PHOTON 99

International Conference on
Structure and Interactions of the Photon
Freiburg im Breisgau, Germany
May $23^{rd} - 27^{th}$, 1999


# Inclusive Hard Processes in $\gamma\gamma$ and $\gamma p$ Interactions


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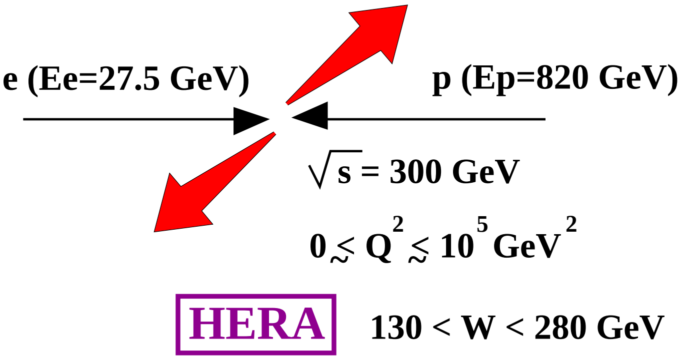


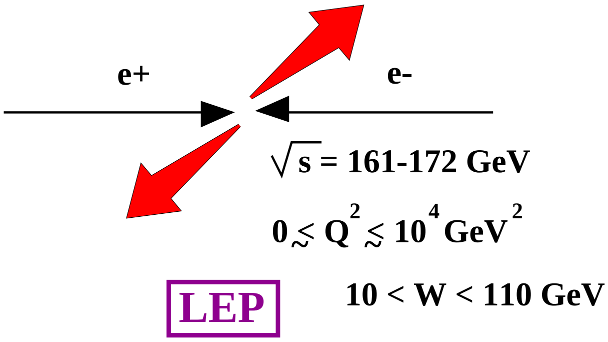

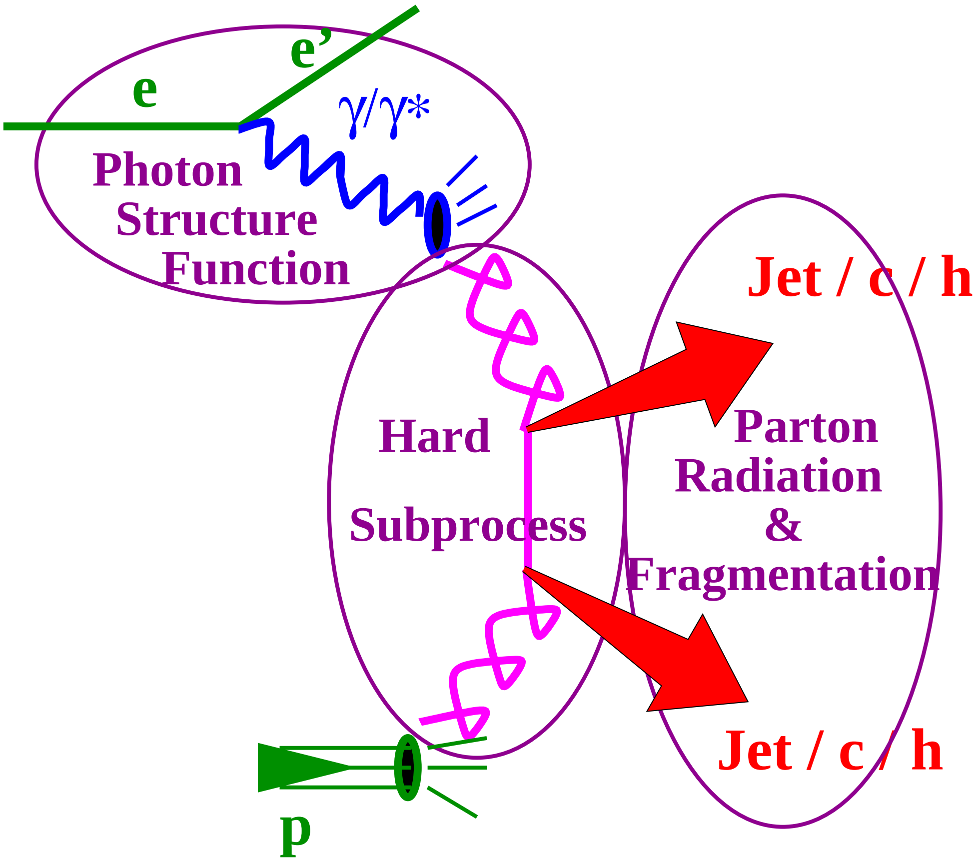


- **Jet cross sections** → Tests of QCD
- **Heavy quark production** Parton densities in the
- **Hadron production** photon

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- **DIS $e\gamma$** → Photon Structure
- **Virtual photon**
- **Prompt photon**

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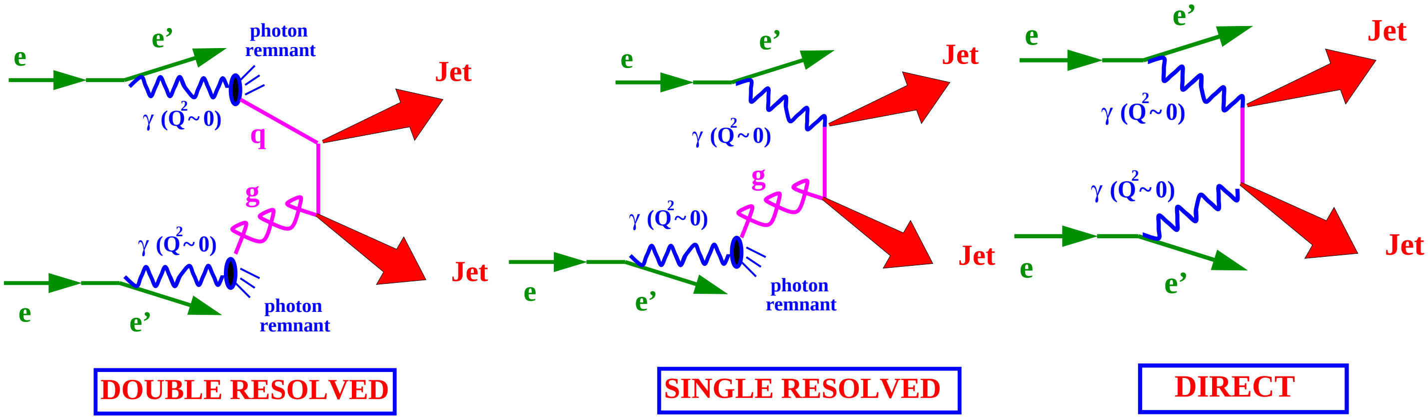
- **Jet substructure** → Parton radiation and
- **Hadron production** fragmentation

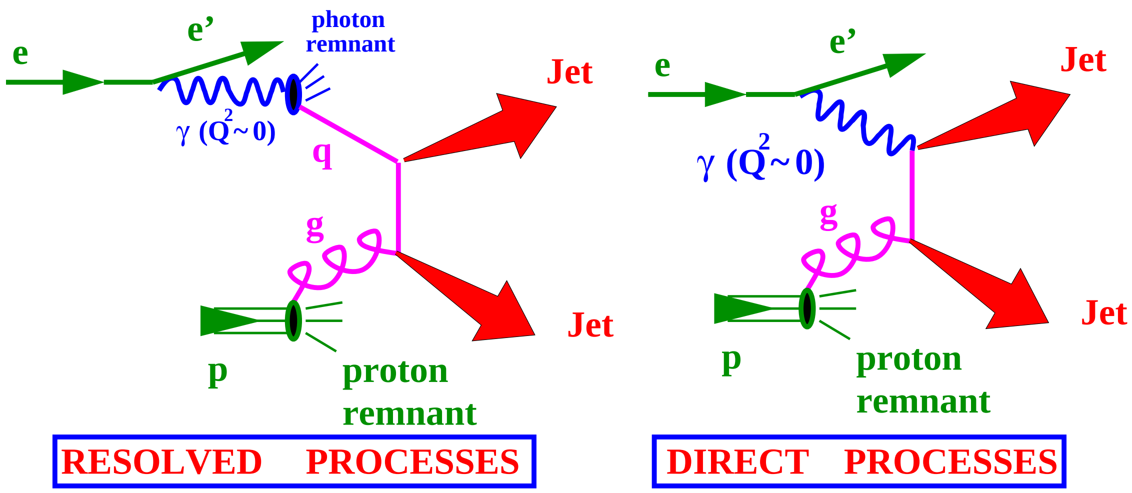
## Jet production at LO QCD in $\gamma\gamma$

$$e^+e^- \rightarrow e^+e^- + \text{jet } (+\text{jet}) + X$$




## Jet production at LO QCD in $\gamma p$

$$ep \rightarrow e + \text{jet } (+\text{jet}) + X$$



## Cross section for jet production at LO QCD

$$\sigma_{LO}^{ep} = \int dPS\; f_{\gamma/e}(y)\; f_{j/p}(x_p, \mu_F^2) \times f_{i/\gamma}(x_\gamma, \mu_F^2)\; d\sigma(ij \rightarrow \text{jet jet})$$

$$\sigma_{LO}^{e^+e^-} = \int dPS\; f_{\gamma/e}(y^{(1)}) f_{\gamma/e}(y^{(2)})\; f_{j/\gamma}(x_\gamma^{(1)}, \mu_F^2) \times f_{i/\gamma}(x_\gamma^{(2)}, \mu_F^2)\; d\sigma(ij \rightarrow \text{jet jet})$$

$f_{\gamma/e}(y)$: **flux of photons in $e$ (Weizsäcker-Williams approximation)**

$f_{j/p}(x_p, \mu_F^2)$: **parton densities in $p$ (determined from other measurements, e.g., $F_2^p$)**

$f_{i/\gamma}(x_\gamma, \mu_F^2)$: **parton densities in $\gamma$ (partial information from other measurements, e.g. $F_2^\gamma$) $\rightarrow \delta(1 - x_i)$ for direct**

$d\sigma(ij \rightarrow \text{jet jet})$: **subprocess cross section (calculable in pQCD)**

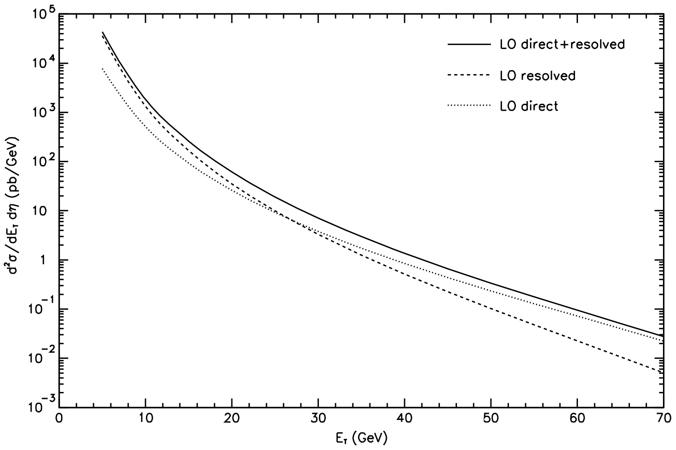
- **Resolved vs. Direct in $\gamma p$ (similar in $\gamma\gamma$):**

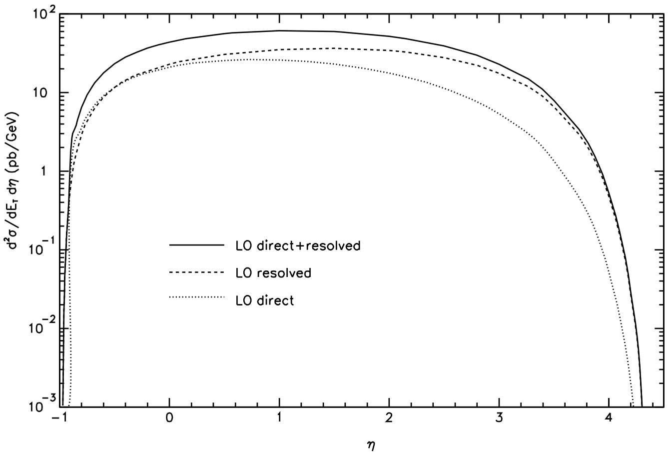
$$\boxed{x_\gamma^{OBS} = \frac{1}{2yE_e}(E_T^{jet1} e^{-\eta^{jet1}} + E_T^{jet2} e^{-\eta^{jet2}})}$$

| Resolved Processes: | Direct Processes: |
|---|---|
| Low $x_\gamma^{OBS}$ | High $x_\gamma^{OBS}$ |

# Jet cross sections in LO QCD

## $\gamma p$ interactions

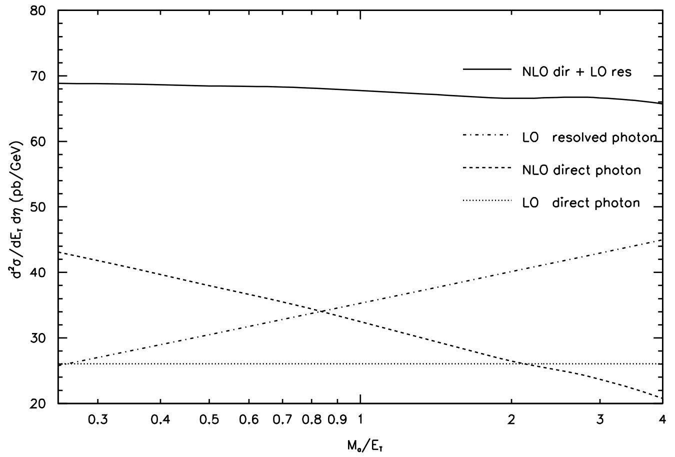


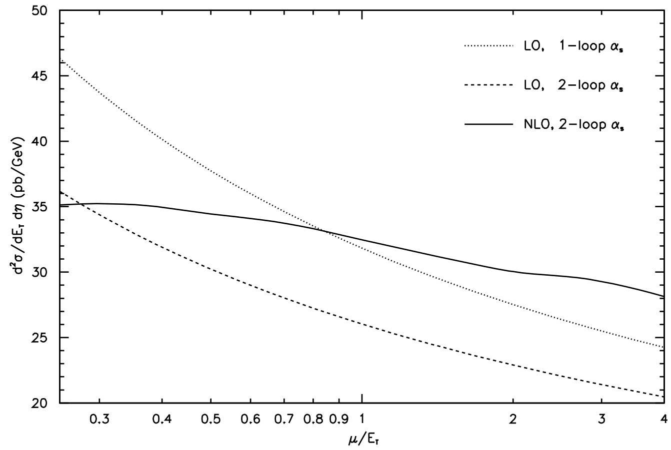




M Klasen, T Kleinwort and G Kramer; Eur Phys J C1 (1998) 1

# Scale dependence of the jet cross sections

## $\gamma p$ interactions



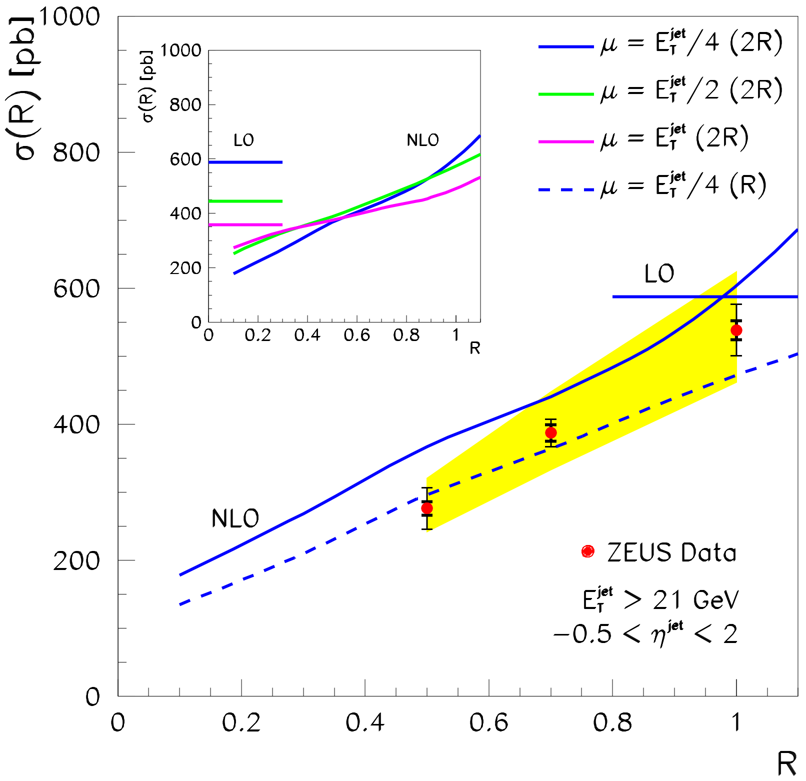

M Klasen, T Kleinwort and G Kramer; Eur Phys J C1 (1998) 1

- large scale dependence in LO calculations
- parton $\equiv$ jet at LO
- separation between resolved and direct (single/double resolved and direct) only meaningful at LO

## Cross section for jet production at NLO QCD

$$\sigma_{NLO} = \int dPS \, \{ d\sigma_{LO} + \frac{\alpha_s(\mu_R)}{2\pi} K_{ij}(R, \mu_F, \mu_R) \}$$

$K_{ij}(R, \mu_F, \mu_R)$: NLO corrections depend on renormalisation and factorisation scales and radius of jet algorithm




ZEUS Collab, Eur Phys J C4 (1998) 591

- $\sigma_{LO}$ independent of $R \leftrightarrow \sigma_{NLO}$ depends on $R$
- reduced dependence of $\sigma_{NLO}$ on $\mu_R$ and $\mu_F$

## NLO QCD calculations in $\gamma\gamma$ and $\gamma p$

- **Calculations performed by:**

→ **P Aurenche, L Bourhis, M Fontannaz and J Guillet**
(Proc of “Future Physics at HERA” (1996) 570)

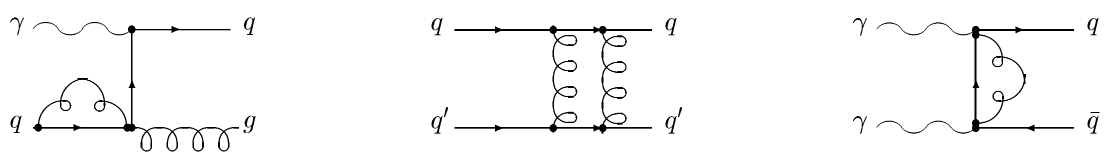
→ **S Frixione and G Ridolfi**
(Nucl Phys B507 (1997) 315)

→ **B Harris and J Owens**
(Phys Rev D57 (1998) 5555)

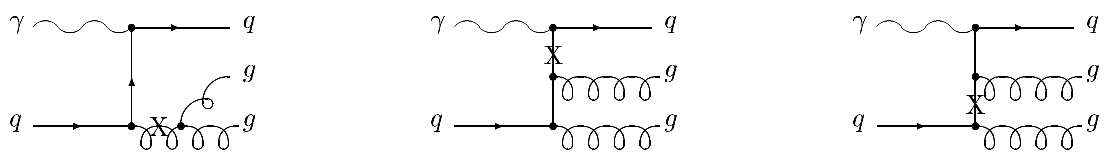
→ **M Klasen, T Kleinwort and G Kramer**
(Eur Phys J C1 (1998) 1)

- **Ingredients:**

→ **virtual corrections with internal particle loops**
**e.g.**




→ **real corrections: e.g. soft and collinear radiation**
**e.g.**



# Comparison of NLO calculations in $\gamma p$

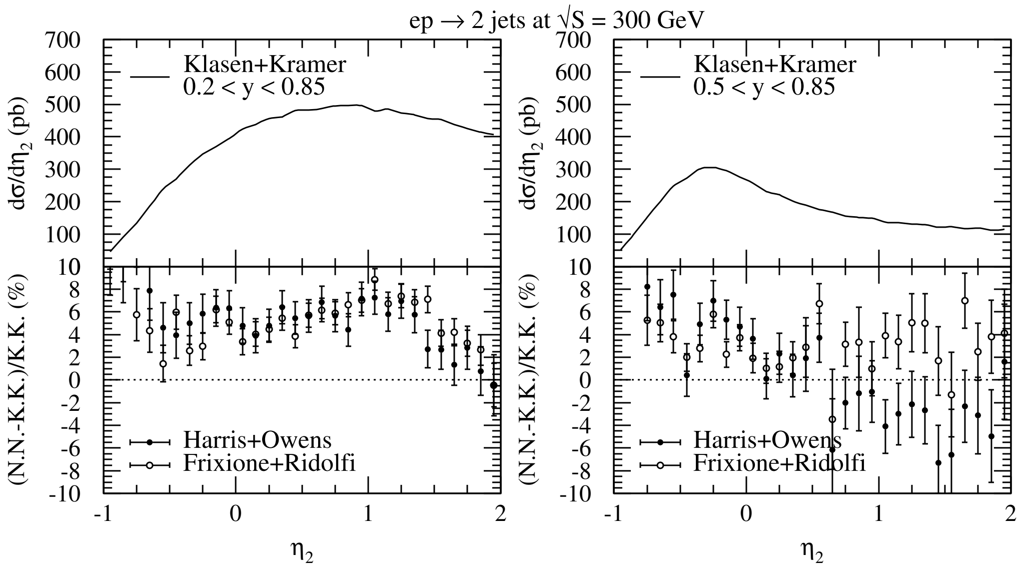
- **Different methods to calculate real corrections:**

$\longrightarrow$ phase space slicing method with invariant mass cut to isolate singular regions of phase space (Klasen et al)

$\longrightarrow$ phase space slicing method with two small cut-offs to delineate soft and collinear regions (Harris et al)

$\longrightarrow$ subtraction method (Frixione et al)

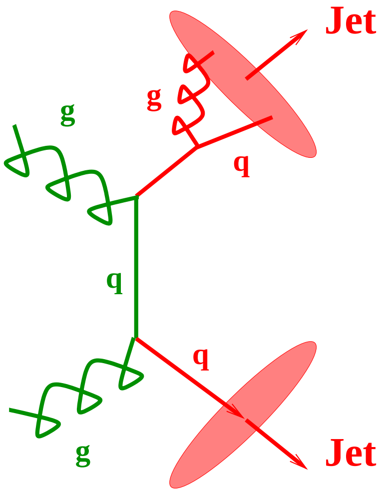
- no unphysical cut-off parameters
- reduced scheme and scale dependence
- implementation of jet definitions




B Harris, M Klasen and J Vossebeld, hep-ph/9905348

- **Calculations differ by up to $\sim 5\%$**

## Cone jet algorithm




In NLO,

jet algorithms applied on partons:

up to two partons in a jet

- Experimentally, jets are searched in pseudorapidity ($\eta$) $-$ azimuth($\varphi$) plane using the transverse-energy flow of the event
- Definition of jet variables: Snowmass Convention

$$E_T^{jet} = \sum_i E_T^i$$

$$\eta^{jet} = \frac{\sum_i E_T^i \cdot \eta_i}{E_T^{jet}}$$

$$\varphi^{jet} = \frac{\sum_i E_T^i \cdot \varphi_i}{E_T^{jet}}$$

- Iterative cone algorithm: (used in hadron interactions) jets are searched by maximizing the summed $E_T$ within a cone of radius $R$: $E_T^{jet} = \sum_i E_T^i$ for every particle $i$ such that

$$R_{i\ jet} = (\eta_i - \eta^{jet})^2 + (\varphi_i - \varphi^{jet})^2 \leq R^2$$

## Comparing theory and experiment

- To perform tests of QCD and to extract information on the parton densities, the experimental and theoretical uncertainties must be reduced as much as possible

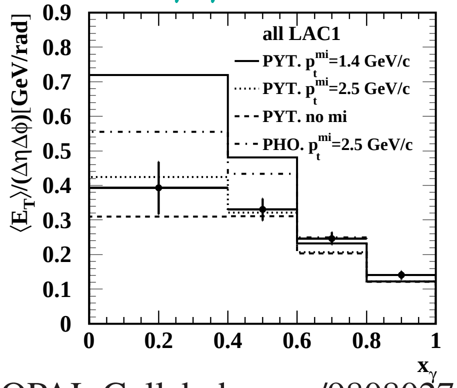
- Experimental uncertainties:
  - $\rightarrow$ "underlying event"
  - $\rightarrow$ energy scale
  - $\rightarrow$ fragmentation/hadronisation

- Theoretical uncertainties:
  - $\rightarrow$ matching experimental jet algorithm
  - $\rightarrow$ higher orders
  - $\rightarrow$ fragmentation/hadronisation

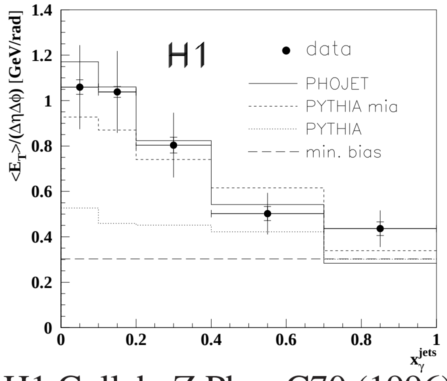
# Experimental uncertainties

## The "underlying event"

**OPAL $\gamma\gamma$ interactions** **H1 $\gamma p$ interactions**



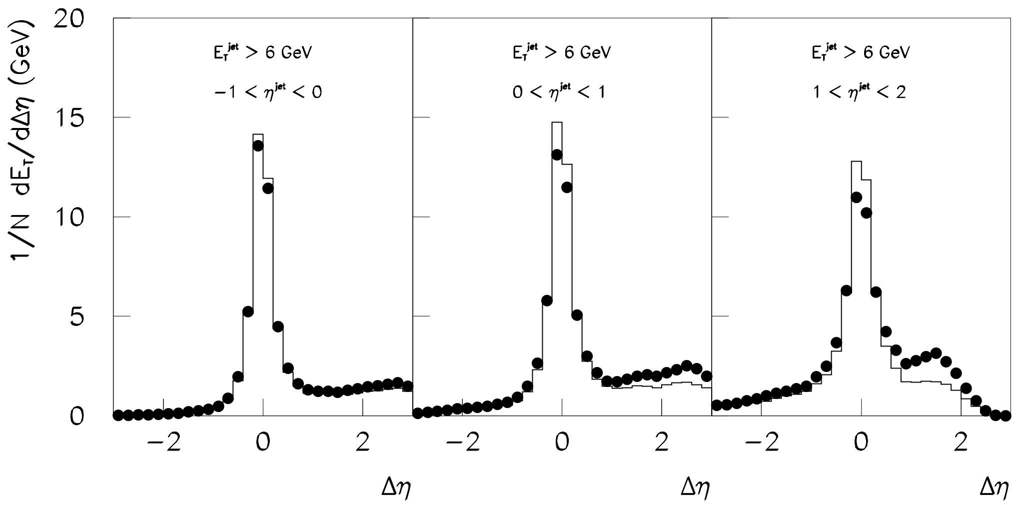

OPAL Collab, hep-ex/9808027




H1 Collab, Z Phys C70 (1996) 17

$\rightarrow$ transverse energy flow too low in the leading-log parton-shower Monte Carlo calculations without multiple interactions

**ZEUS $\gamma p$ interactions** Phys Lett B342 (1995) 417




$\rightarrow$ Jets in data broader for $1 < \eta^{jet} < 2$ and accompanied by larger $E_T$-flow than in the leading-log parton-shower Monte Carlo calculations without multiple interactions

$\longrightarrow$ **Indication of the presence of a possible "underlying event" (non-perturbative effect)**

## Reducing experimental uncertainties

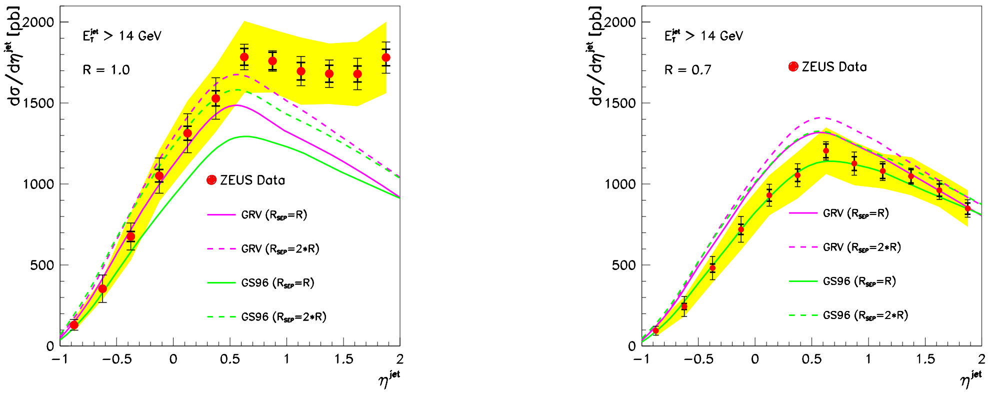
- **Subtraction of the underlying event?**

$\rightarrow$ **not possible to do it unambigously**

**(a fraction of the jet pedestal comes from QCD radiation of partons and a fraction from soft collisions)**

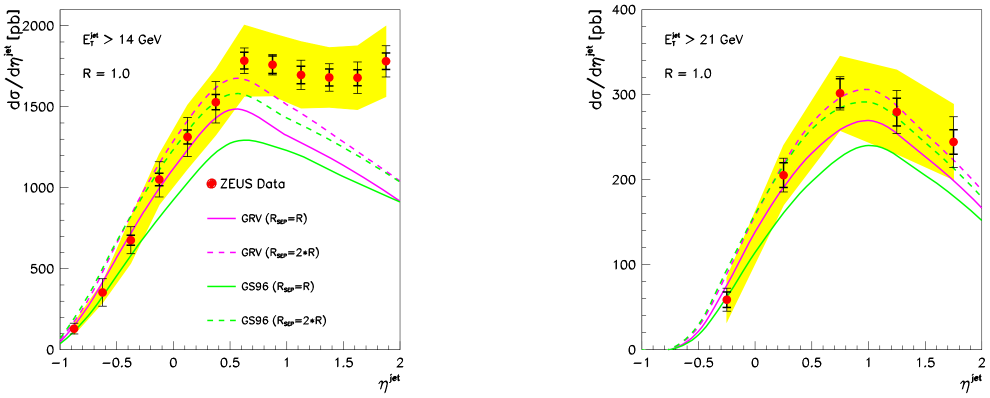
- **Find region of phase space where the contribution of the underlying event is expected to be reduced:**

$\longrightarrow$ **decrease cone radius:**




$\longrightarrow$ **increase $E_T^{jet}$:**

ZEUS Collab, Eur Phys J C4 (1998) 591




- **Good description of data by NLO calculations when reducing the cone radius and/or increasing $E_T^{jet}$**

- **energy scale: typically $\sim \pm 12\%$**
- **hadronisation: $10\%$ for $R = 1.0$, $20\%$ for $R = 0.7$ (estimated from LO Monte Carlo)**

## Theoretical uncertainties in NLO

- **Missing higher-order QCD terms:** usually estimated by varying the **renormal./factor. scale** $\mu$ ($\alpha_s$, $f_{i/p}$, $f_{i/\gamma}$) between $\mu = E_T^{jet}/4$ and $\mu = E_T^{jet} \longrightarrow \sim 5\%$ for $R = 0.7$

- **Uncertainty in matching the experimental and theoretical jet algorithms:**
  $\rightarrow$ They are particularly important for the iterative cone algorithm (effects of merging and overlapping of jets)
  $\rightarrow$ Solution: introduction of ad-hoc parameter $R_{SEP}$ to control parton recombination in the theoretical jet algorithm

**Two partons are not combined if their distance in the $\eta - \varphi$ plane is larger than $R_{SEP}$**

- **Effect on the calculations estimated by varying $R_{SEP}$ between $R_{SEP} = R$ and $R_{SEP} = 2 \cdot R$**
  $\longrightarrow \sim 20\%$ for $R = 0.7$ (major source of uncertainty in the NLO QCD calculations)

## Theoretical uncertainties in NLO II

- $R_{SEP}$ solution limited only to NLO calculations

- The cone algorithm is not infrared safe beyond NLO

→ Best solution: improve the iterative cone algorithm or use the inclusive $k_T$ cluster algorithm instead

- Inclusive $k_T$ algorithm: (used in $e^+e^-$ collisions) jets are identified by successively combining nearby pairs of particles $d_{ij} = \min(E_T^i, E_T^j)^2 \cdot (\Delta\eta_{ij}^2 + \Delta\varphi_{ij}^2)$ until a jet is complete

- transparent translation of the theoretical jet algorithm to the experimental set-up by avoiding the ambiguities related to the merging and overlapping of jets
- infrared safe to all orders

→ M Seymour

(Nucl Phys B513 (1998) 269)

## Photon structure

• The structure of the photon can be studied by

$\rightarrow$ measurement of $F_2^\gamma$ in deep inelastic $e\gamma$ scattering: direct measurement of the photon structure function (sensitive mainly to quark density in the photon)

⋆ parametrisation of the photon structure function

⋆ test of the universality of the photon structure function in other processes

$\rightarrow$ measurement of cross sections for processes with a hard interaction scale (jets, heavy quarks, prompt photons, high$-p_T$ hadron production):

⋆ comparison to NLO calculations

⋆ test of available photon parton densities parametrisations

⋆ global fits *à la* $F_2^p$

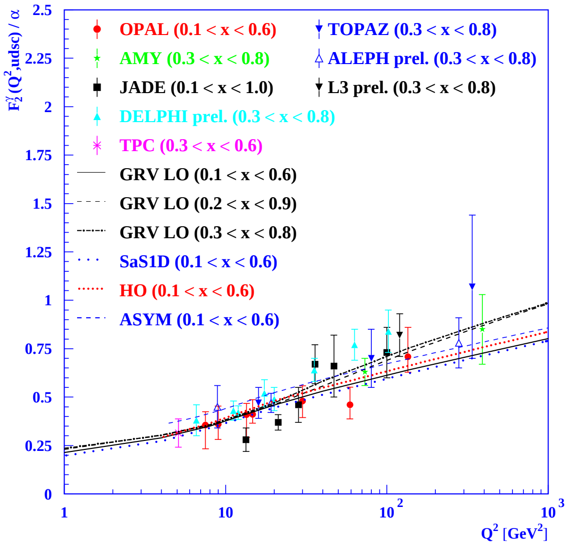
⋆ extraction of effective parton densities

$\rightarrow$ determination of the photon structure as a function of the virtuality of the photon: study of the real and virtual photon structure

# Photon structure function $F_2^\gamma(x, Q^2)$

$$f_{i/\gamma}(x,\mu^2) = f_{i/\gamma}^{\rm had}(x,\mu^2) + f_{i/\gamma}^{\rm anom}(x,\mu^2)$$

$$F_2^\gamma(x,\mu^2) = \sum_q x e_q^2 (f_{q/\gamma}(x,\mu^2) + f_{\bar{q}/\gamma}(x,\mu^2))$$

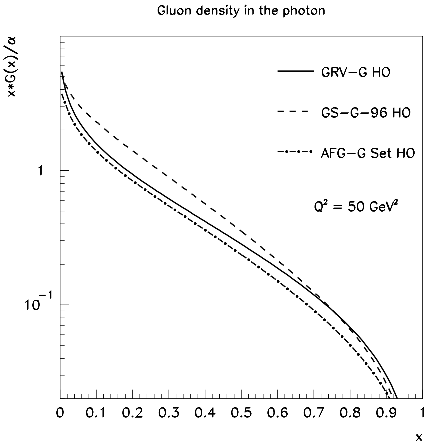


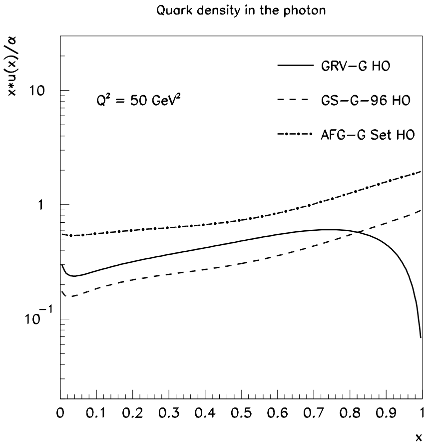

R Nisius; hep-ex/9811024

$\rightarrow$ **quark density: direct measurement in DIS $e\gamma$**

$\rightarrow$ **no momentum sum rule applies to the photon: difficult determination of the gluon density from $F_2^\gamma$**

$\rightarrow$ **There exist several parametrisations of the photon**

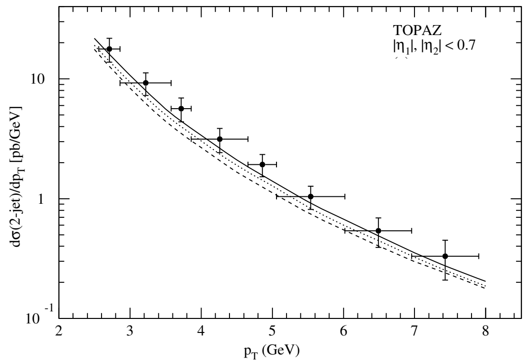


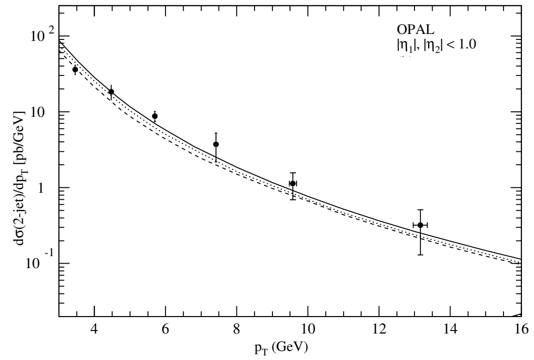

**parton densities to be tested in other experiments**

# Jet cross sections in $\gamma\gamma$

- Comparison of measured dijet cross section $\frac{d\sigma}{dp_T}$ in $\gamma\gamma$ with NLO calculations based on different photon-parton parametrisations




TOPAZ data



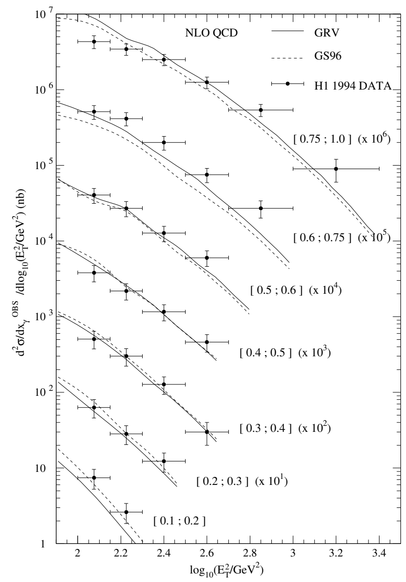

OPAL data

T Kleinwort and G Kramer; Z Phys C75 (1997) 489

- Possibility of discriminating between different parametrisations when uncertainties decrease

## Jet cross sections in $\gamma p$

H1 data

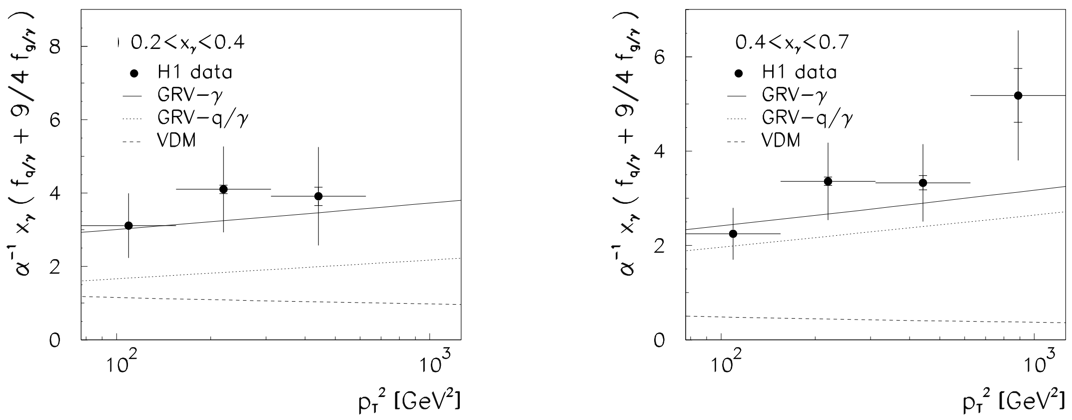


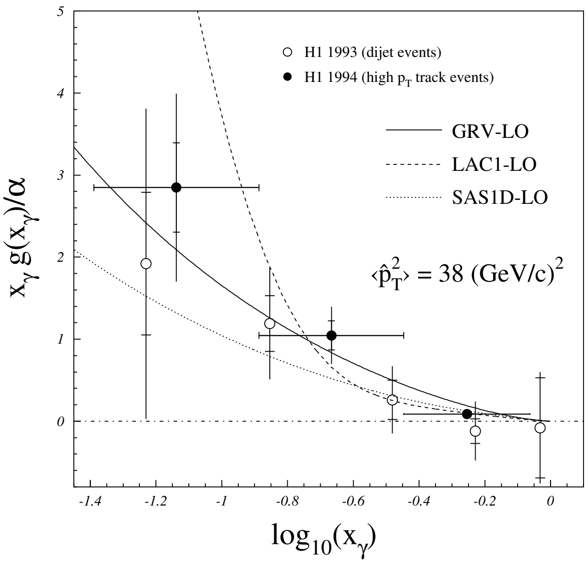
- **Comparison of measured dijet cross section $\frac{d^2\sigma}{dx_\gamma^{OBS} d\log E_T^2}$ in $\gamma p$ with NLO calculations to discriminate between different photon-parton parametrisations**
  - energy scale (hadronisation): $\sim 20(20)\%$

M Klasen, T Kleinwort and G Kramer; Eur Phys J C1 (1998) 1

- **Measured cross sections used to extract a LO effective parton density in the photon**

H1 Collab, Eur Phys J C1 (1998) 97

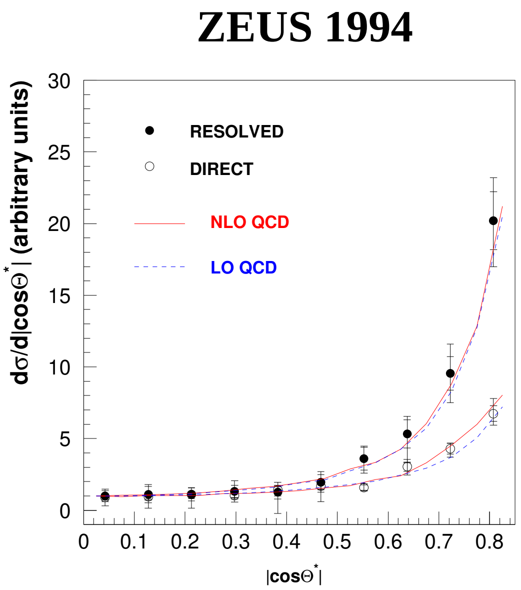




- **Gluon density in the photon at LO extracted from measurements of dijet cross sections and high-$p_T$ inclusive particle production**

H1 Collab, DESY 98-148

# The hard subprocess in $\gamma p$




- **Sensitive to the spin of the exchanged particle**

**resolved: gluon exchange**

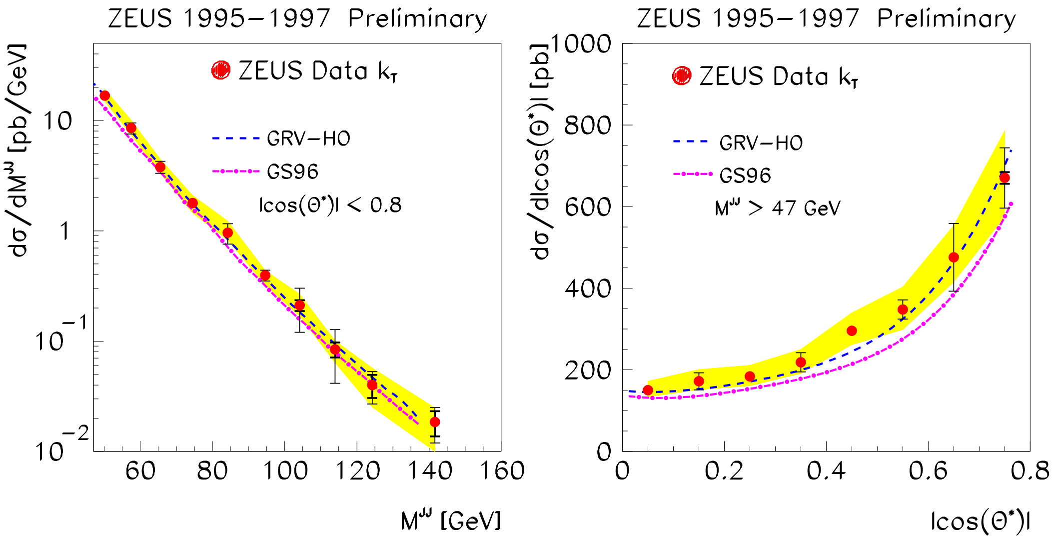
$$\sim (1 - |\cos\theta^*|)^{-2}$$

**direct: quark exchange**

$$\sim (1 - |\cos\theta^*|)^{-1}$$

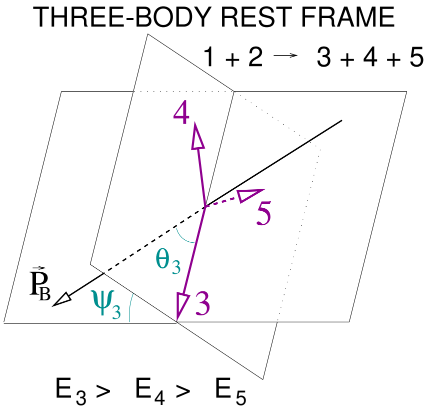
ZEUS Collab, Phys Lett B384 (1996) 401

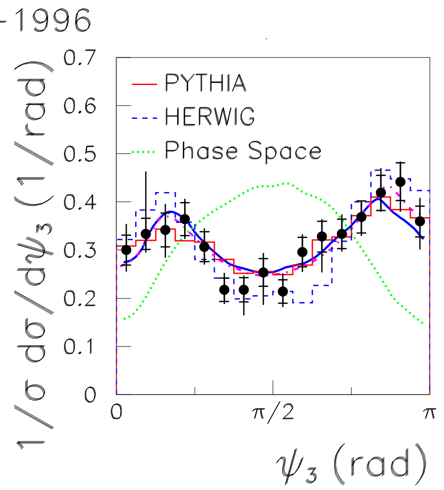
- **New particles or resonances may be identified by deviations of the measured cross sections w.r.t. QCD**




ZEUS Collab,

ICHEP'98 805



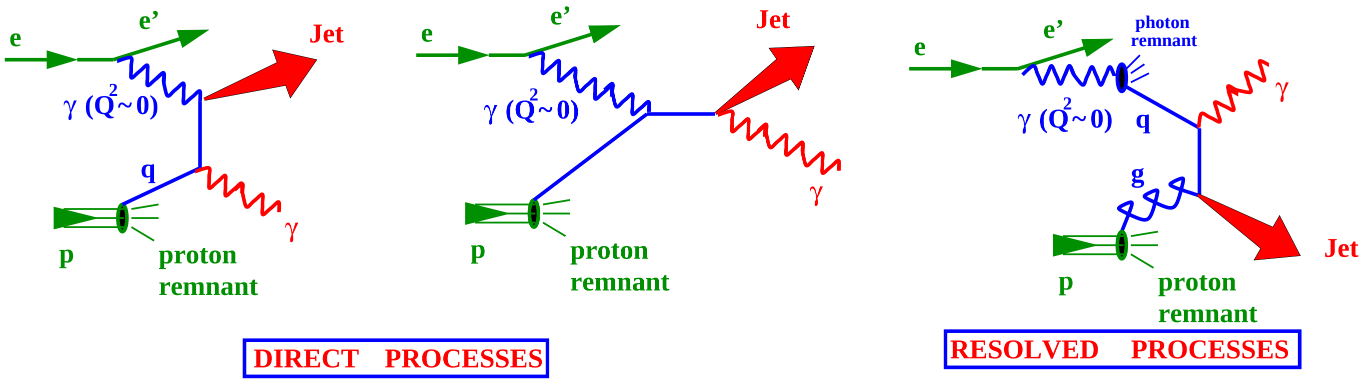




- **Angular distribution different from phase space; consistent with QCD**

ZEUS Collab,
Phys Lett B443 (1998) 394

## Prompt photon production in $\gamma p$

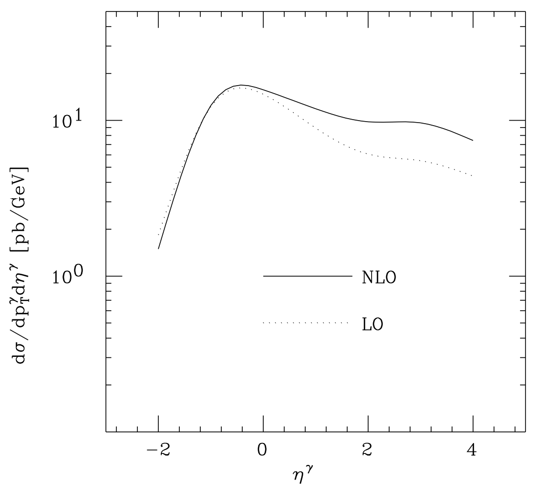
$$ep \to e + \gamma + \text{jet} + X$$




$$\sigma^{ep}_{LO} = \int dPS\, f_{\gamma/e}(y)\, f_{j/p}(x_p, \mu_F^2) \times$$
$$f_{i/\gamma}(x_\gamma, \mu_F^2)\, d\sigma(ij \to \gamma\ \text{jet})$$

- Prompt photon processes provide a means to study the quark and gluon content of the proton and the quark content of the photon

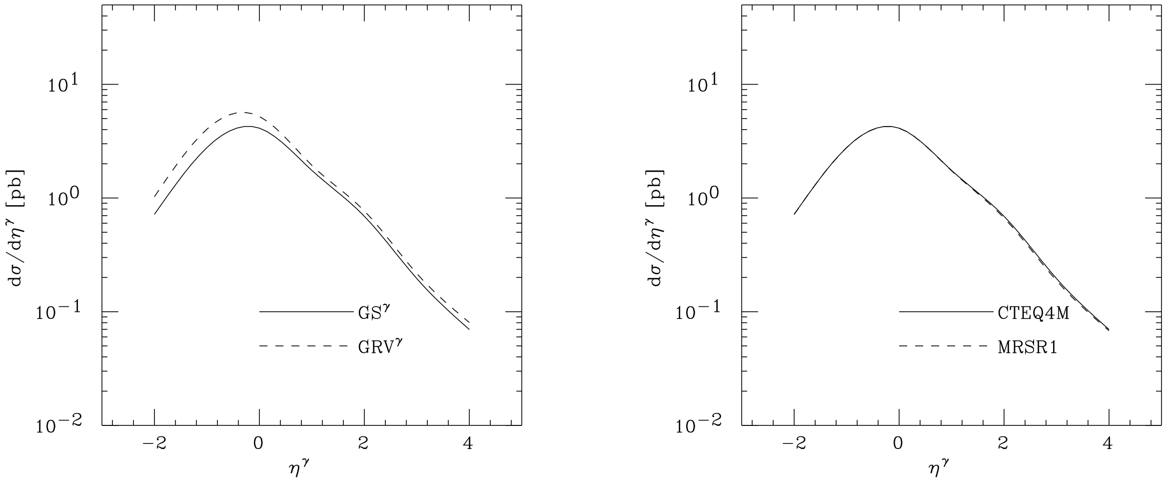
- Advantage with respect to jet cross sections: the observed final-state photon emerges directly from the hard interaction (no hadronisation)



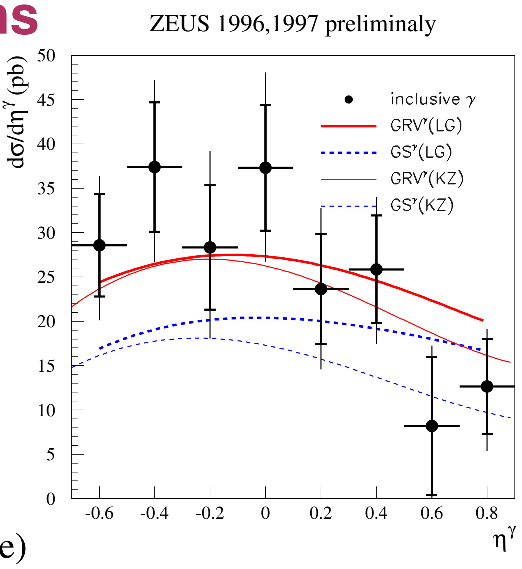

L E Gordon,
Phys Rev D57 (1998) 235

## Prompt photon production in $\gamma p$ at NLO QCD

- **NLO calculations of prompt photon + jet production performed by**
  - $\rightarrow$ **L E Gordon** (Phys Rev D57 (1998) 235)
  - $\rightarrow$ **M Krawczyk and A Zembrzuski** (hep-ph/9810253)
- **Calculations performed using the phase space slicing method: possibility of implementing photon isolation and jet algorithms as in the experiment**
- **Measurements of $d\sigma/d\eta^{\gamma}$ sensitive to (mainly) quark density in the photon:**



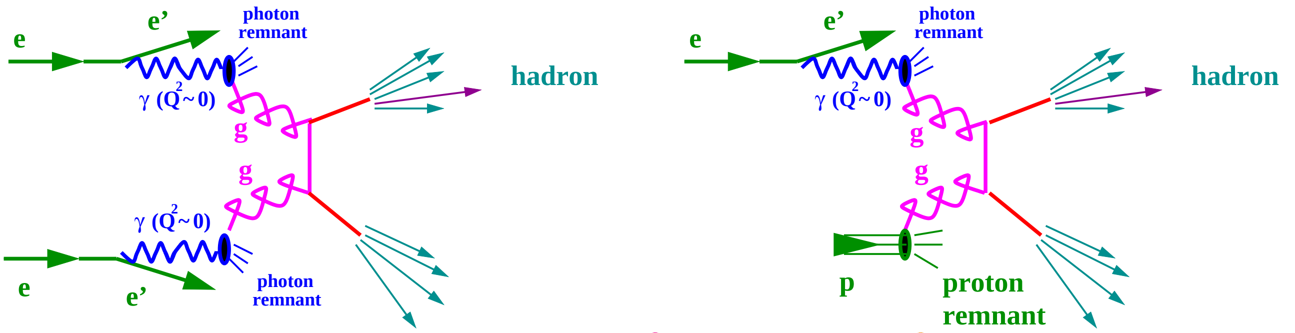

- **Comparison of measured cross section $d\sigma/d\eta^{\gamma}$ with NLO calculations based on different photon-parton parametrisations**




(See talk by Sung Won Lee)

# Inclusive hadron production

- Inclusive hadron production at high $p_T$ provides a test of QCD and is sensitive to the photon-parton densities
- The detection of single mesons and baryons allows the study of fragmentation
- Advantages with respect to jet cross sections: no ambiguities due to jet algorithms, the uncertainties from energy scale and underlying event are largely reduced
- Disadvantage: need information about the fragmentation functions




$$\sigma_{LO}^{ep} = \int dPS\ f_{\gamma/e}(y)\ f_{j/\gamma}(x_\gamma, \mu_F^2)\ f_{i/p}(x_p, \mu_F^2) \times F_{h/k}(x_h, M_h^2)\ d\sigma(ij \to kl)$$

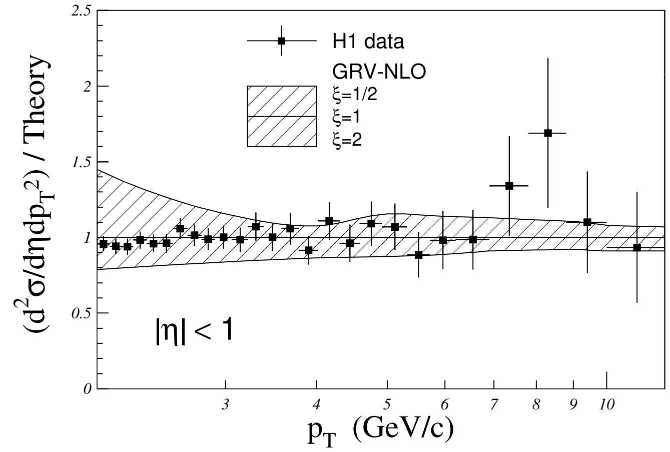
$$\sigma_{LO}^{e^+e^-} = \int dPS\ f_{\gamma/e}(y^{(1)})\ f_{j/\gamma}(x_\gamma^{(1)}, \mu_F^2)\ f_{\gamma/e}(y^{(2)})\ f_{i/\gamma}(x_\gamma^{(2)}, \mu_F^2) \times F_{h/k}(x_h, M_h^2)\ d\sigma(ij \to kl)$$

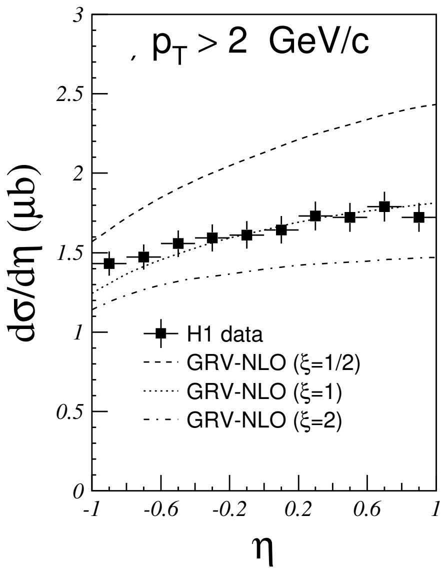
- NLO calculations by
  - $\to$ B A Kniehl and G Kramer ($\gamma p$) (Z Phys C62 (1994) 53)
  - $\to$ J Binnewies, B A Kniehl and G Kramer ($\gamma\gamma$) (Phys Rev D53 (1996) 6110)

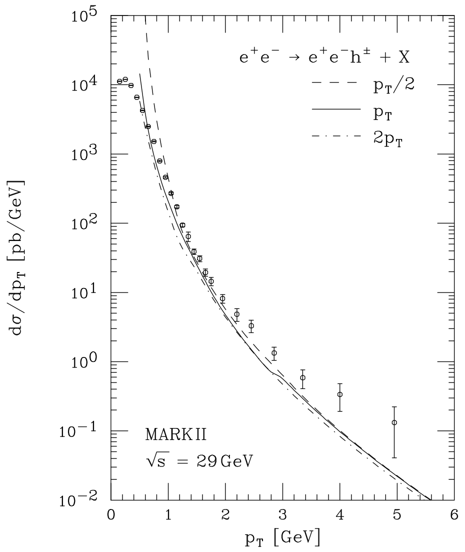
# Inclusive hadron production

- **Good description of data by NLO calculations in $\gamma p$**

H1 Collab, DESY 98-148



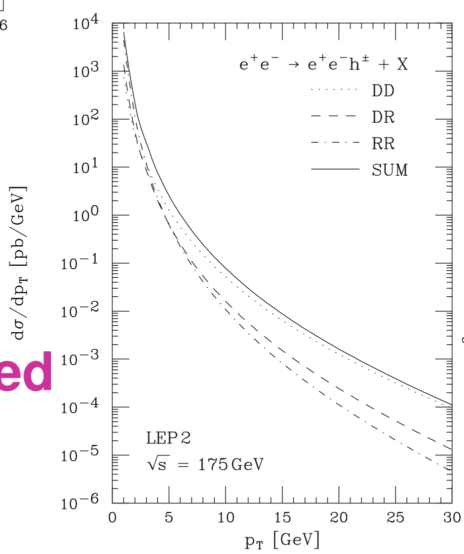



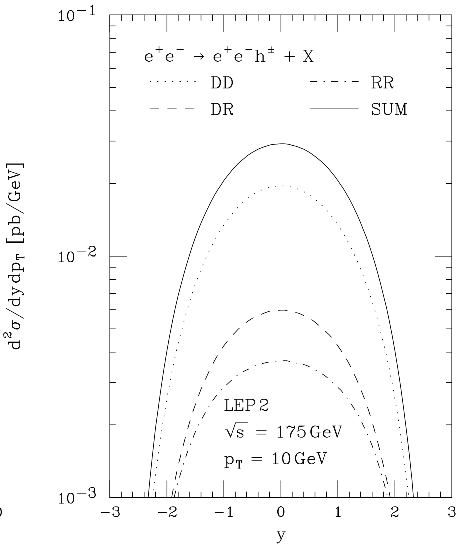

- **Description of $\gamma\gamma$ data at low $\sqrt{s}$ fails at large $p_T$**

J Binnewies, B A Kniehl and G Kramer, Phys Rev D53 (1996) 6110

- **Calculations at LEP energies prepared to be tested**

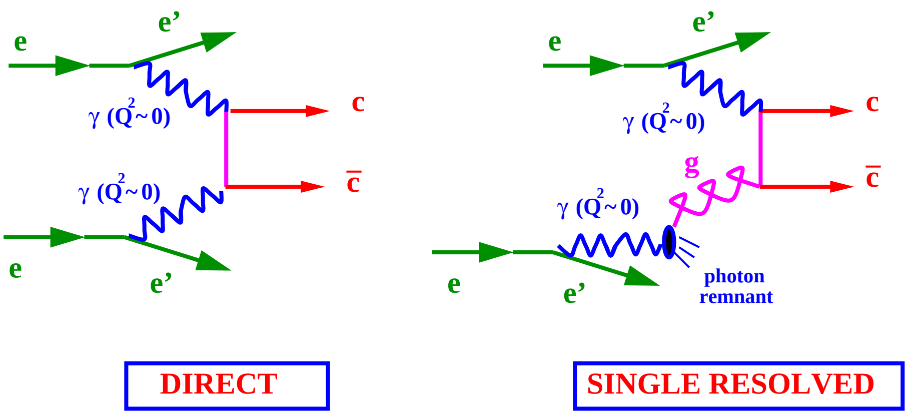
(See talk by Bernd Surrow)



## Heavy quark production in $\gamma\gamma$

$$e^+e^- \to e^+e^- + c\bar{c} + X$$




- At LEP energies, the direct and single resolved are predicted to give comparable contributions; the contribution from double resolved is expected to be small

- The dominant contribution in single resolved is that of the photon-gluon fusion process: $\gamma g \to c\bar{c}$

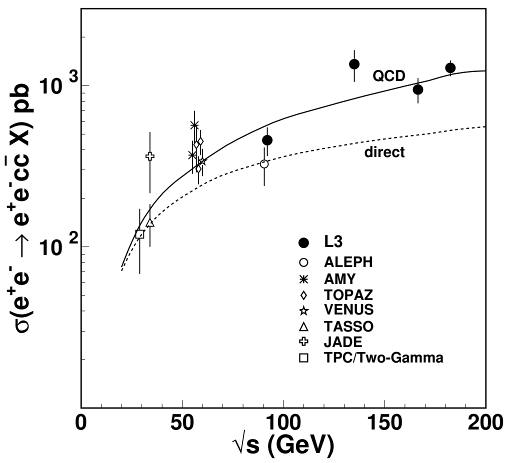
- Charm production in $\gamma\gamma$ provides a test of QCD and is sensitive to the gluon density in the photon

- NLO calculations by
  $\to$ M Drees, M Krämer, J Zunft and P M Zerwas (Phys Lett B306 (1993) 371)

- Significant gluon content in the photon

(See talks by Roger McNeil and Jochen Patt)

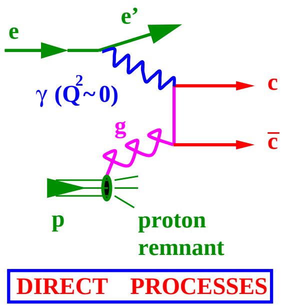
- Measurement by L3 using semi-leptonic decays ($e^\pm$, $\mu^\pm$)

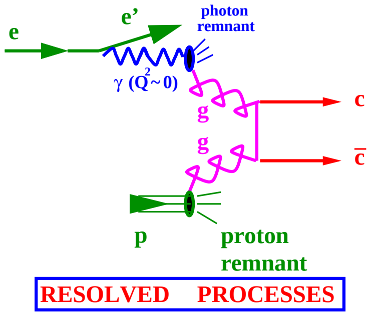



L3 Collab, CERN-EP 98-185

# Heavy quark production in $\gamma p$

$$ep \rightarrow e + c\bar{c} + X$$



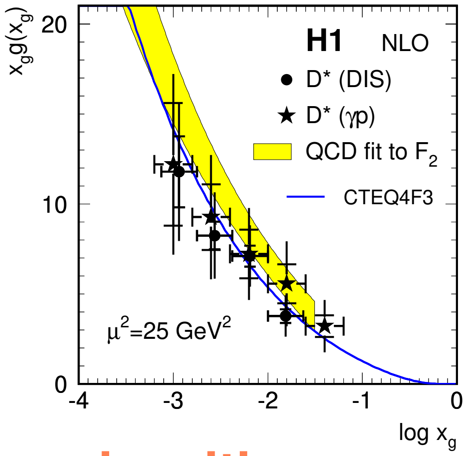

**Charm tagged by reconstructing $D^*$ mesons**

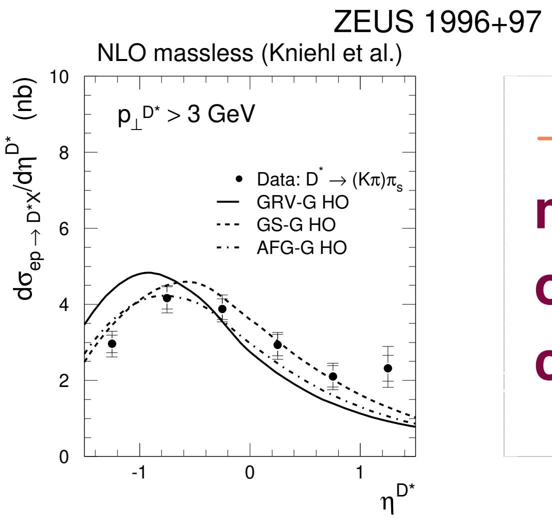
- **Charm production in $\gamma p$ is sensitive to**

**gluon in the proton/photon** | **charm in the photon**

**$\rightarrow$ gluon in the proton: select region of phase space where resolved contribution is reduced**

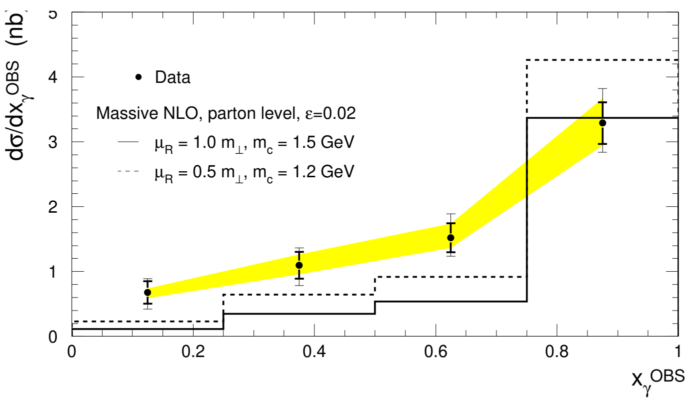
H1 Collab, DESY 98-204



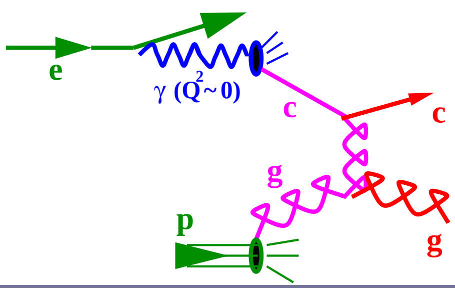




**$\rightarrow$ photon-parton densities: measurements made in region of phase-space where resolved contribution is sizeable**

ZEUS Collab, Eur Phys J C6 (1999) 67




**$\rightarrow$ charm in the photon?**



# Virtual photon structure

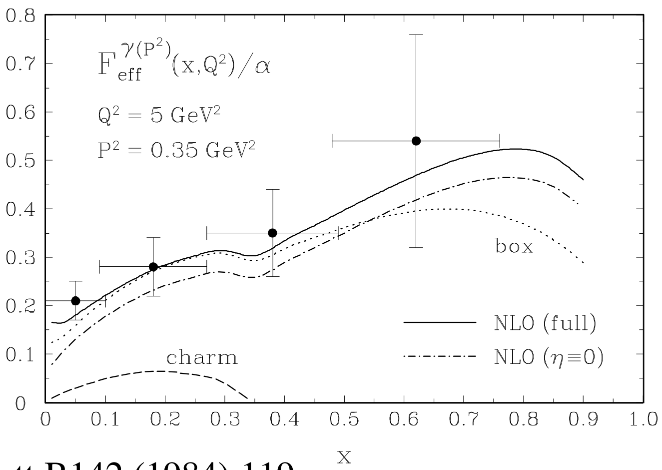
- Real photons have partonic structure (measurements of $F_2^\gamma$ in $e\gamma$ interactions and observation of resolved process in $\gamma p$ interactions and of single- and double-resolved processes in $\gamma\gamma$)

- Virtual photons should also have a partonic structure: QCD predicts that the parton densities of virtual photons become logarithmically suppressed as $P^2$ (virtuality of the probed photon) increases at fixed $\mu^2$ (scale of interaction: $Q^2$ in DIS $e\gamma$ and $E_T^{jet}$ in jet production)

- For $\mu^2 > P^2$, it is possible to "resolve" the photon

$$f_{i/\gamma^*}(x, P^2, \mu^2) = f_{i/\gamma^*}^{\text{had}}(x, P^2, \mu^2) + f_{i/\gamma^*}^{\text{anom}}(x, P^2, \mu^2)$$

- Measurement of $F_{\text{eff}}^{\gamma^*} \equiv F_2 + \frac{3}{2} F_L$ by PLUTO




PLUTO Collab, Phys Lett B142 (1984) 119
M Glück, E Reya and M Stratmann, Phys Rev D51 (1995) 3220

# Virtual photon structure

- Even less experimental information than for real photons

- Parametrisations of the virtual-photon parton densities:

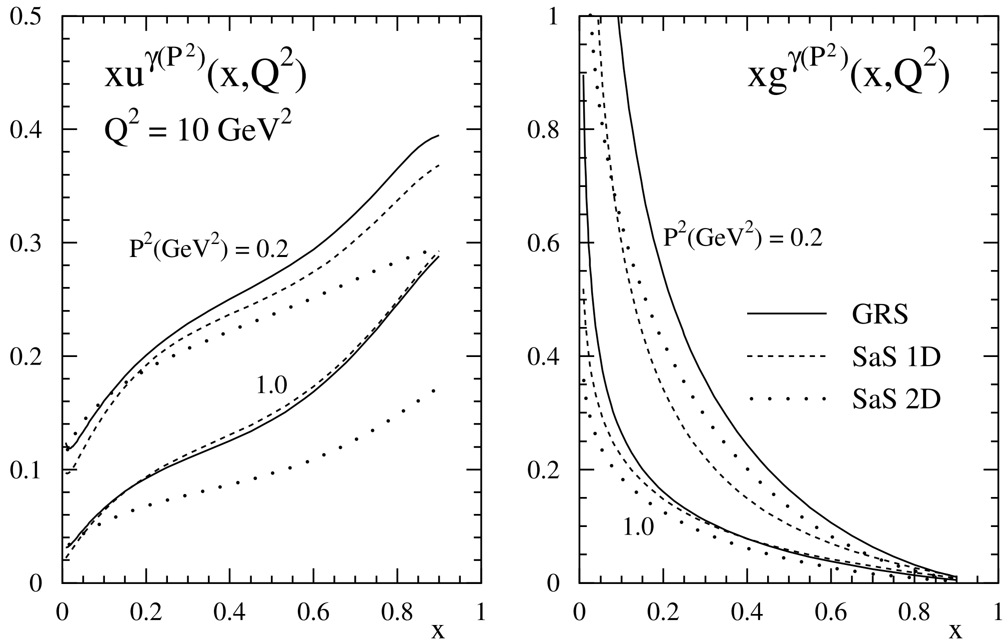
  $\rightarrow$ G A Schuler and T Sjöstrand
  (Phys Lett B376 (1996) 193)

  $\rightarrow$ M Glück, E Reya and M Stratmann
  (Phys Rev D54 (1996) 5515)

- Both parametrisations extrapolate the real ($P^2 = 0$) photon parton densities to $P^2 > 0$ with the hadronic part as

  $\rightarrow$ GRS: $\pi$ parton densities

  $\rightarrow$ SaS: fit to a coherent sum of the lowest-lying vector meson states $\rho$, $\omega$, $\phi$

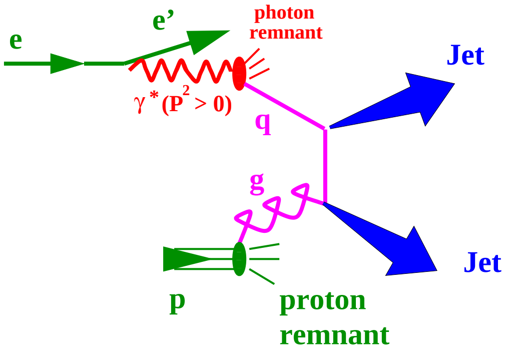


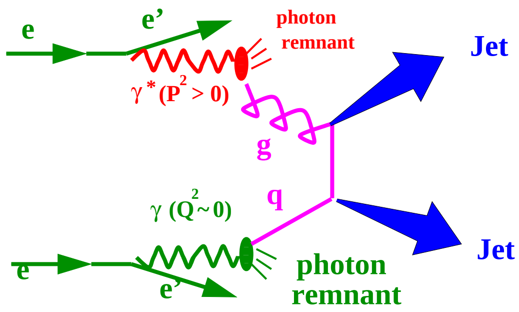

M Glück, E Reya and M Stratmann, Phys Rev D54 (1996) 5515

$\rightarrow$ parametrisations available to be tested

## Virtual photon structure in $\gamma\gamma$ and $\gamma p$

$$\gamma^*(\gamma/p) \rightarrow \text{jet} + \text{jet} + X$$

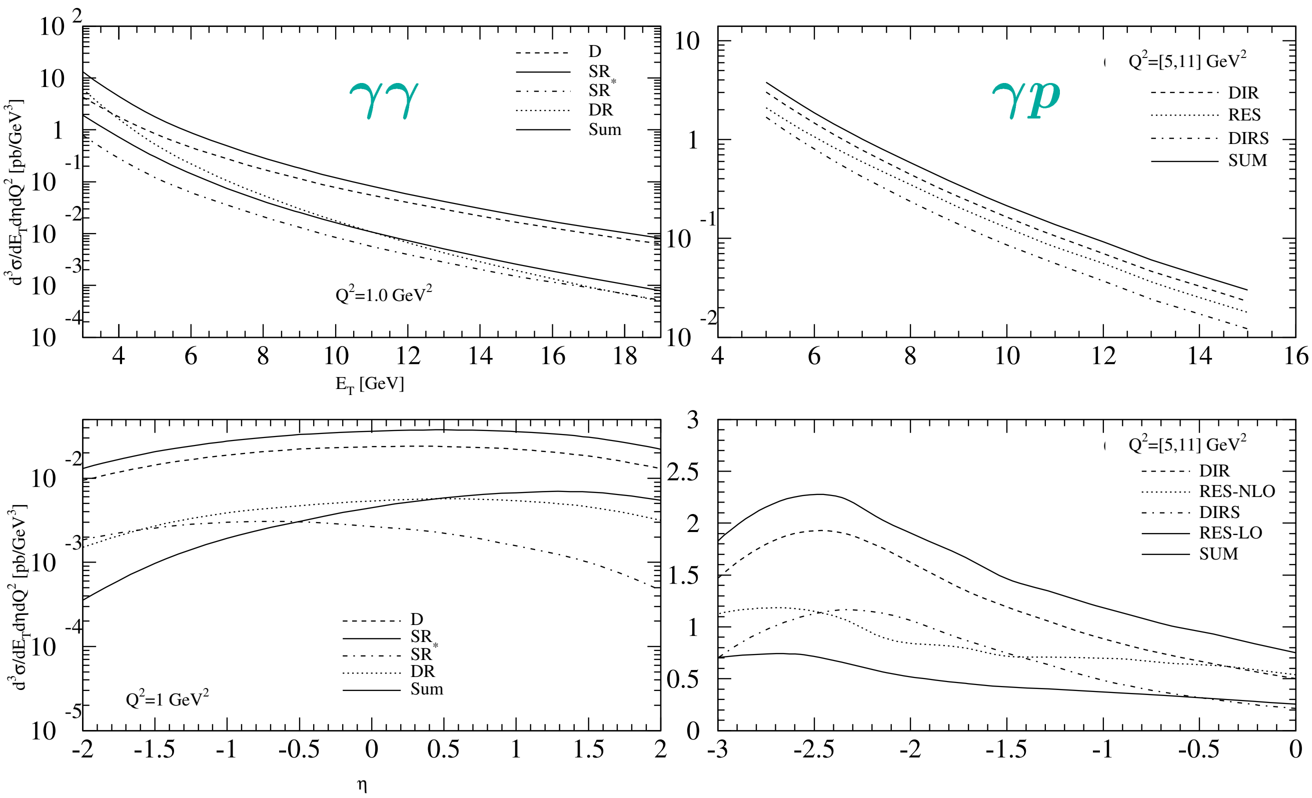



$$\sigma_{LO}^{ep(e\gamma)} = \int dPS\ f_{\gamma^*/e}(y)\ f_{j/p(\gamma)}(x_{p(\gamma)}, \mu_F^2) \times$$

$$f_{i/\gamma^*}(x_{\gamma^*}, \mu_F^2, P^2)\ d\sigma(ij \rightarrow \text{jet jet})$$

- **NLO calculations in $\gamma\gamma$ and $\gamma p$ by**
  $\rightarrow$ **M Klasen, G Kramer and B Pötter**
  (Eur Phys C1 (1998) 261)



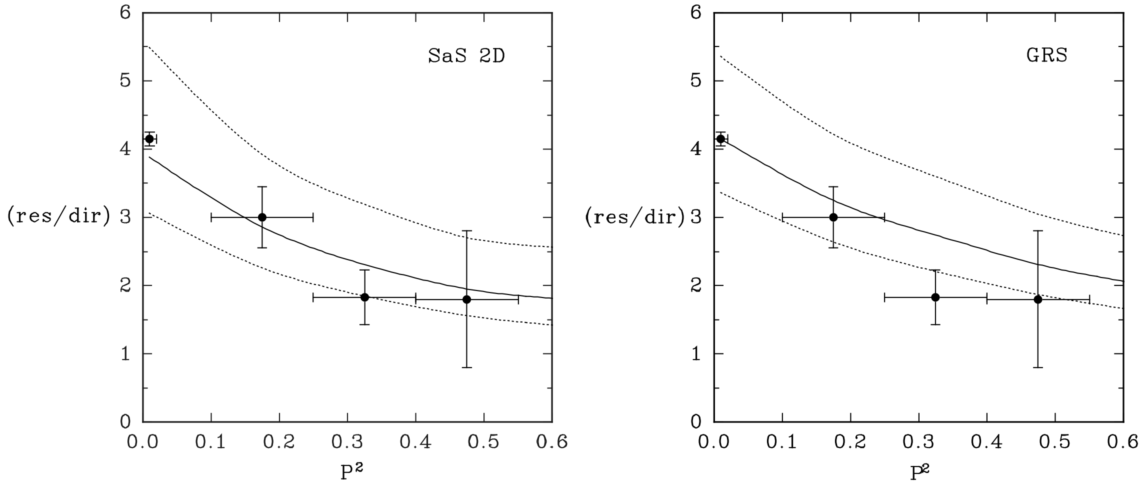
## $\frac{d\sigma_{RES}}{d\sigma_{DIR}}$ vs $P^2$ in $\gamma p$

- **LO calculations of $\frac{d\sigma_{RES}}{d\sigma_{DIR}}$ by**

  $\rightarrow$ **D de Florian, C García Canal and R Sassot**

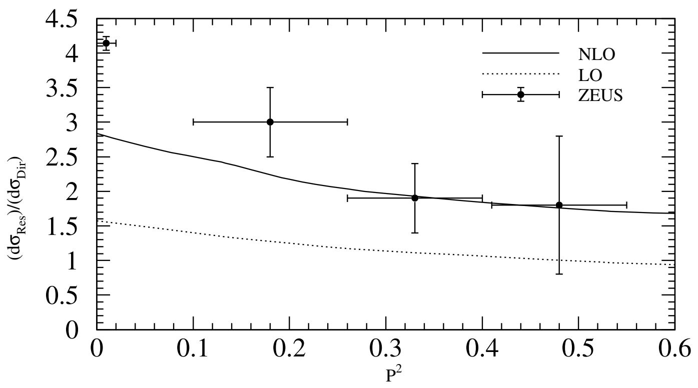
  (Z Phys C75 (1997) 265)

**ZEUS data**




- **Comparison of measured dijet cross section $d\sigma_{RES}/d\sigma_{DIR}$ in $\gamma p$ as a function of $P^2$ with NLO calculations**

**ZEUS data**




M Klasen, G Kramer and B Pötter, Eur Phys C1 (1998) 261

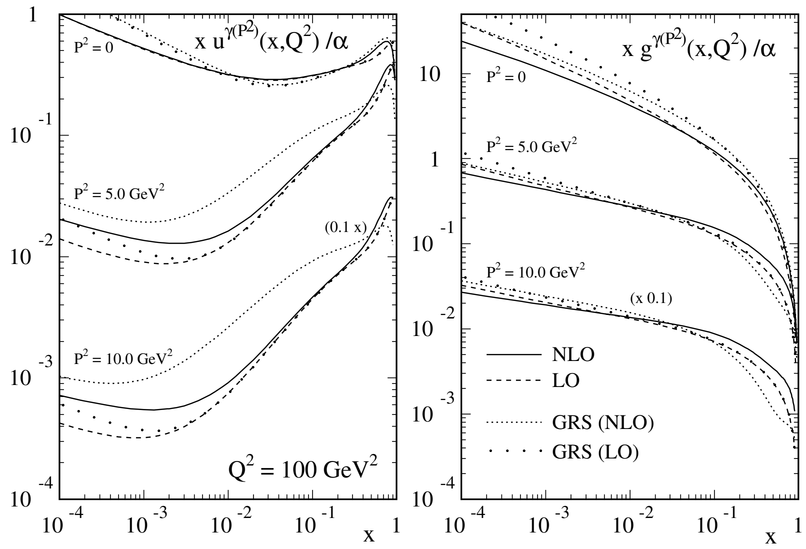
- **Possibility of discriminating between different parametrisations when uncertainties decrease**

## Virtual photon structure

- **New virtual-photon parametrisation:**

$\rightarrow$ M Glück, E Reya and I Schienbein (hep-ph/9903337)

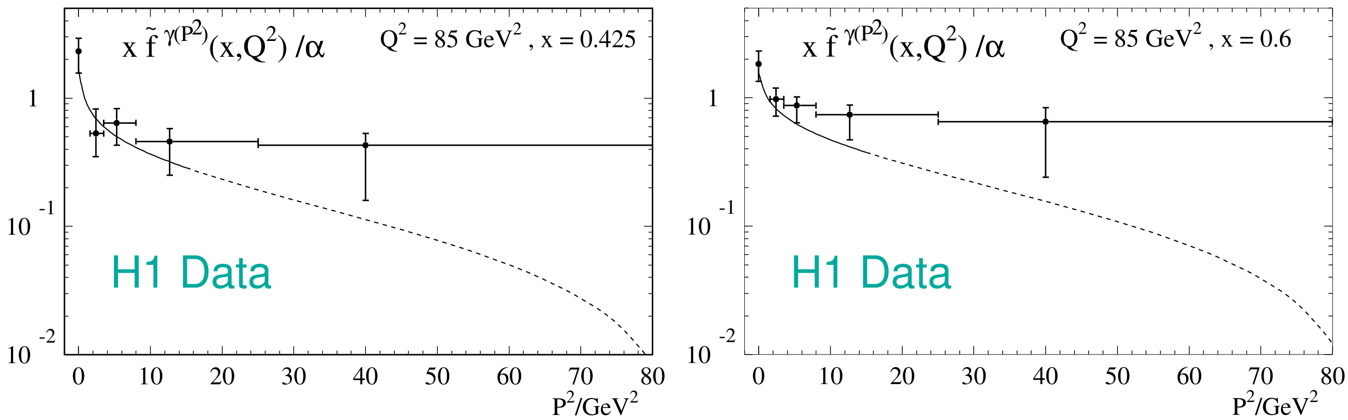
- **The photon-parton densities extend from the real ($P^2 = 0$) to the virtual ($P^2 > 0$) photon**




- **Comparison of extracted effective parton density at LO in the virtual photon**

$$\tilde{f}_{\gamma^*} = \sum_{q=u,d,s}(q_{\gamma^*} + \bar{q}_{\gamma^*}) + \frac{9}{4} g_{\gamma^*}$$

**in $ep$ as a function of $P^2$ with LO predictions**



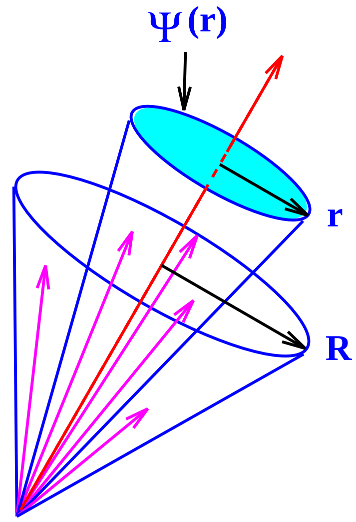

$\rightarrow$ **Description fails when $P^2$ approaches $Q^2$**

# Jet substructure

## Jet shape

• average fraction of the jet's transverse energy inside an inner cone $r < R$, concentric with the jet defining cone

$$\psi(r) = \frac{1}{N_{jets}} \sum_{jets} \frac{E_T(r)}{E_T(r = R)}$$




## QCD predictions

• At sufficiently high $E_T^{jet}$, the jet shape is expected to be driven by gluon emission off the primary parton, and therefore, calculable in pQCD

• Gluon jets are predicted to be broader than quark jets due to the gluon-gluon coupling strength being larger than that of the quark-gluon

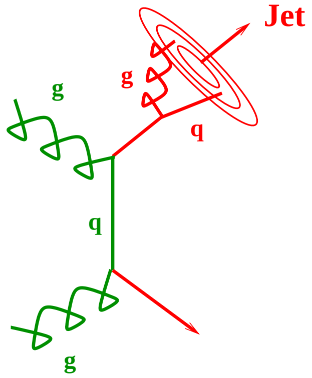
## QCD calculations

• At LO a jet consists of only ONE parton and thus it has no structure

• NLO calculations give the lowest non-trivial order contribution to the jet structure

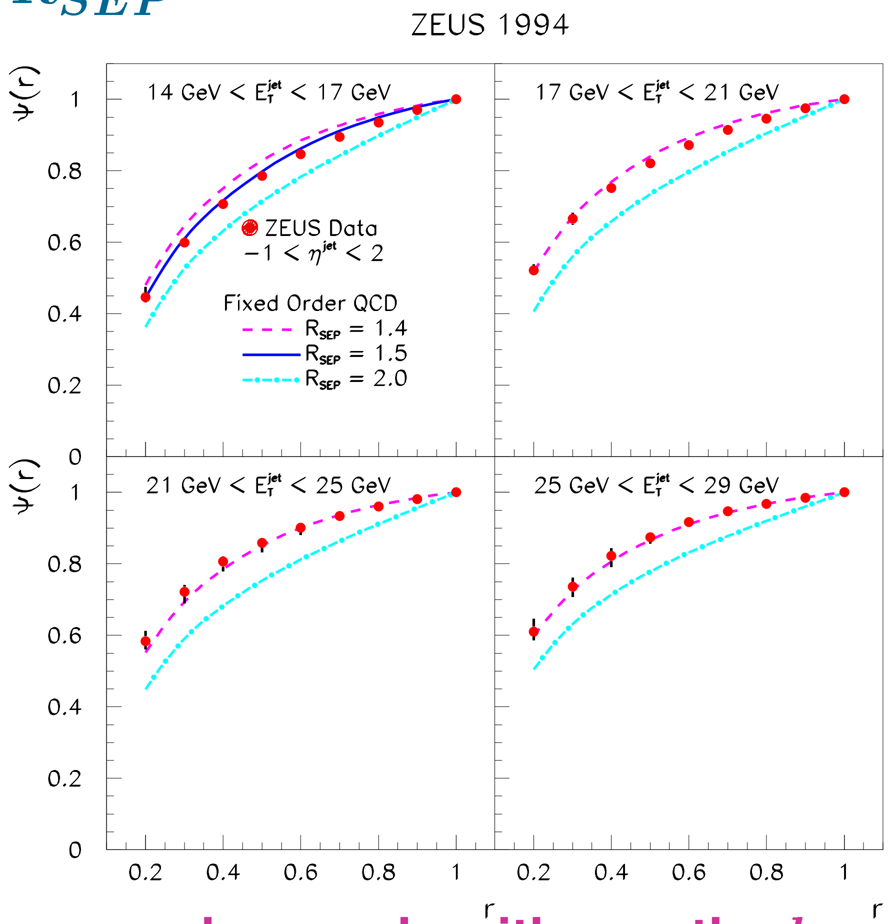
- **Calculations by**

  $\rightarrow$ **M Klasen and G Kramer** (Phys Rev D56 (1997) 2702)




**Only up to three partons in the final state: not more than two partons build up a jet**

- **The calculation are $O(\alpha_s)$ $\rightarrow$ strong dependence on $\mu$ and $R_{SEP}$**




ZEUS Collab,

Eur Phys J C2 (1998) 61

- **An improved cone algorithm or the $k_T$ algorithm will allow to make very stringent tests of the jets sub-structure in QCD**
- **The $k_T$ algorithm allows the study of subjets ("jets within jets") $\rightarrow$ independent test of the jet substructure**

(See talk by Sabine Wölfle)

## Conclusions pre PHOTON'99

• Significant progress in comparing measurements and NLO calculations of jet cross sections, heavy quark production and hadron production has been achieved

• Experimental and theoretical uncertainties have been reduced to help constrain the parton densities in the real and virtual photon

• Measurements of the jet shapes and subjets will allow a very stringent test of the QCD substructure of the jets when higher order corrections are available

## ... and challenges for PHOTON'99

$*$ Hadronisation/underlying event:

$\Longrightarrow$ tuning of $\gamma\gamma$ and $\gamma p$ Monte Carlo

$*$ Statistically-limited measurements (e.g. prompt photon, virtual photon):

$\Longrightarrow$ more data needed

$*$ Global analysis of hard inclusive photon-induced processes:

$\Longrightarrow$ new generation of photon parton densities