Dijet Photoproduction

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Representing the H1 and ZEUS collaborations

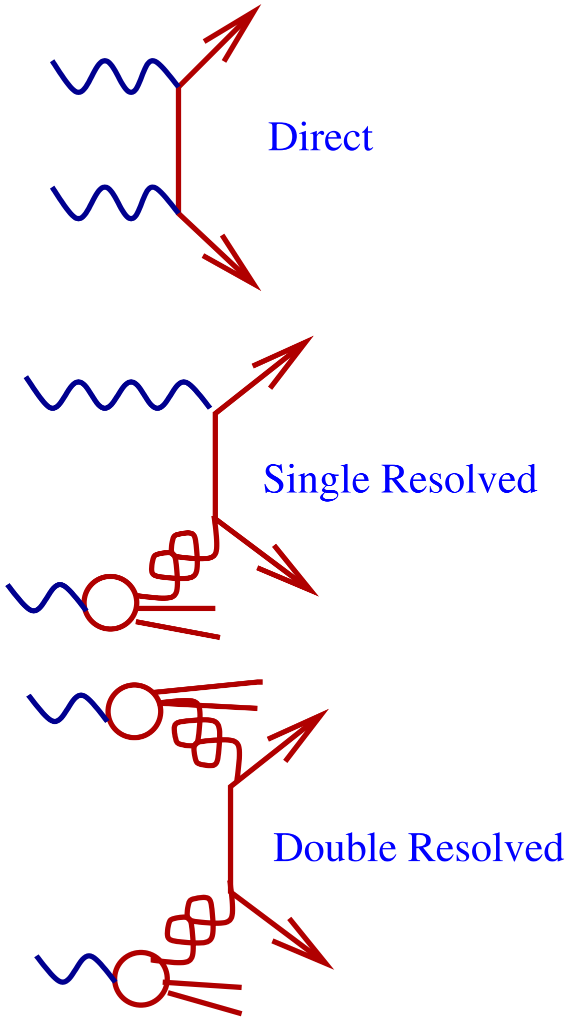
Outline:

- **Introduction**
- **Photon Structure**
- **Jet Substructure**
- **Virtual Photons**

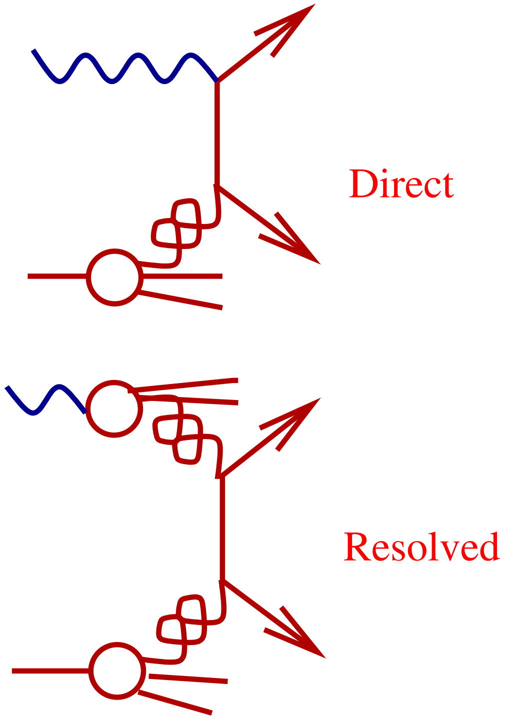
Focus on latest results.

Introduction: Resolved and Direct Processes

Photon-Photon



Photon-Proton



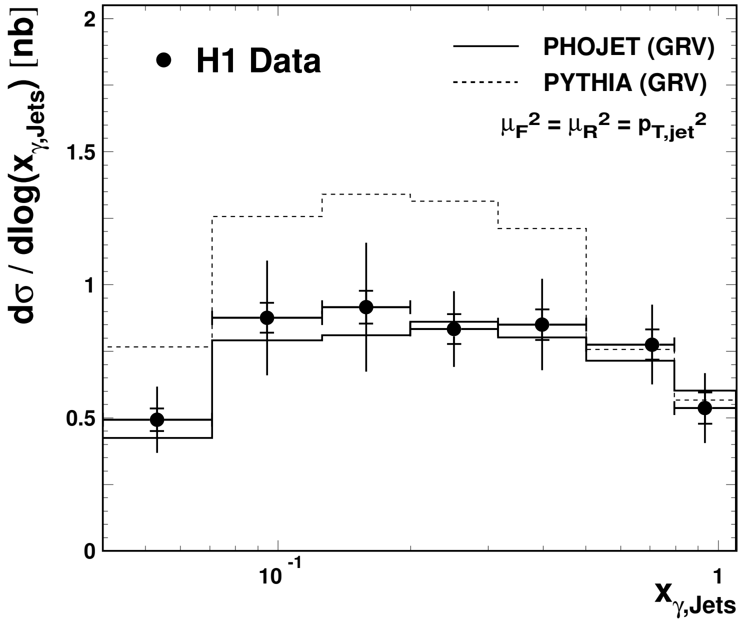
Leading order processes for jet, particle and heavy quark production.

Photon virtualities P^2 (Q^2 at HERA!). Virtual parton probes "less virtual" photon at scale related to E_T^2.

Resolved and direct separation becomes a matter of choice at higher orders (and in real life...)

Dijet Cross Sections

Low E_T^{Jet} (4 GeV).



$$x_\gamma^{\mathrm{JETS}} = x_\gamma^{\mathrm{OBS}} \equiv \frac{\sum E_T^{\mathrm{Jet}} e^{-\eta^{jet}}}{2yE_e}$$
$$= \frac{\sum_{jets} E - p_z}{(E - p_z)_\gamma}$$

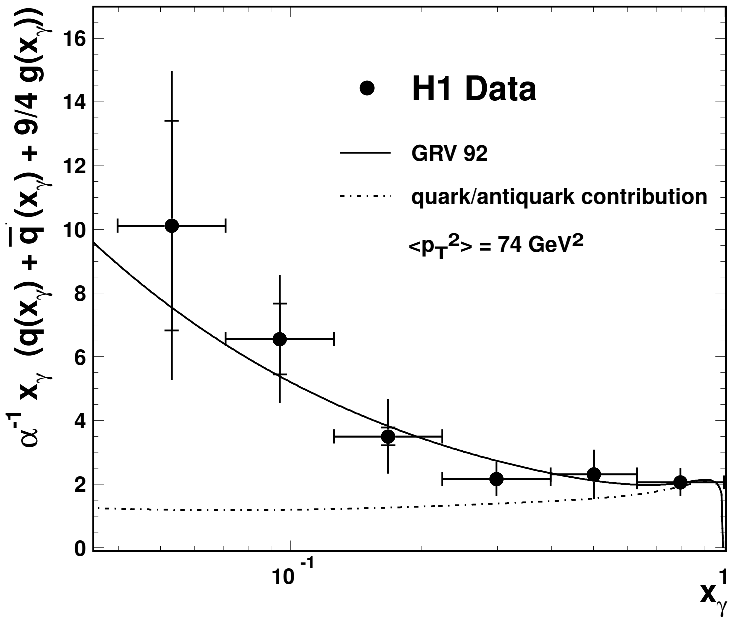
Low $E_T^{\mathrm{Jet}} \Rightarrow$ predominantly resolved photon events.

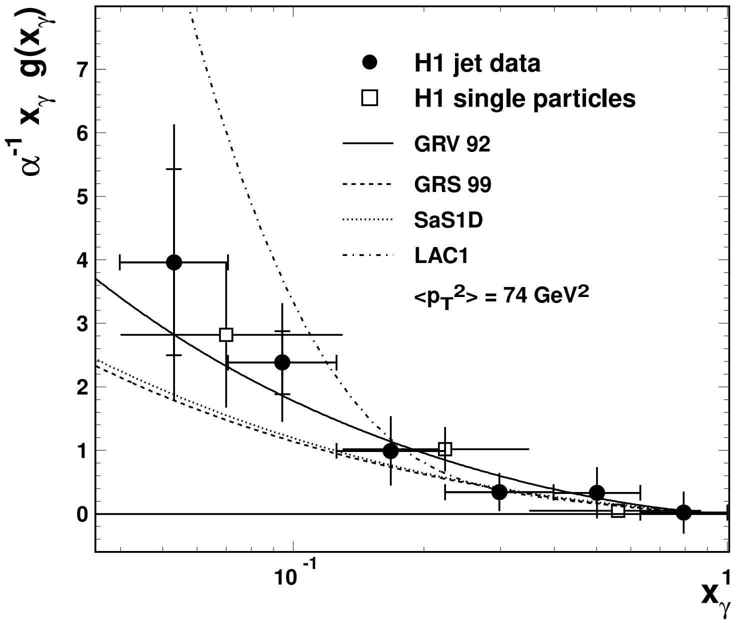
Sensitive to underlying event, non-perturbative effects (e.g. $\hat{p}_T^{\mathrm{min}}$) and the gluon distribution.

Subtract "underlying event" based upon Monte Carlo expectations, then demand $E_T^{\mathrm{Jet}} > 6$ GeV $\Rightarrow$

See: H1, Phys. Lett. B483 (2000) 36-48.

LEADING ORDER ESTIMATE OF PHOTON STRUCTURE



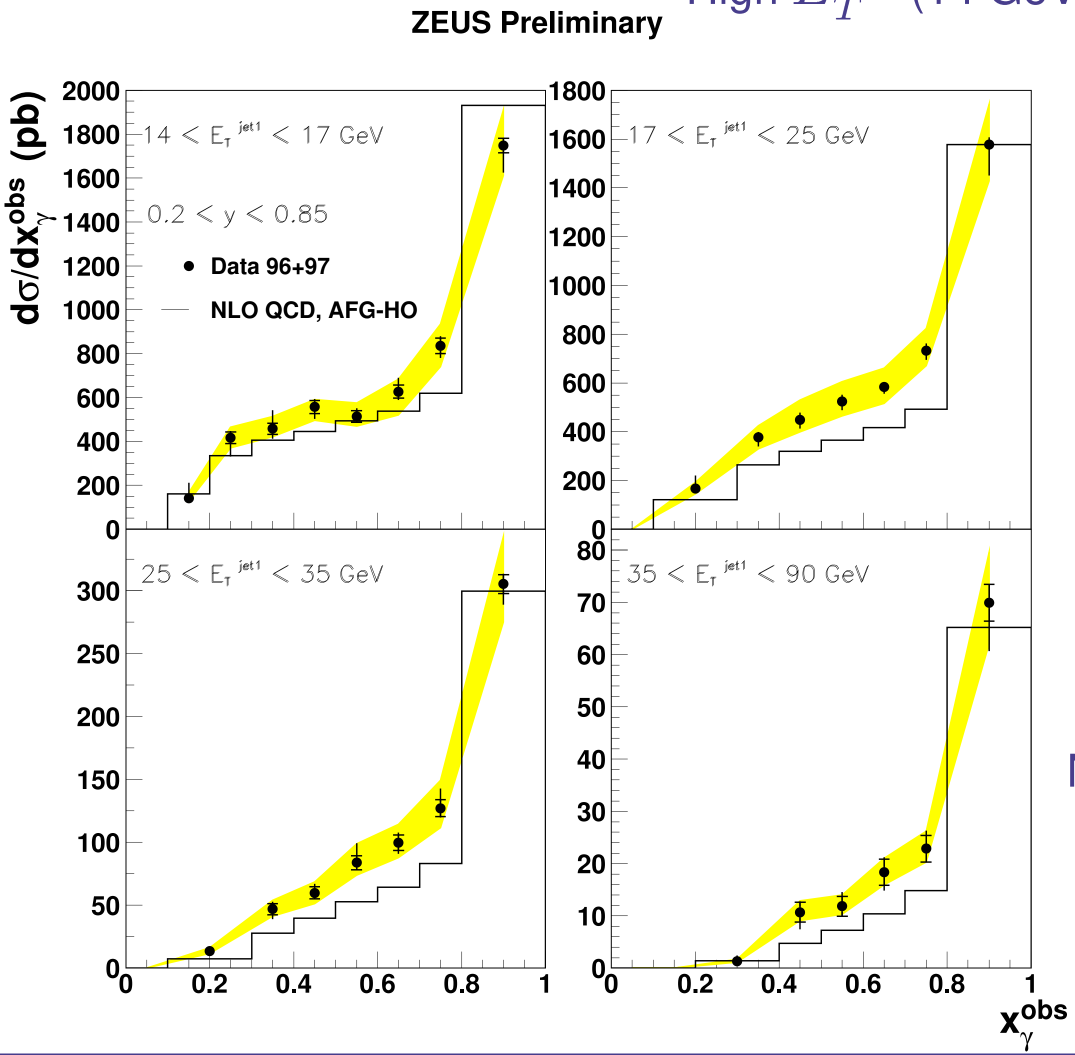


Assume all subprocesses have the same angular distribution (reasonable approximation for resolved) and extract an effective parton distribution.

Note - large model dependent uncertainties.

Dijet Cross Sections

High E_T^{Jet} (14 GeV).



Use higher E_T^{Jet} jets to define the hard scale.

k_T algorithm.

Effects of underlying event small and hadronisation corrections $< 15\%$ in MC.

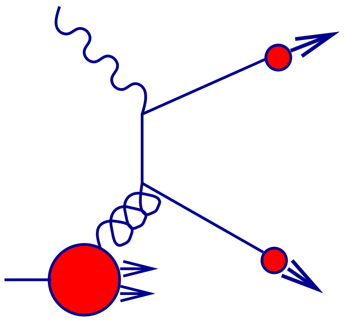
Excess at low x_γ^{OBS} when compared to NLO QCD Previously seen in the η cross sections.

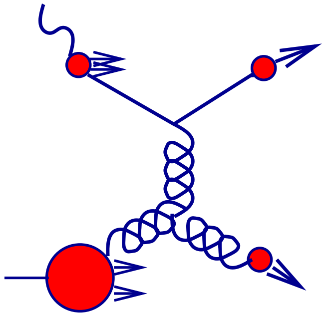
Not decreasing with increased E_T^{Jet}.

(The low E_T^{Jet} H1 results could be consistent with these results. Need NLO analysis.)

DYNAMICS AND JET STRUCTURE

Dominant subprocesses:

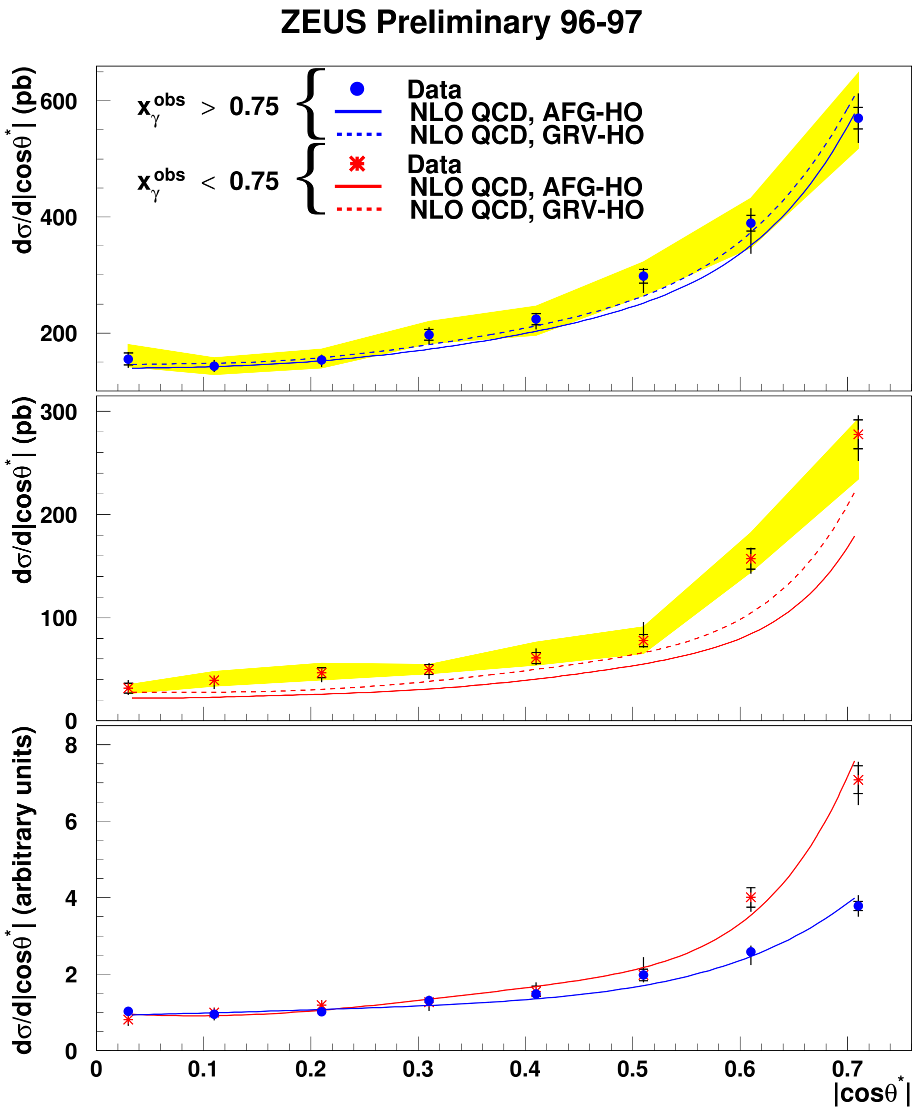
Direct:  $\gamma g \to q\bar{q}$

Resolved:  $q(\bar{q})g \to q(\bar{q})g$

Selecting direct events means that quark exchange processes dominate angular distribution $\approx (1 - |\cos\theta^*|)^{-1}$.

Selecting resolved events means that gluon exchange processes dominate angular distribution $\approx (1 - |\cos\theta^*|)^{-2}$.

DYNAMICS AND JET STRUCTURE



To make quantitative statements, must look more closely at the jets: *How well do we understand the production mechanisms?*

Angular distributions sensitive to the propagator.

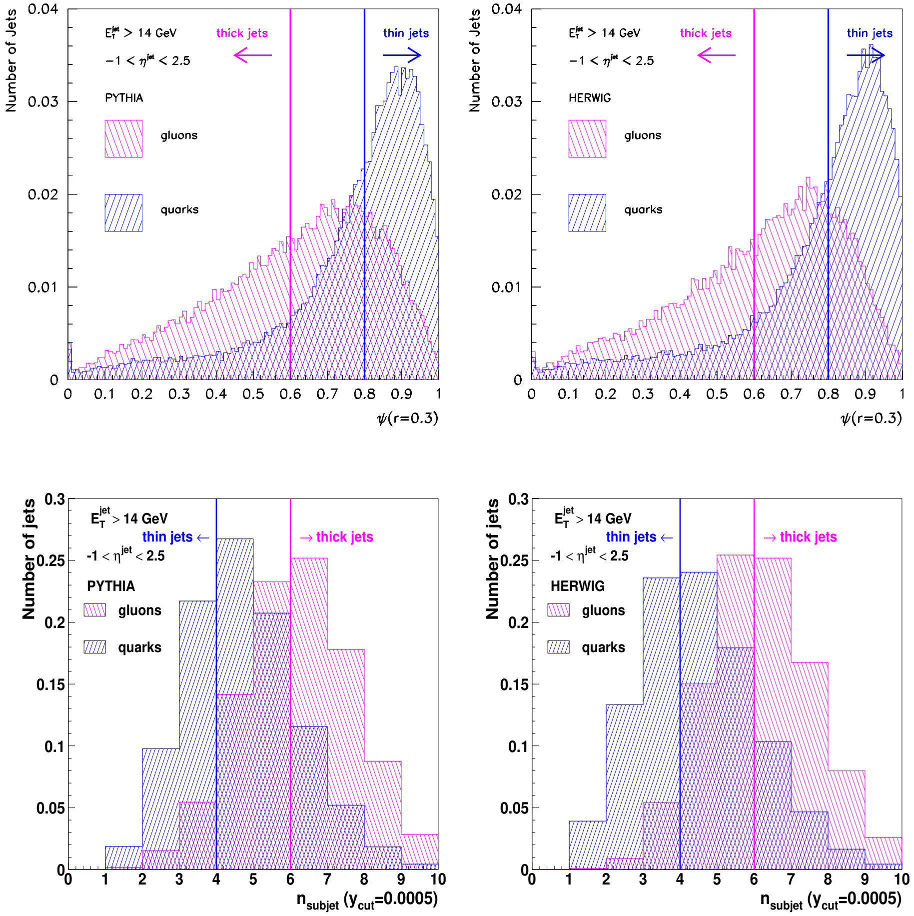
Normalisation shows the same effect, of course, but the shape is well described.

The excess events look like the others...

DYNAMICS AND JET STRUCTURE

In general (cf e^+e^- results) gluon-initiated jets are broader than quark-initiated jets.

Use this to get a handle on the subprocess composition in photoproduction.



← Jet shape (fraction of $E_T^{\rm Jet}$ within 0.3 units of the axis)

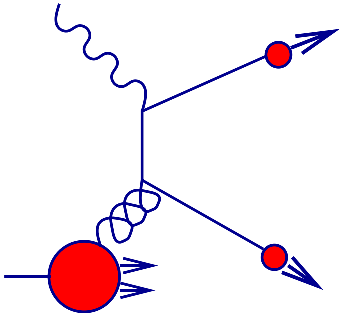
or

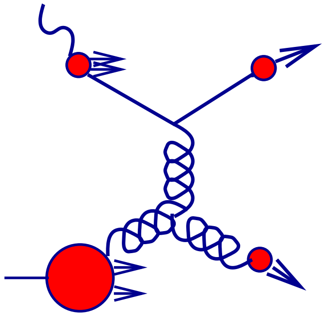
← Subjet multiplicity (k_T within jet).

Both used to define "thick" and "thin" jet samples

DYNAMICS AND JET STRUCTURE

Dominant subprocesses:

Direct:  $\gamma g \to q\bar{q}$

Resolved:  $q(\bar{q})g \to q(\bar{q})g$

Selecting quark jets means that quark exchange processes dominate angular distribution

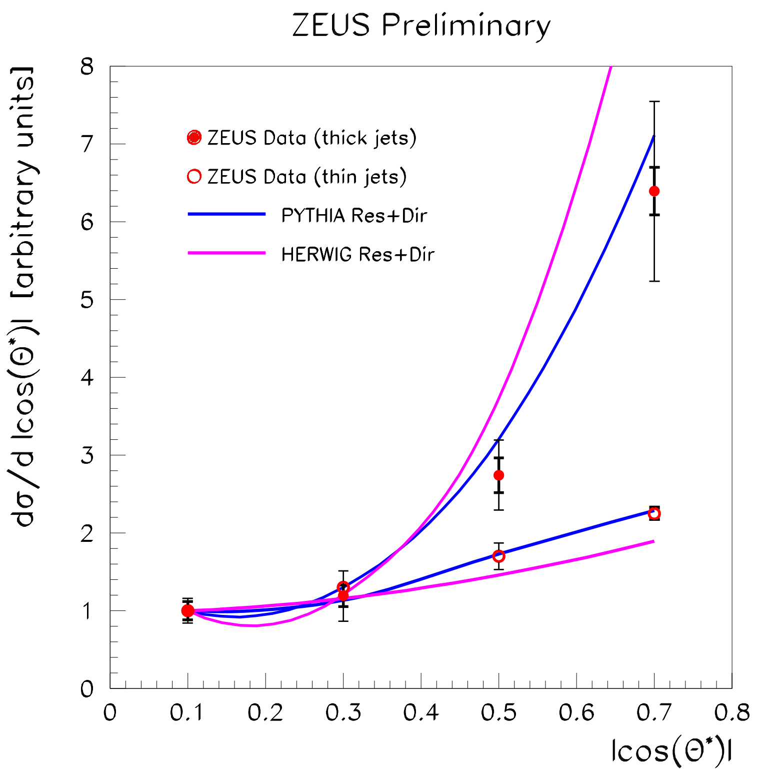
$$\approx (1 - |\cos\theta^*|)^{-1}.$$

Selecting gluon jets means that gluon exchange processes dominate angular distribution

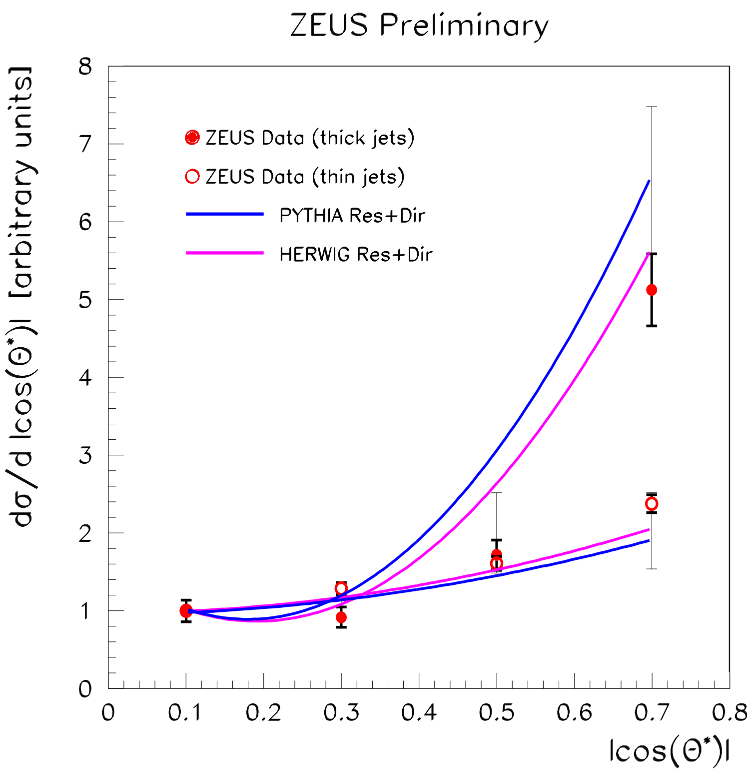
$$\approx (1 - |\cos\theta^*|)^{-2}.$$

Dynamics and Jet Structure

Angular distributions:



Jet shape method



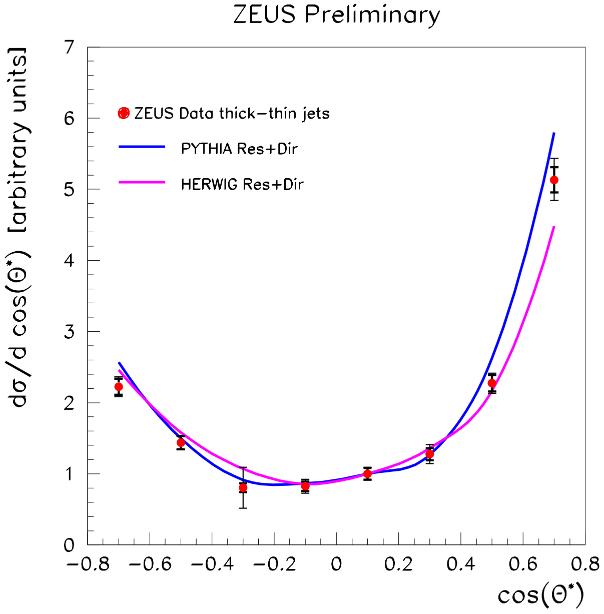
Subjet method

Steeper rise for thick jets than for thin jets, consistent with the expectation.

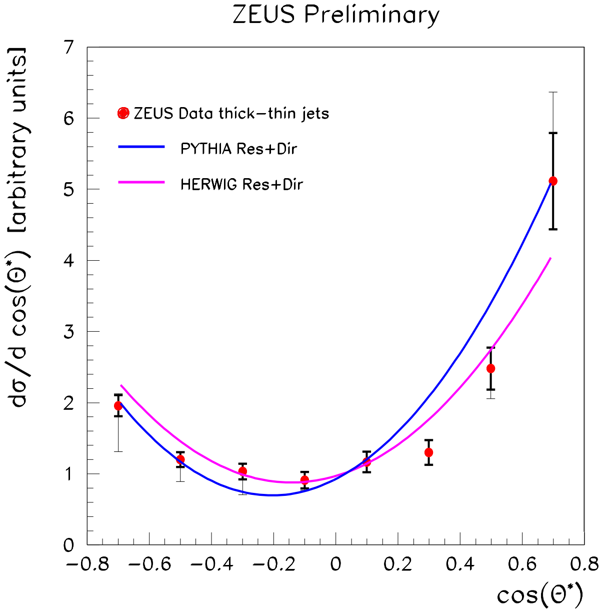
Dynamics and Jet Structure

Angular distributions (“thin-thick”):

Selecting one jet thick, the other thin, and plot angle between the thick jet and the beam. axis - distinguishes forward & backward directions (c.f. three-jet analysis).



Jet shape method



Subjet method

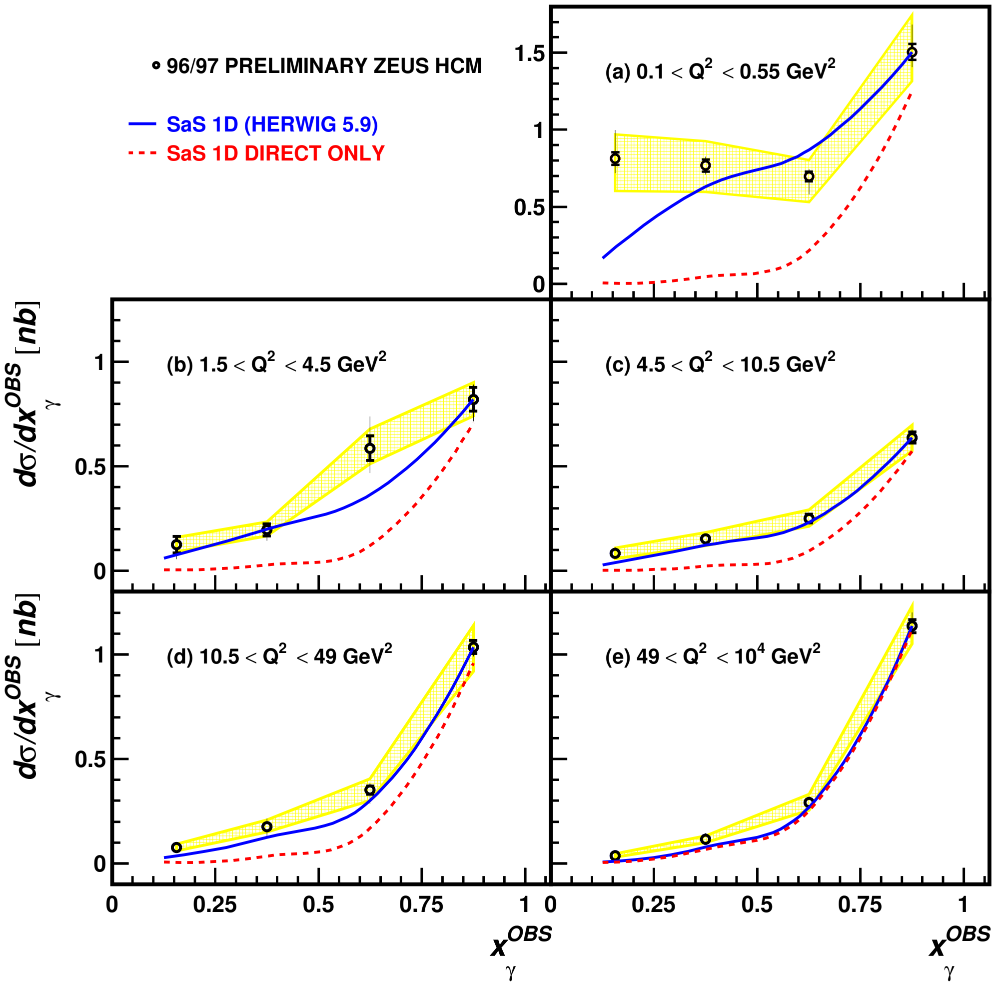
Forward peaked, consistent with expectation of more gluons from the proton than the photon, which scatter closer to the proton beam line.

Transition from Real to Virtual Photons

With respect to direct photon processes, expect perturbative part of resolved to fall $\approx \ln(\mathrm{Q}^2/\mathrm{P}^2)$ whilst non-perturbative ("vector meson") part should fall $\approx m_v^2/(m_v^2 + \mathrm{P}^2)$.

Above is implemented in SaS pdfs.

With resolved component included according to SaS, x_γ^{OBS} distribution fairly well modelled at all Q^2 except the lowest.



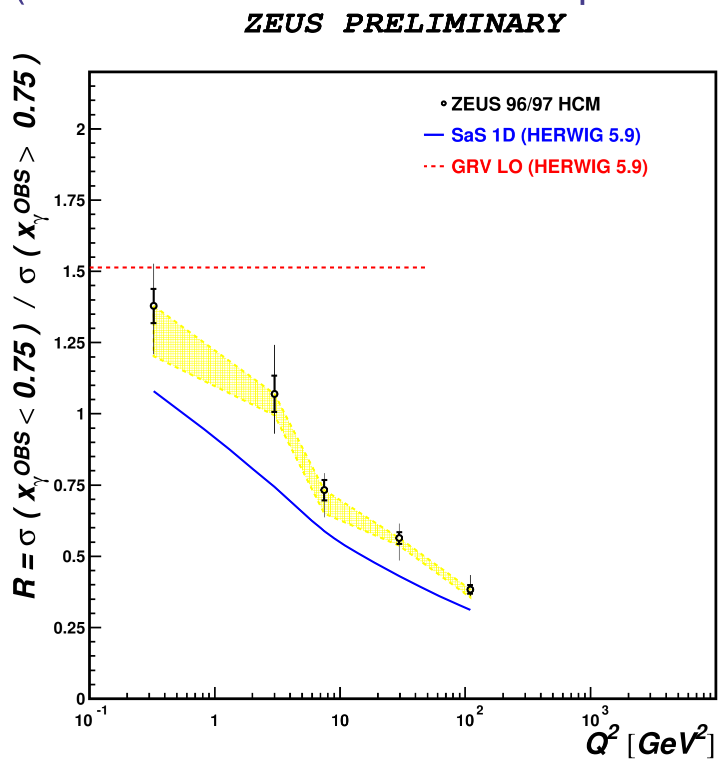
See also:

H1, Eur. Phys. J. C13 (2000) 397-414, Phys. Lett. B415 (1997) 418-434.
ZEUS, Phys. Lett. B - 479 (2000) 37-52.

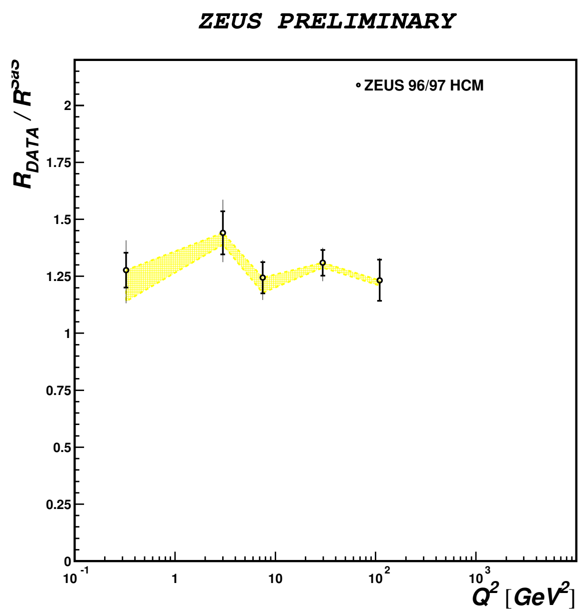
Ratio of Resolved to Direct

... as a function of photon virtuality.

GRV is shown only for illustration (was not intended for virtual photons).



Discrepancy w.r.t. SaS is not changing rapidly with photon virtuality



Need for a 'resolved' component at high photon virtuality. It is gradually suppressed as virtuality increases.

SUMMARY

- **At high E_T^{Jet}**

Uncertainties (theoretical and experimental) are getting small.

Dynamics and subprocesses well understood.
More resolved events than expected in NLO QCD.

Increased pdfs in photon? (quarks or gluons?)

- **At low E_T^{Jet}**

Accurate measurements with sensitivity in principle to the gluon distribution in the photon.

Limited by understanding of underlying event and low $\hat{p}_T^{\mathrm{min}}$ physics.

Need to improve models, compare across experiments.

- **At non-zero virtualities**

Improved accuracy, measured in $\gamma - p$ rest system.

Confirms qualitatively expectations of SaS for evolution from photoproduction to DIS.

Developing a consistent picture of these interactions.

FUTURE

Wish list / predictions.

NLO QCD fits including HERA and LEP data for the photon pdfs.

Charged particle distributions have potential to add information.

Improved data on subprocesses - gluons, charm, beauty, after the upgrade.

Better tests & measures of the underlying event (needed for accurate measurements at hadron colliders).