

extract LO gluon density in the photon from x_γ distribution



Scale: $< p_T^2 > = 38$ GeV^2

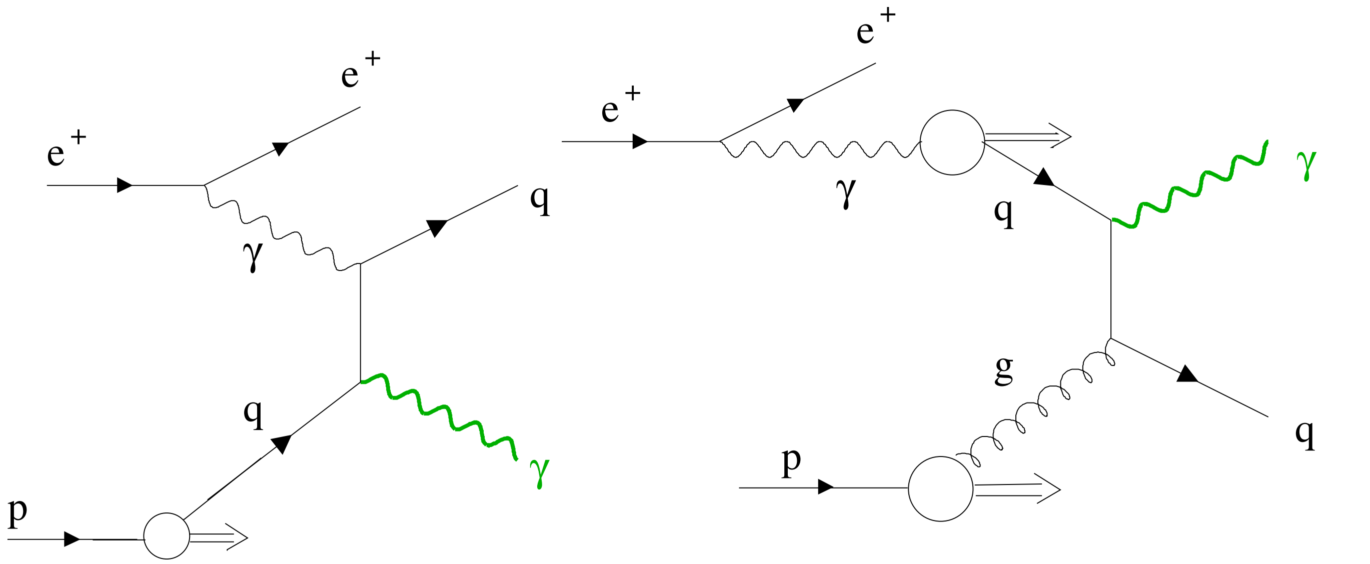
good agreement with measurement with di-jet events
significantly smaller errors

High p_T isolated photons: Prompt photons

hard photon emitted in QCD subprocess

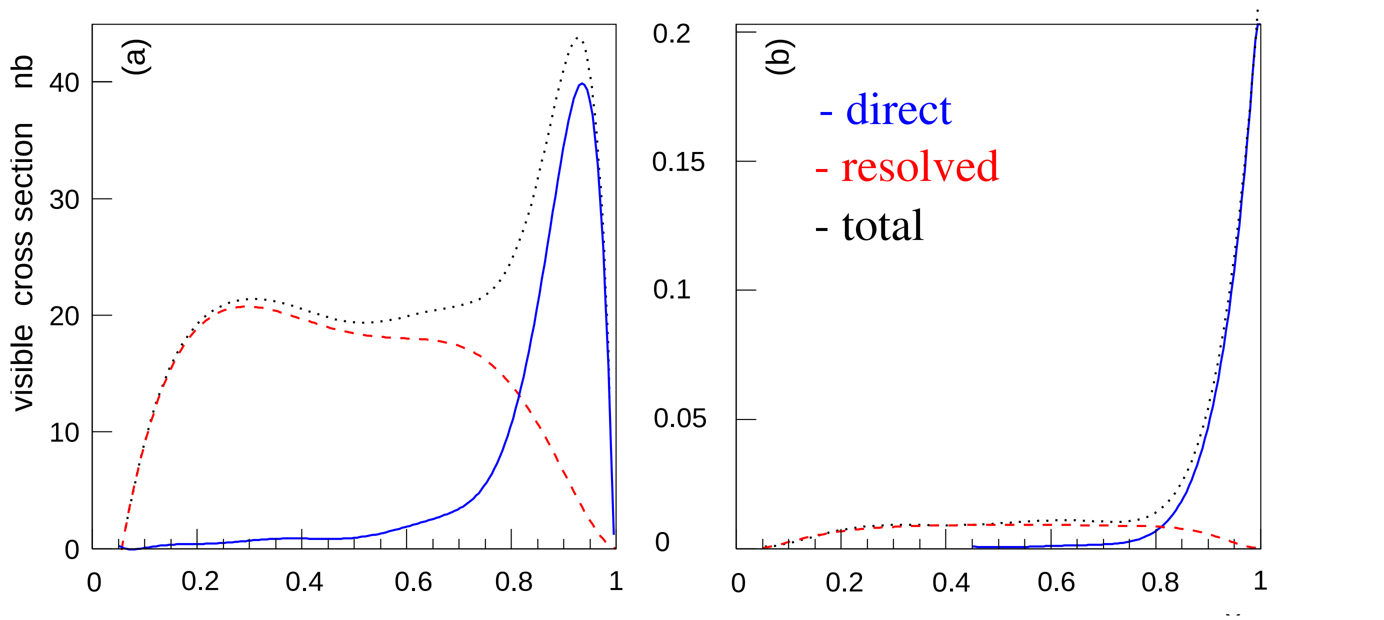
direct: $q\gamma \rightarrow q\gamma$ — probe partons in proton

resolved: $qg \rightarrow q\gamma$ ($q\bar{q} \rightarrow g\gamma$) — partons in proton and photon

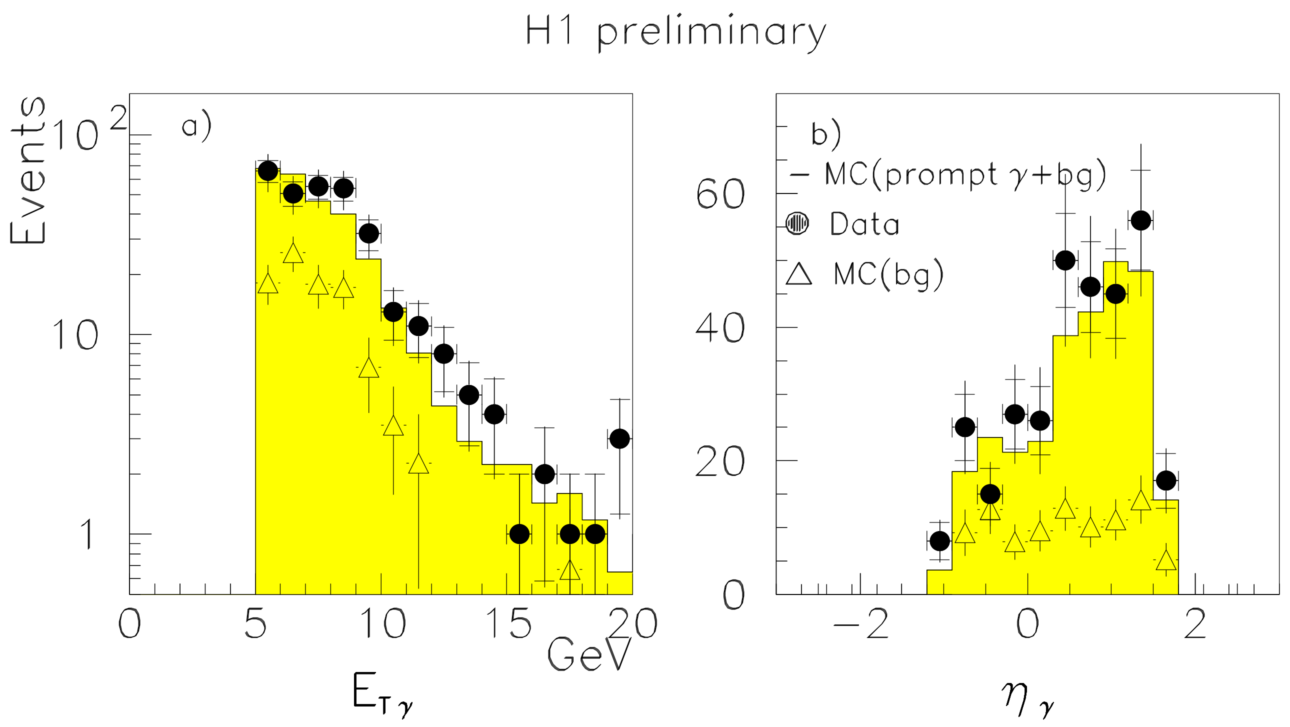


- directly observe particle from hard subprocess
- less dependence from QCD model and fragmentation
- low cross section

di-jet cross section — prompt photon cross section



Prompt photons: Background rejection



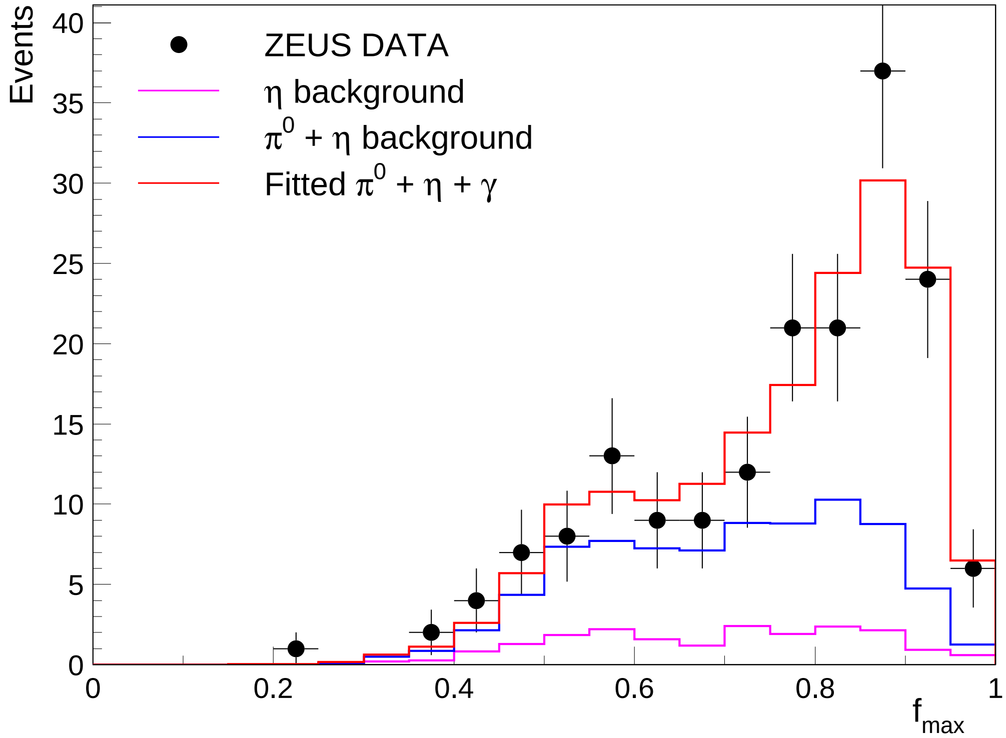
background from final state radiation from quark and misidentified π^0, η

- Isolation No track in a cone of radius 0.8 (H1)
  Energy fraction in cone (H1 and ZEUS)

- Cluster shape Energy in 4 hottest cells
  transverse shower profile (H1)
  Energy fraction in first layer
  max energy fraction in cell

Prompt photons: Background rejection

energy fraction deposited in cell with max. energy



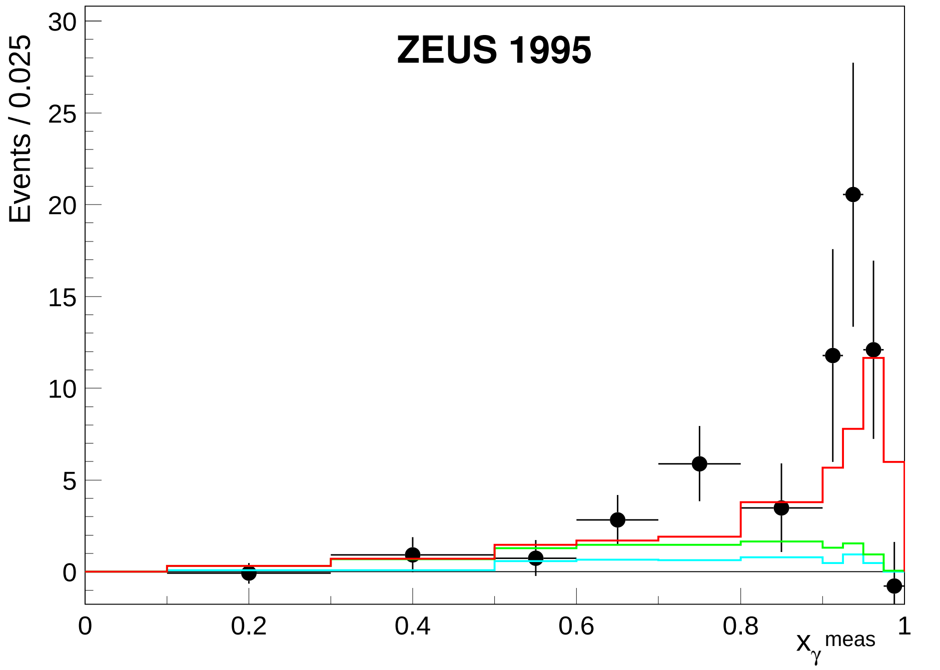
photon signal: concentrated in one cell $f_{max} > 0.8$
background: estimate shape of distribution $f_{max} < 0.75$

- ZEUS: fit of distribution of max cell energy
- H1: remaining background subtracted statistically 25% background

Prompt photons: x_γ x_p distribution ZEUS

$$x_\gamma = (E_{T\gamma} \cdot e^{-\eta_\gamma} + E_{TJet} \cdot e^{-\eta_{Jet}})/(2yE_e)$$

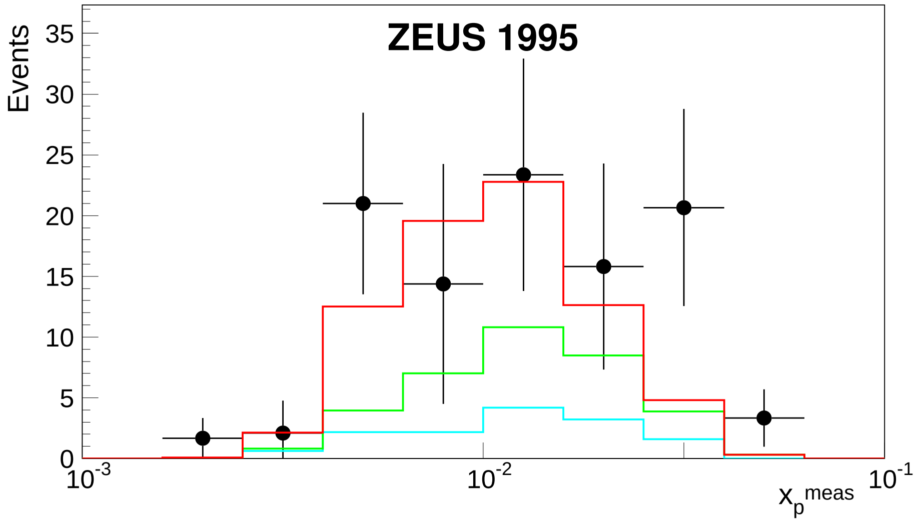
$$x_p = (E_{T\gamma} \cdot e^{\eta_\gamma} + E_{TJet} \cdot e^{\eta_{Jet}})/(2E_p)$$



$E_{T\gamma} > 5$ GeV
$-0.7 < \eta_\gamma < 0.8$

$E_T^{Jet} > 5$ GeV
$-1.5 < \eta_{Jet} < 1.8$

$0.16 < y_{JB} < 0.8$



— resolved+ direct+ rad
— resolved+ radiative
— radiative

direct process dominating

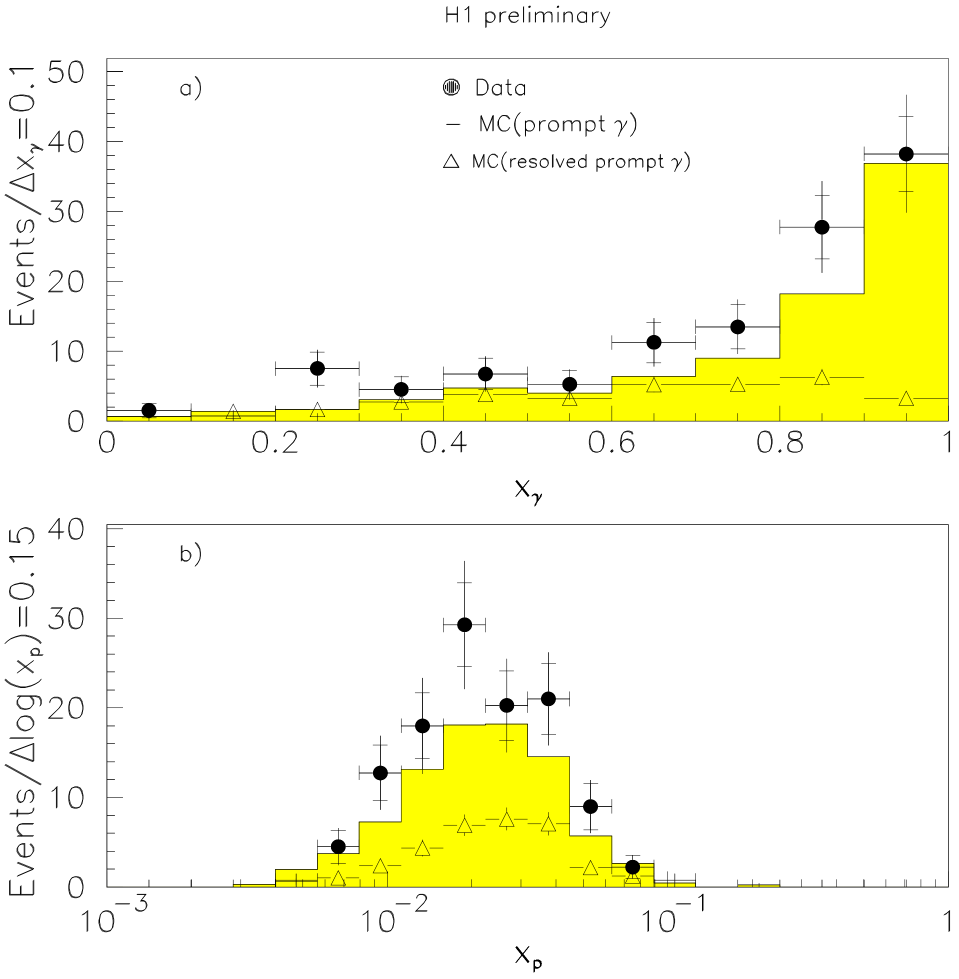
Cross section for direct process $\gamma p \to \gamma + \mathrm{Jet} + X$, $x_\gamma > 0.8$

ZEUS $\sigma_{\gamma p \to \gamma + Jet} = 15.3 \pm 3.8(stat) \pm 1.8(syst)$ pb

good agreement with NLO calculation (Gordon) 14.05 pb (GS), 17.93 (GRV)

Prompt photons: x_γ x_p distribution H1

$E_{T\gamma} > 5$ GeV, $-1.2 < \eta_\gamma < 1.6$, $y_{JB} > 0.05$
E_{TJet} >4 GeV, $-0.5 < \eta_{Jet} < 2$



dominating syst. error: error in elmgn. energy scale (6%), trigger efficiency ((6%) and background subtraction (10%)

$x_\gamma < 0.9$ (resolved process substantial): data above the MC expectation

Cross section for the process $\gamma p \rightarrow \gamma + X$

H1 $\sigma_{\gamma p \rightarrow \gamma + X} = 104.8 \pm 5.9(stat) \pm 15.7(syst)$ pb

Summary and conclusions

Di-jet events

- double differential cross section $(x_\gamma{}^{jets}, E_T)$
  GRV and GS describe data: universality of photon parton distributions
- effective parton distribution rise with p_t^2 as seen in e^+e^-
- resolved/direct processes decreases with Q^2

High p_t charged particles

- New method to extract x_γ with charged particles
- determination of gluon density in photon

Prompt photon process at HERA

- Prompt photon process measured at HERA
  direct component dominating, resolved part higher than LO-GRV
- Cross section for the process $\gamma p \to \gamma + X$
  with $E_{T\gamma} > 5$ GeV and $-1.2 < \eta_\gamma < 1.6$, $y_{JB} > 0.05$:
  H1 $\sigma = 104.8 \pm 5.9(stat) \pm 15.7(syst)$ pb
- Cross section for direct process $x_\gamma > 0.8$
  $E_{T\gamma} > 5$ GeV and $-0.7 < \eta_\gamma < 0.8$ with $E_T^{Jet} > 5$ GeV
  and $-1.5 < \eta_{Jet} < 1.8$ and $0.16 < y_{JB} < 0.8$
  ZEUS $\sigma_{\gamma p \to \gamma + Jet} = 15.3 \pm 3.8(stat) \pm 1.8(syst)$ pb