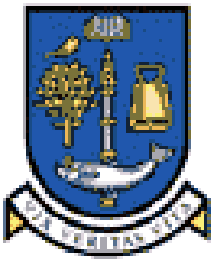
# VIRTUAL PHOTON STRUCTURE AT HERA.

P J BUSSEY

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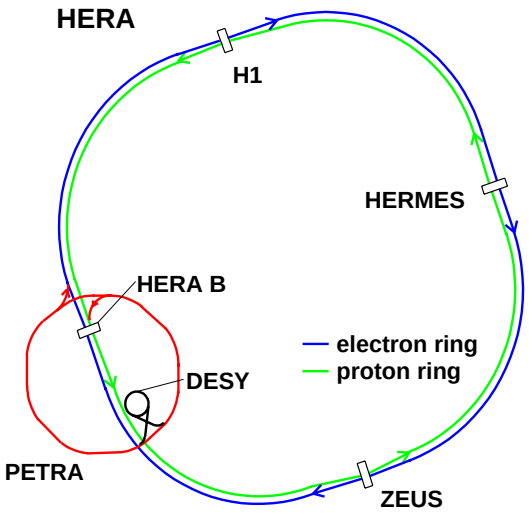
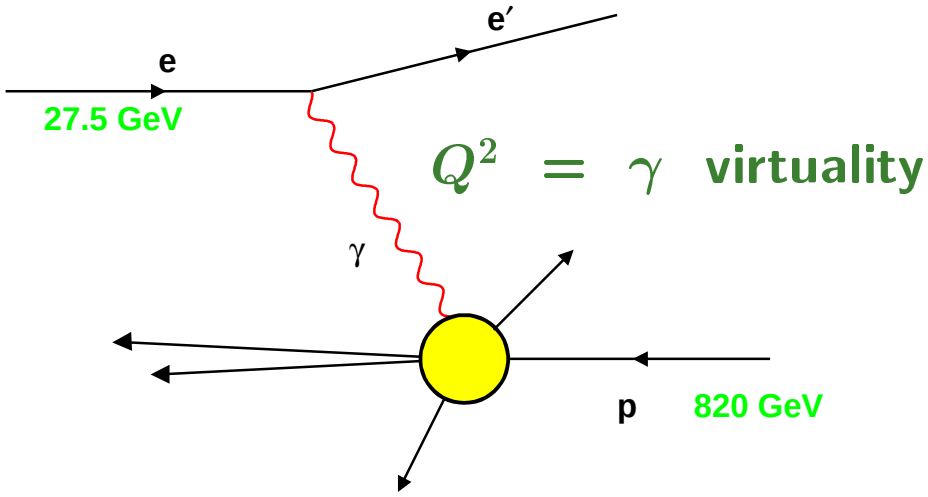
## CONTENTS

# THE HERA COLLIDER



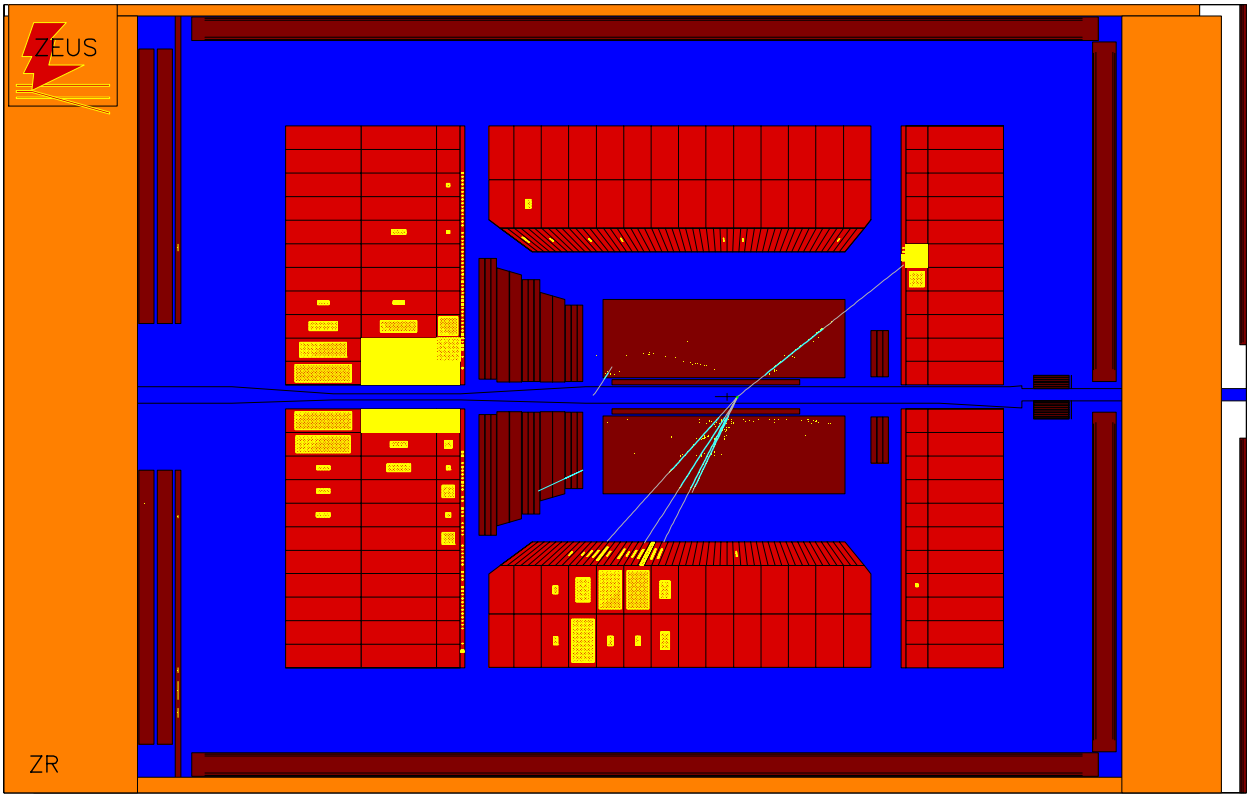

$Q^2 \approx 0$ — photoproduction $\gamma p$

$Q^2 = O(1\ \ \text{GeV}^2)$ — 'Low $Q^2$' transition region

$Q^2 \gg 1\ \ \text{GeV}^2$ — Deep Inelastic Scattering (DIS)

**Wish to study photon structure over these regions with special regard to transition region and DIS.**

## A typical DIS event



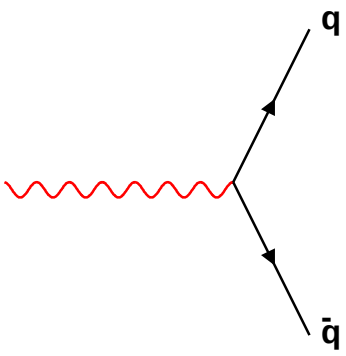

At lowest order (quark parton model) the virtual photon ejects a single quark from the proton: $\rightarrow$ one jet

No equivalent in photoproduction ( $Q^2 \approx 0$ )

Can tag with $e'$ for $Q^2 \gtrsim 0.2$ GeV$^2$ using low-angle 'beam-pipe' + rear calorimeters $\rightarrow$ measure dijet events through transition region from photoproduction.

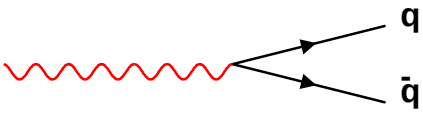
Use tag to reconstruct $\gamma^* p$ c.m. frame.

# TYPES OF PHOTON COUPLING




point-like (perturbative)

hadronic (non-perturbative)



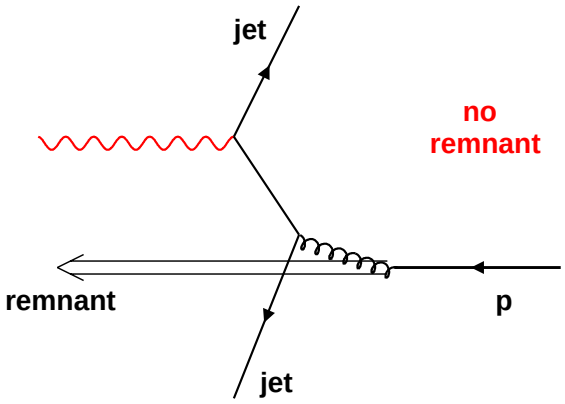

anomalous (perturbative)

**These couplings can in principle be studied at all $Q^2$ .**

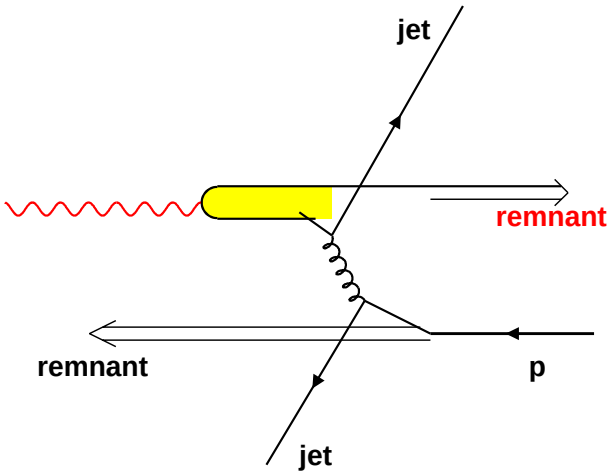
$\rightarrow$ **sensitivity to photon structure**

# TYPES OF PHOTON PROCESS

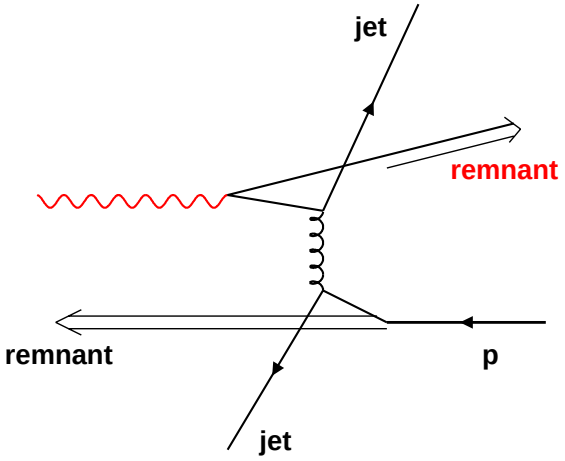
## Examples of dijet processes.




DIRECT




RESOLVED




looks resolved.

NLO since 3 perturbative vertices

Direct / resolved fully distinct only at LO.

# THEORETICAL FRAMEWORK

**Aim: to study effective structure of virtual photon as function of $Q^2$ , with special reference to 'transition region' $Q^2 = O(1)$ GeV $^2$**

**In perturbative QCD, assuming factorisation (OK at NLO):**

$$d\sigma_{ep\to e+2\text{jets}} = \Sigma_{a,b} \int_0^1 dy\, f_{\gamma^*/e}(y, Q^2) \int_0^1 dx_{\gamma^*}\, f_{a/\gamma^*}(x_{\gamma^*}, Q^2, \mu^2_{F\gamma^*}) \times \int_0^1 dx_p\, f_{b/p}(x_p, \mu^2_{Fp})\, d\sigma_{ab\to 2\text{jets}}(\mu_R)$$

**where there are two contributions to the $\gamma*$ PDFs:**

$$f_{a/\gamma^*} = f^{\text{had}}_{a/\gamma^*} + f^{\text{pert}}_{a/\gamma^*}$$

**Boundary is factorisation-scale $(\mu_F)$ dependent.**

**DISASTER++ (D. Graudenz)**
**used as NLO parton-level Monte Carlo.**

**PYTHIA and ARIADNE**
**used to convert data and NLO partons to the hadron level.**

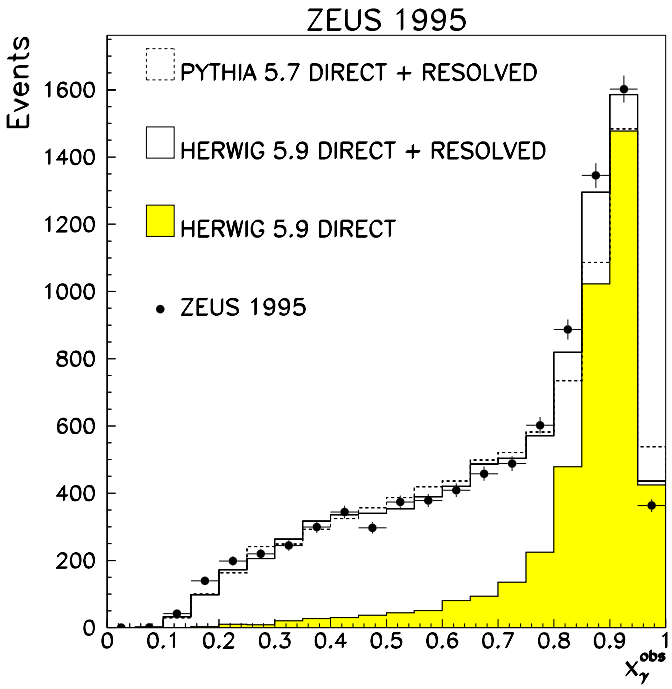
# DIJET EVENTS

**Dijet events identified in $\gamma^* p$ c.m. frame**
**$E_T^1$, $E_T^2 > 7.5, 6.5$ GeV, $-3 < \eta < 0$**

**A measure of the fraction of the photon energy given to the dijet final state is:**

$$x_\gamma^{\rm obs} = \left(E_T^1 e^{-\eta_1} + E_T^2 e^{-\eta_2}\right)/2E_\gamma$$

**$x_\gamma^{\rm obs}$ in photoproduction (typical)**



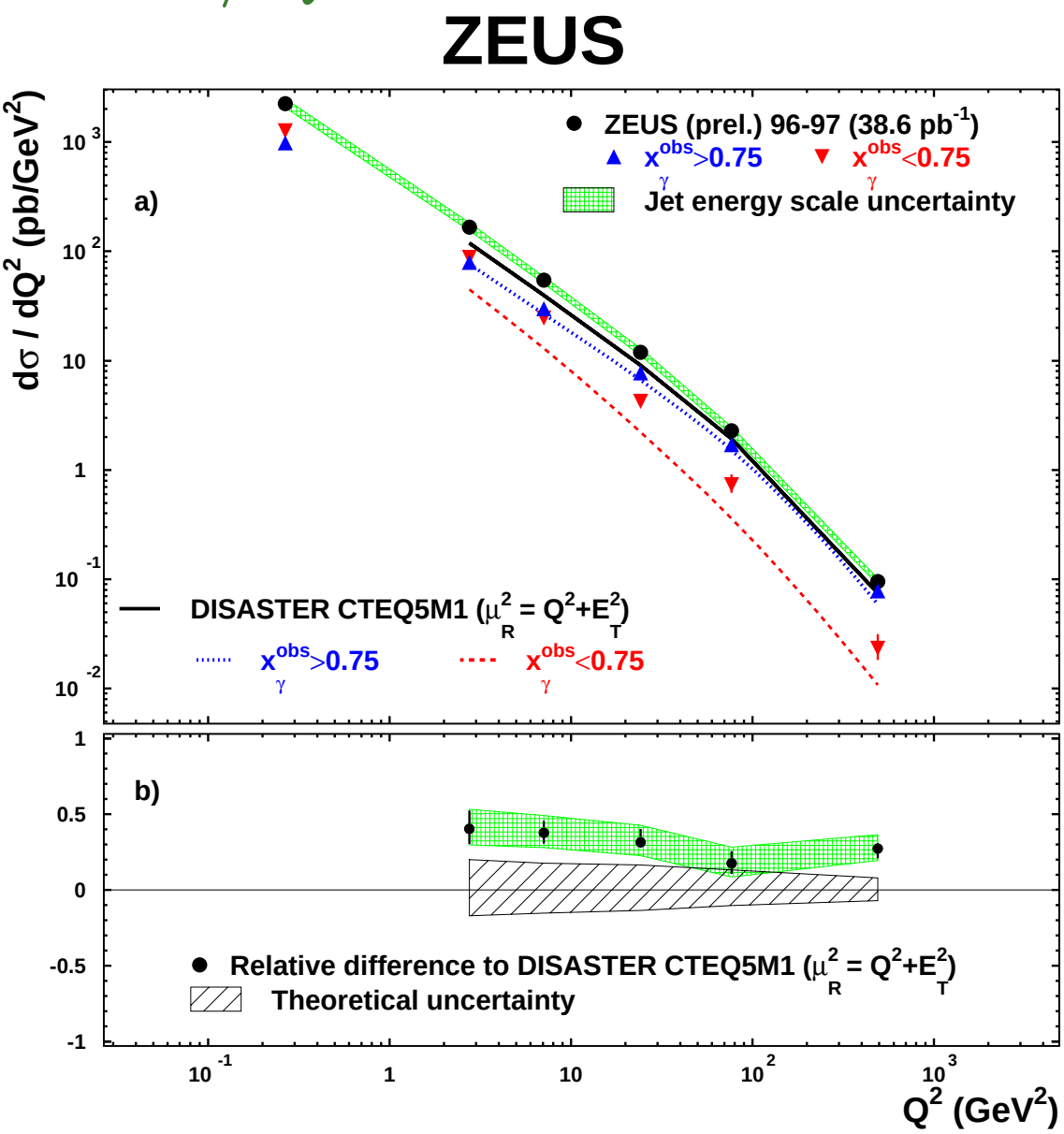

**$x_\gamma^{\rm obs} < 0.75$ Resolved-dominated**
**$x_\gamma^{\rm obs} > 0.75$ Direct-dominated**

**The ratio**

$$R = \frac{d\sigma}{dQ^2}(x_\gamma^{\rm obs} < 0.75)/\frac{d\sigma}{dQ^2}(x_\gamma^{\rm obs} > 0.75)$$

**is a measure of the resolved fraction of the virtual photon events within the acceptance. Various experimental and theoretical uncertainties cancel in $R$ .**

## Results for $d\sigma/dQ^2$




Using QCD renormalisation scale $\mu_R^2 = Q^2 + E_T^2$ :

— Data tend to lie above DISASTER NLO

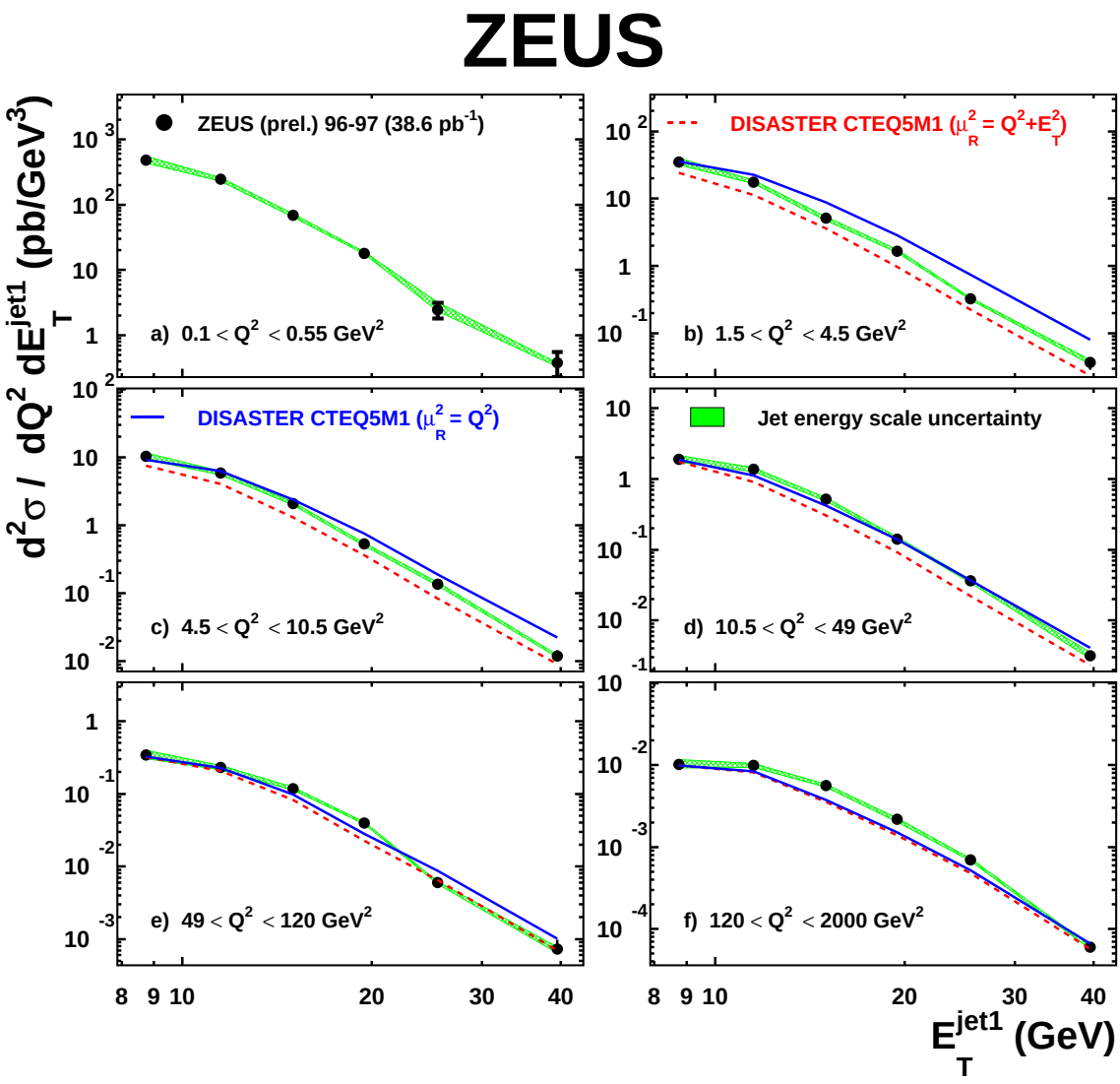
— But good agreement with $x_\gamma^{\rm obs} > 0.75$ component

— Discrepancy mainly with the $x_\gamma^{\rm obs} < 0.75$ component

DISASTER contains only perturbative processes,
no hadronic component to photon.

# RESULTS

**Plot against higher $E_T^2$ for varying $Q^2$ ranges:**




**Comparison with NLO is not strongly $E_T^{\rm jet}$ dependent.**

**Note presence of two hard QCD scales, $Q^2$ and $E_T^{\rm jet}$ .**

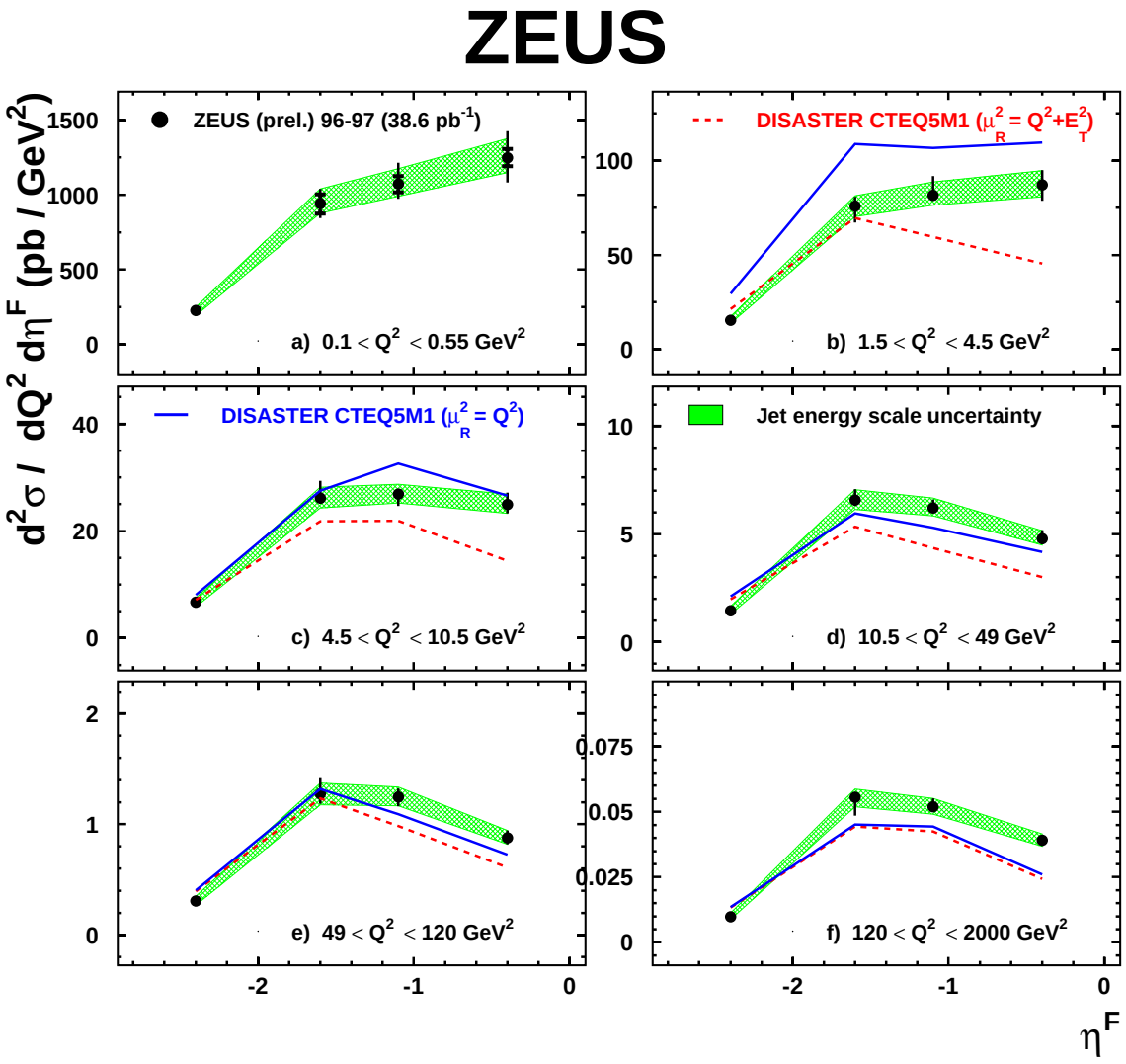
**More natural to use $\mu_R^2 = Q^2 + E_T^2$ .**

**Using $\mu_R^2 = Q^2$ raises the prediction.**

**Is this a better procedure?**

# RESULTS

## $d\sigma/dQ^2$ vs forward jet pseudorapidity enhances resolved contribution




At low $Q^2$ , big sensitivity to $\mu_R^2$

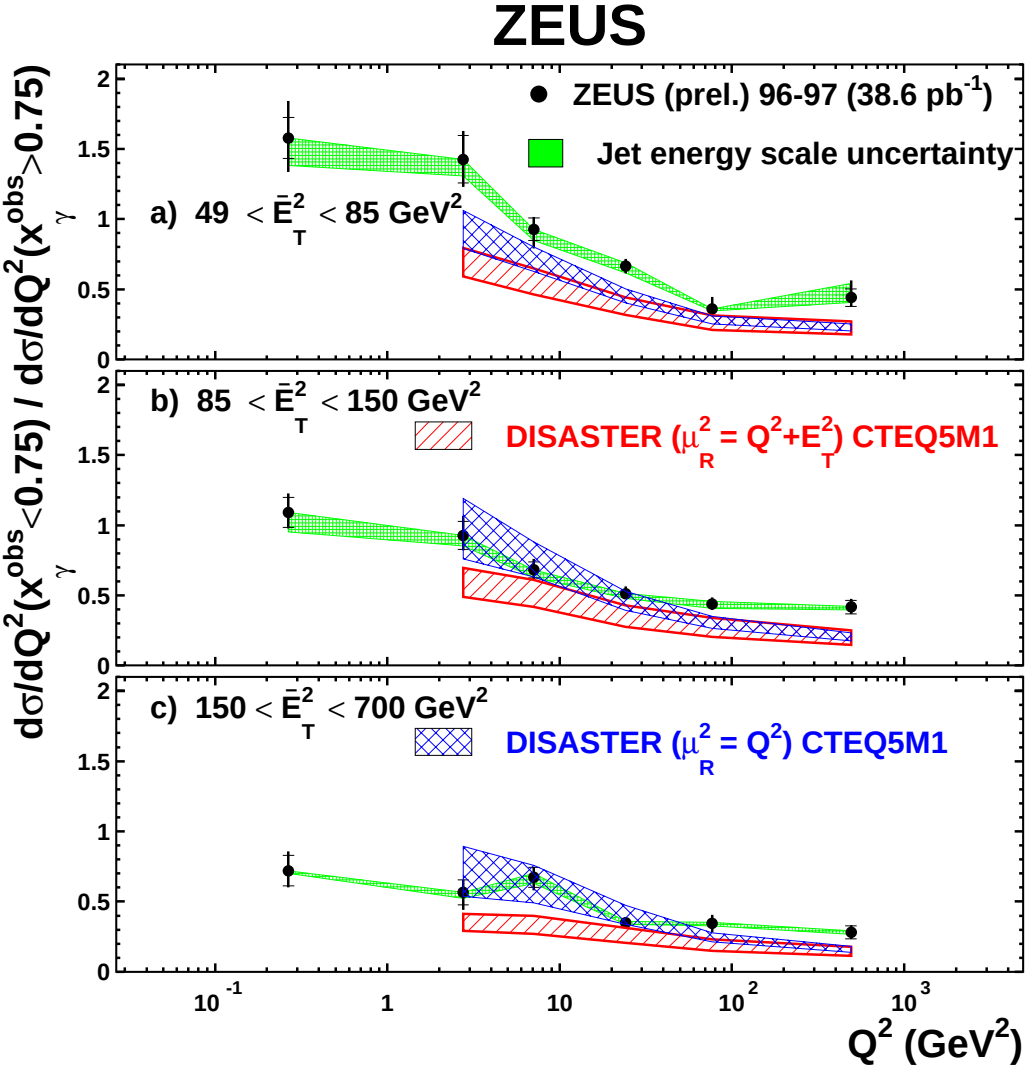
At high $Q^2$ , low sensitivity; data tend to be above theory in both cases.

So decreasing $\mu_R^2$ is not a successful solution.

# RESULTS

$R = \frac{d\sigma}{dQ^2}(x_\gamma^{\rm obs} < 0.75) / \frac{d\sigma}{dQ^2}(x_\gamma^{\rm obs} > 0.75)$

vs $Q^2$ in ranges of $E_T^{\rm jet}$




→ all resolved effects fall with $Q^2$ and $E_T^{\rm jet}$

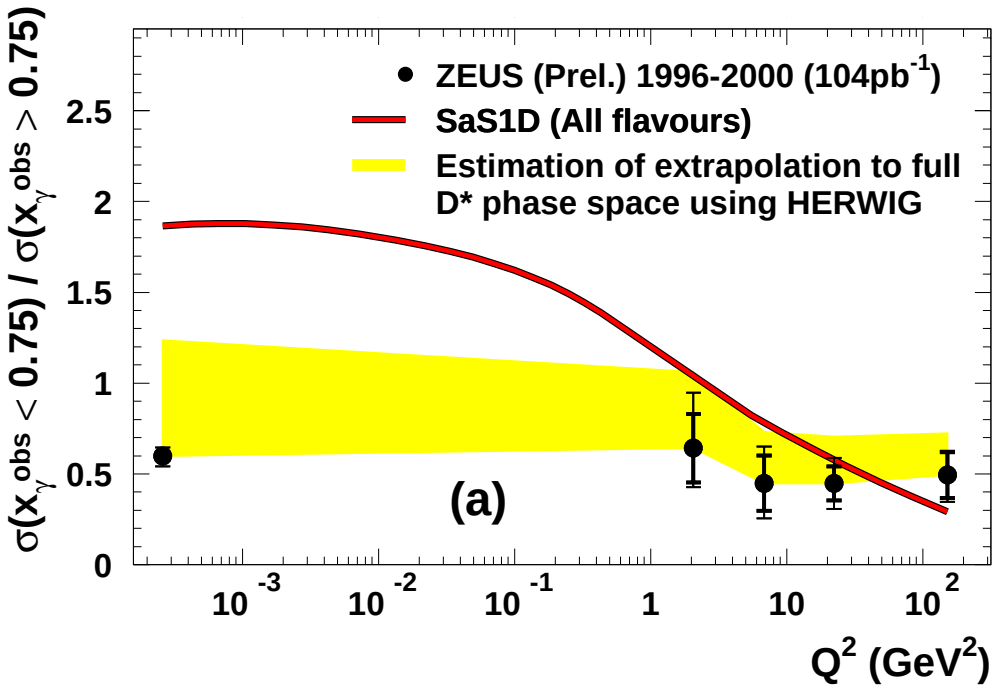
( $R$ at $Q^2 \approx 0$ estimated similar to $Q^2 \approx 0.3$ )

Comparison with DISASTER NLO $(\mu_R^2 = Q^2 + E_T^2)$ is insensitive to either hard scale. Data lie above theory.

→ consistent need for higher-order resolved contribn. (hadronic!) to photon even at high $Q^2$

# COMPARISONS

**Compare with prelim. ZEUS data with identified charm (D meson) required in event.**
**Jet selections similar to present analysis.**




**Presence of $c$ quark forces hard scale on process.**

**Flat in $Q^2$**

**Should all be perturbatively calculable.**

# CONCLUSIONS

— Have measured dijet cross sections in ZEUS over a range of $Q^2$ values crossing the transition between photoproduction and DIS.

— There is a component to the cross sections which is not modelled in NLO QCD, and is associated with resolved processes.

— Decreasing the renormalisation scale does not satisfactorily account for the discrepancy.

— Suggests presence of a hadronic part of the photon even at high $Q^2$ values.

— The effect appears absent in dijets with heavy quarks

— Need a NLO MC which includes general photon PDFs to test these ideas further.