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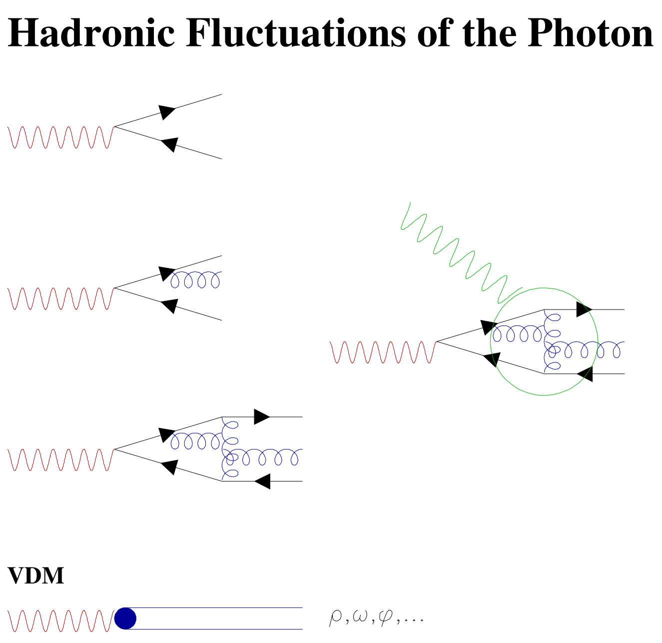
Current issues in low E_T real and virtual photoproduction.

- Illustration: measuring the parton densities of real and virtual photons
  - Focus on assumptions made and problematic areas
  - example: Multiple Interactions

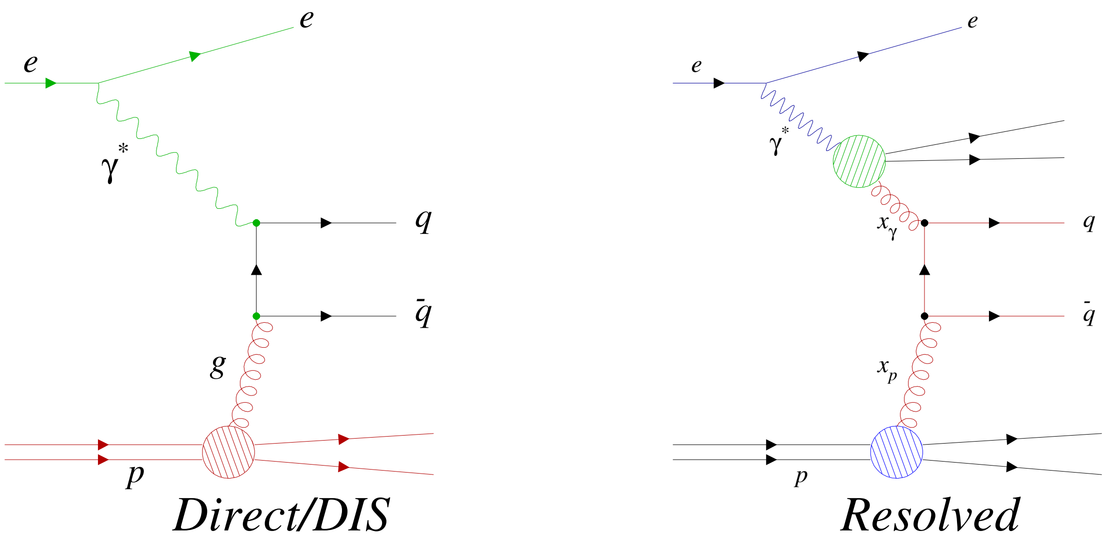
Two *LO* analyses from H1 leading to extraction of effective parton Densities

- Real photon Parton Densities
  DESY-00-035 / hep-ex/0003011 / submitted to Phys. Lett B
- Virtual photon Parton Densities
  Eur.Phys.J. C13 (2000) 371-396

Photon can develop hadronic structure through fluctuations:-



In LO, can produce dijets by Direct or Resolved Processes:-



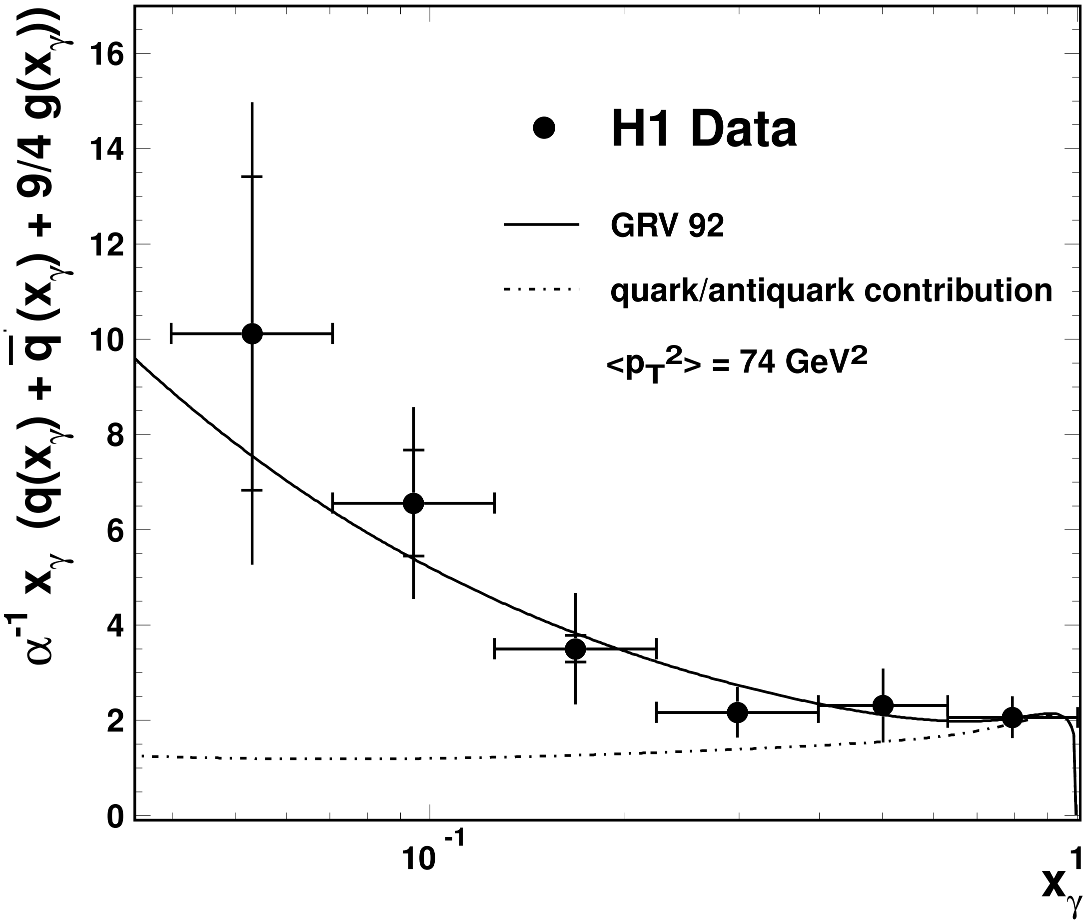
- Direct $x_\gamma \to 1$. Resolved $x_\gamma < 1$ + remnant.
- dijet cross-section sensitive to γ pdf's $\Leftrightarrow$ photon structure probed by High p_T jets

Target size $\sim 1/Q^2$
Structure resolvable if probe scale $\gg$ virtuality
not an issue for real photons!

Measuring the effective parton density in γ's

A *LO* analysis of dijet production by real photons in ep:

DESY-00-035 / hep-ex/0003011 / submitted to Phys. Lett B



Measuring the effective parton density in γ^*'s

A LO analysis of dijet production by virtual photons in ep:

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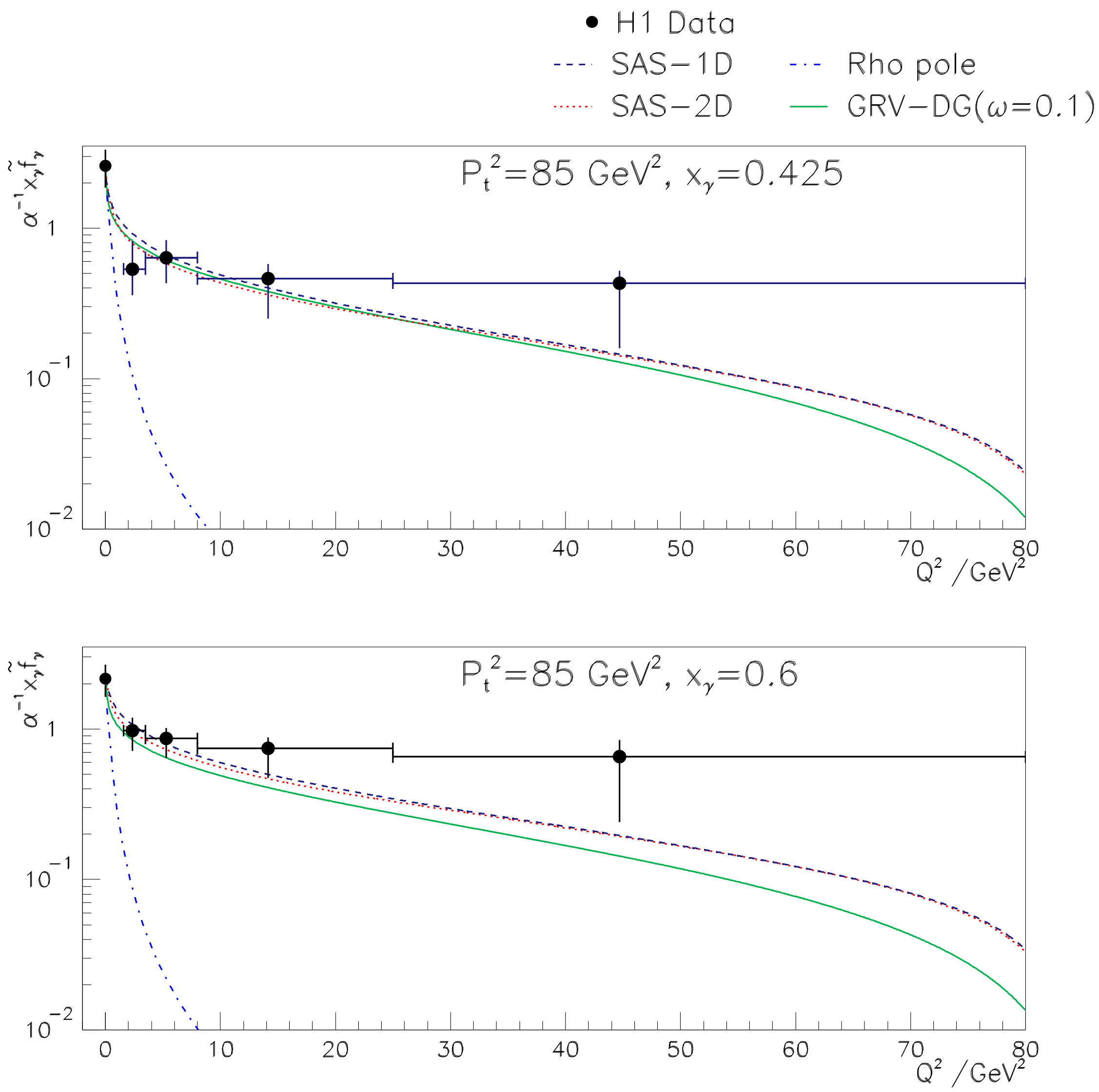


Virtual photon analysis Two-step measurement:-

- measure dijet cross-section $\mathrm{d}^3\sigma/\mathrm{d}\overline{E_t}^2\mathrm{d}Q^2\mathrm{d}x_\gamma^{jets}$
  - $0.1 < y < 0.7$
  - $1.6 < Q^2 < 80\mathrm{GeV}^2$
  - corrected for detector effects using Bayesian unfolding HERWIG and RAPGAP to establish correlations.
    - (cross section *includes* effects of multiple interactions)
- correct back to LO parton level and infer the effective parton density under the various model assumptions
  - use MC and Bayesian method again.
    - (cross section *corrected for* effects of multiple interactions)

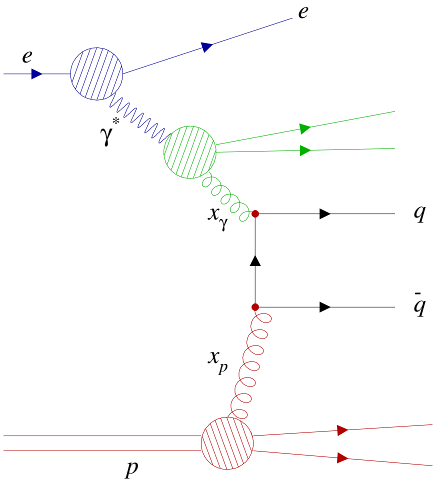
Must decide how to define x_γ:

- for $Q^2 = 0$
-

$$x_\gamma^{jets} = \frac{\sum_{jet1,jet2} E_t^{jet} e^{-\eta}}{2E_\gamma} = \frac{\sum_{jet1,jet2}(E - p_z)}{\sum_{everything}(E - p_z)}$$

- For $Q^2 \neq 0$ *use second expression.* ($p_{\mathrm{parton}} \sim x_\gamma q$). Assumes collinear partons.

Assume can *factorize* cross section into pdf's and $2 \to 2$ matrix elements



- *flux factor*
- *photon pdf's*
- *proton pdf's*
- $2 \to 2$ *matrix elements*

$$\frac{d^5\sigma}{dy\, dx_\gamma\, dx_p\, d\cos\theta^*\, dQ^2} = \frac{1}{32\pi s_{ep}} \sum_{k=T,L} \frac{f^k_{\gamma/e}(y,Q^2)}{y}$$

$$\sum_{ij} \frac{f^k_{i/\gamma}(x_\gamma, P_t^2, Q^2)}{x_\gamma} \frac{f_{j/p}(x_p, P_t^2)}{x_p} |M_{ij}(\cos\theta^*)|^2 \,.$$

...but:-

- Can't distinguish polarisation state of photon
- Can't distinguish incoming/outgoing partons

...more assumptions

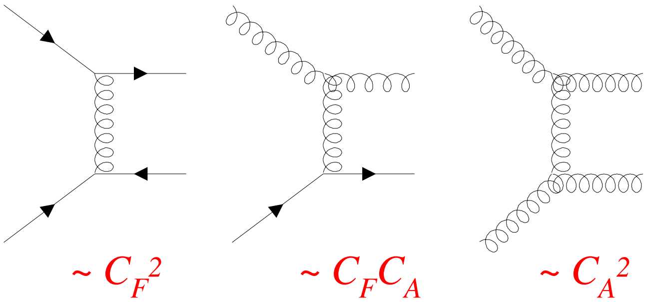
- average photon pdf's:-

$$f_{i/\gamma}(x_\gamma, P_t^2, Q^2) \equiv f_{i/\gamma}^T(x_\gamma, P_t^2, Q^2) + \overline{\epsilon} f_{i/\gamma}^L(x_\gamma, P_t^2, Q^2)$$

$$\overline{\epsilon} = \overline{\frac{f_{\gamma/e}^L(y, Q^2)}{f_{\gamma/e}^T(y, Q^2)}} \qquad f_{\gamma/e}^T(y, Q^2) = \frac{\alpha}{2\pi}\left(\frac{1+(1-y)^2}{y}\frac{1}{Q^2} - \frac{2m_e^2 y}{Q^4}\right)$$

$$f_{\gamma/e}^L(y, Q^2) = \frac{\alpha}{2\pi}\frac{2(1-y)}{y}\frac{1}{Q^2}.$$

- *Single Effective Subprocess Approximation*



$$\approx \frac{f_{\gamma/\mathrm{e}}^T(y, Q^2)}{y}\,\frac{f_{eff/\gamma}(x_\gamma, P_t^2, Q^2)}{x_\gamma}\,\frac{f_{eff/\mathrm{p}}(x_\mathrm{p}, P_t^2)}{x_\mathrm{p}}\,|M_{SES}(\cos\theta^*)|^2$$

$$f_{eff/\mathrm{A}} \equiv (f_{q/A} + f_{\overline{q}/A}) + \frac{9}{4} f_{g/A}$$

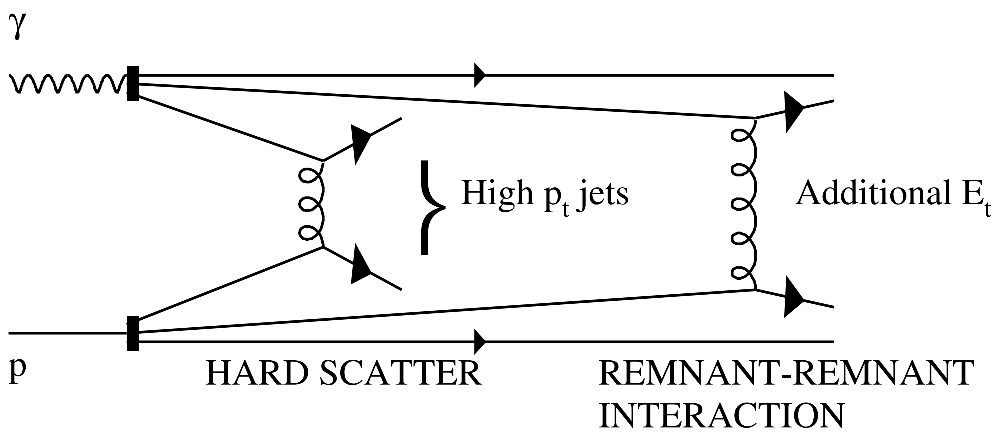
How good are these approximations?

- SES good to $\sim 20\%$ from MC studies
- very little known about *longitudinal* parton densities
  - small?
  - at least not enhanced by large logs?
  - $\Rightarrow$ *We should try to measure it!*
    - y dependence
- Implications for factorisation of cross section
- Valid for large Q^2 (if $E_t^2 \gg Q^2$)?

At present the analyses must take these as assumptions

Multiple Interactions in γ and $\gamma^* p$

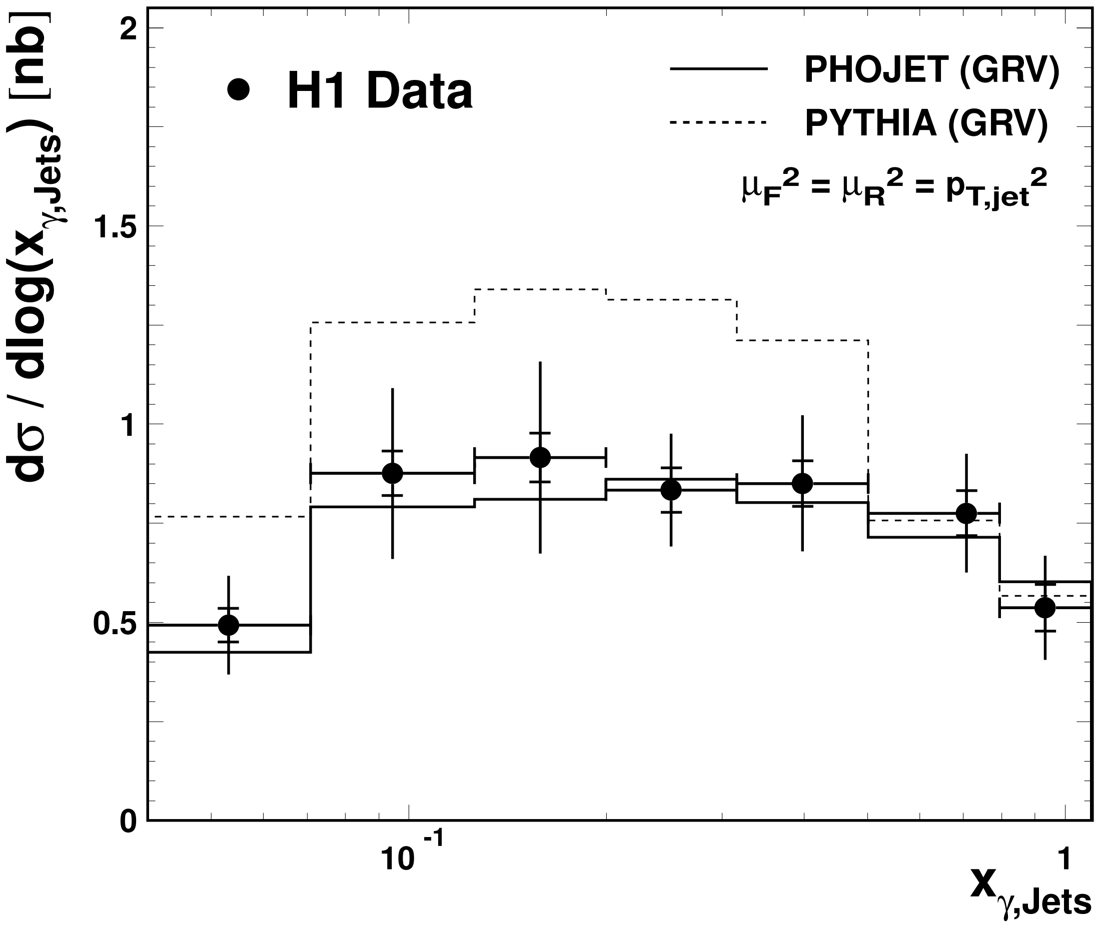
- resolved photon processes $\Rightarrow$ *remnant-remnant* interactions.



- Remnant energy redistributed into central η region
- *soft underlying event.* E_t flow in the event independent of hard scatter
  - $\Rightarrow$ jet pedestals
  - messes up jet E_T measurement hence cross-section (threshold)
- Also: hadronisation, HO processes (parton showers), soft stuff
- Experimentally:
  - must use models...e.g.
    * PHOJET, PYTHIA+MI, HERWIG+JIMMY - MI models
    * HERWIG+SUE - soft underlying event
  - MI models typically controlled by a $\hat{p}_t$ cut
  - SUE: control amount of redistributed E_t and frequency

e.g. in Real photon analysis

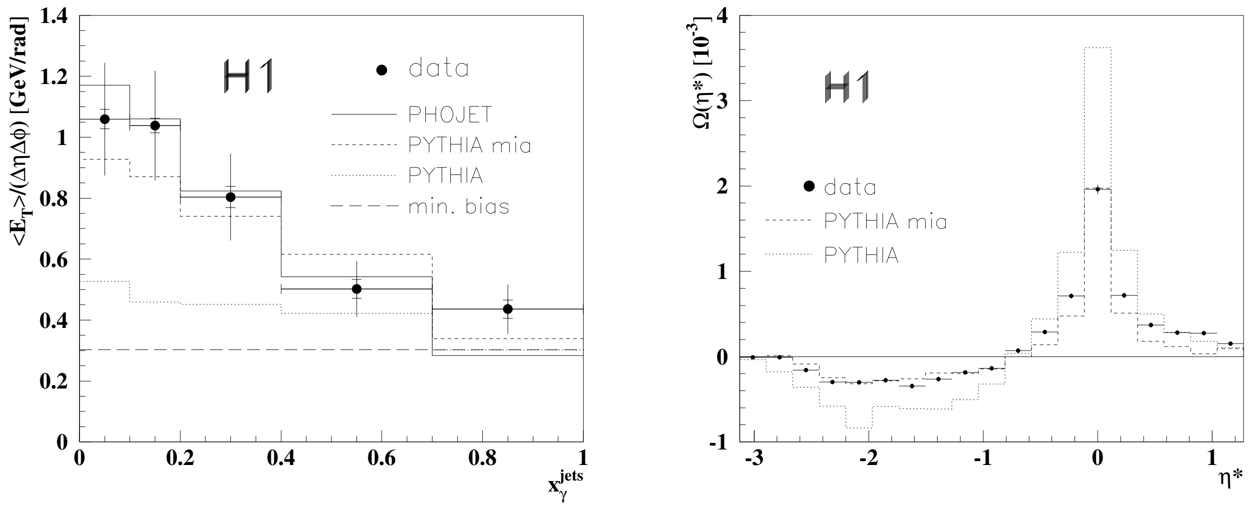
- Measure dijet cross-section:
  - $E_{t,jet} > 4\text{GeV}$, $M_{1,2} > 12\text{GeV}$
  - $-0.5 < \eta_{jet} < 2.5$, $\Delta\eta < 1$, $0.5 < j < 0.7$
- corrected using Bayesian unfolding (PYTHIA, PHOJET $\sim 10\%$)
- *but* Models differ by 40% in prediction for corrected cross section
  $\Rightarrow$ very sensitive to *underlying event*, how cross section regularised



What else do we know experimentally from ep?

Measure E_T flow in a region outside the two highest E_t jets

In photoproduction data:



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- increases as energy in remnant increases
- *uncorrelated with energy in jets*
- ...as expected for MI

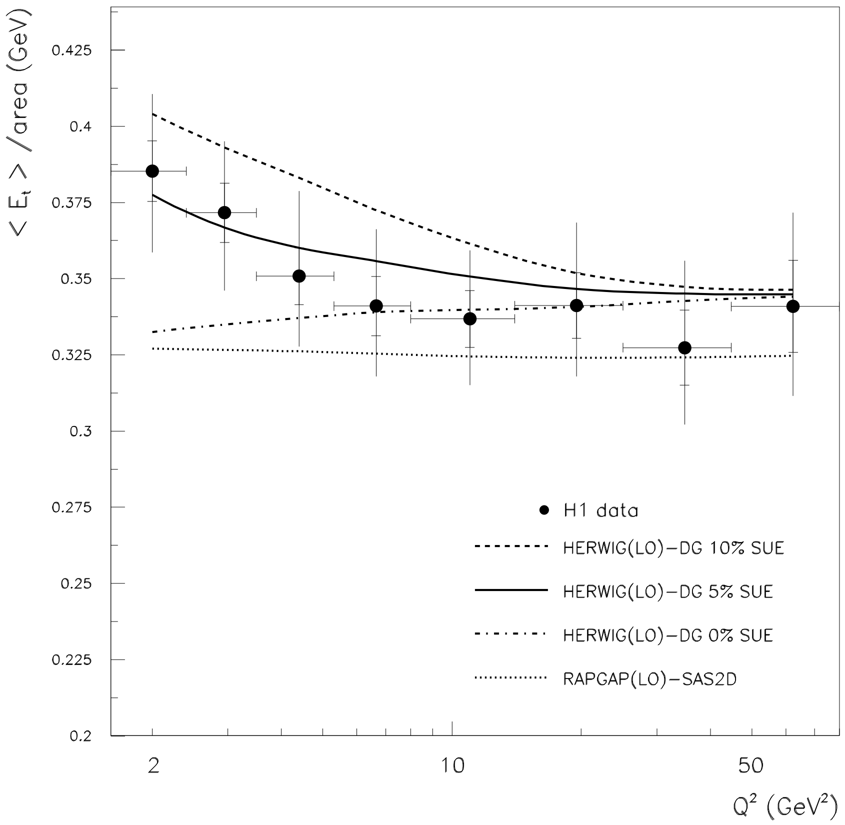
From MI models we also expect...

- dependence on pdf's

As photon goes off-shell?

For virtual photons, expect MI to be *suppressed*

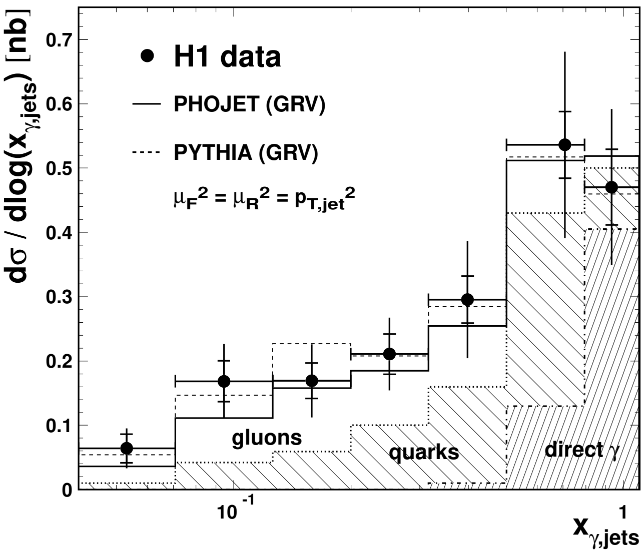
- associated with resolved processes
- photon *shrinks* (?)



- simple models able to describe global features

How to deal with MI?

- Work where influence small →
  - → high E_t or go offshell
- *Correct* jet energies
  - e.g in real photon analysis:
  - subtract pedestal energy (estimated from MC as fn of η)
  - raise E_t cut to 6 GeV (after subtraction)
  - → good agreement between average jet and parton energies
  - → ..and improves correlation in individual events



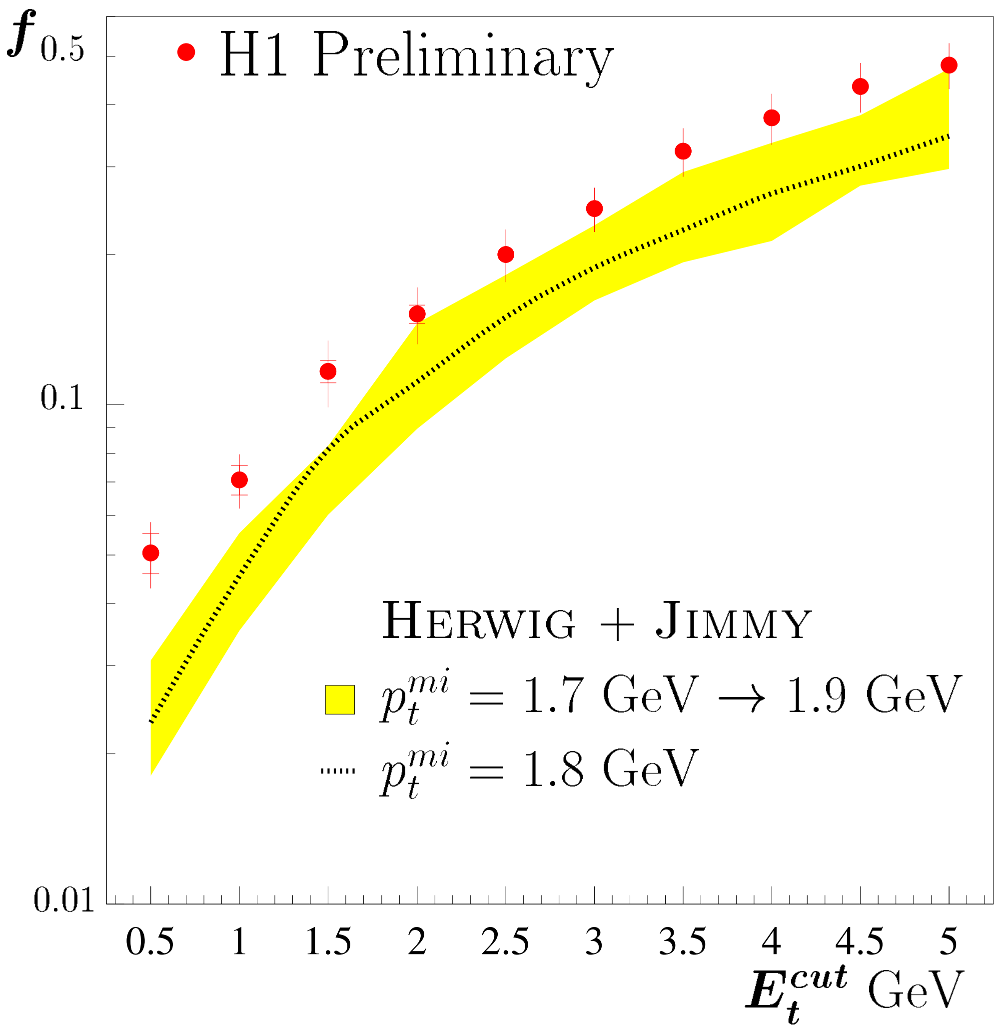
  - unfold again extract the effective pdf (see back)
- Or (virtual photon analysis) unfold directly without pedestal subtraction.
- → lead to inflation of systematics (typically ∼ 20%) which must be conservatively estimated.

- More measurements specifically designed to study MI
- Most analyses treat on a statistical basis
  eg models can describe the average E_T flow in by depositing little energy in many events or more enery in fewer events.
- Test models in many different processes (already extensively done for e.g. JIMMY)

Other measurements are very sensitive to MI:

Example: rapidity gaps between jets

- Look for gaps in energy flow between jets



Conclusions

- Cross sections for low E_T photoproduction of jets by real and virtual photons have been measured.
- Extraction of partonic quantities like effective pdf's requires a chain of assumptions and consequently systematic errors from model dependence are large.
- The low E_T, low x_γ region is particularly vulnerable to multiple interactions.
- *Nevertheless a picture of resolved photon structure which persists to moderate values of Q^2 has emerged*
- *Way forward is to reduce systematic errors by refining models*
- Continued efforts to understand these are very valuable elsewhere - not least for experiments at future colliders with very large cms energies!