Production of Jets in Photoproduction and in Transition Region to DIS

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for H1 and ZEUS collaborations

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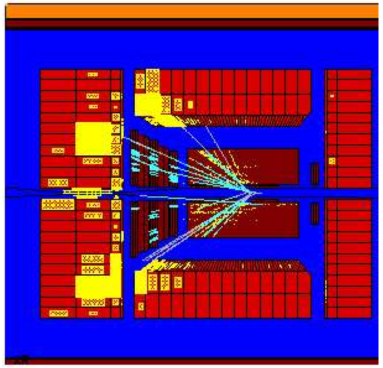
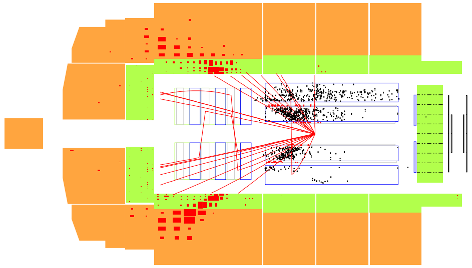
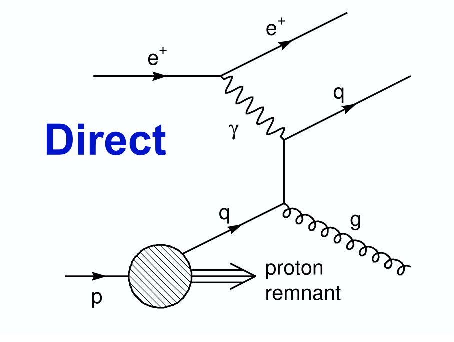


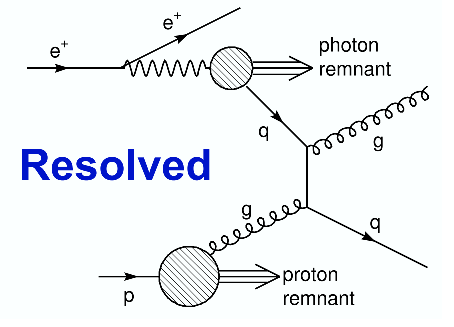


Introduction I - Structure of photon

photon = quantum of gauge field , massless, chargeless, pointlike coupling

- QFT - $\gamma \rightarrow q\overline{q}$: leads to *hadronic* (partonic structure of photon) $\Rightarrow$ photon behaves as hadron
- Depending on whether photon couples electromagnetically or strongly: direct and resolved processes:





  - direct = photon couples pointlike, EM process
  - resolved = interaction with parton from photon, strong process

Beyond LO this classification becomes ambiguous

Introduction II - Theory vs. experiment

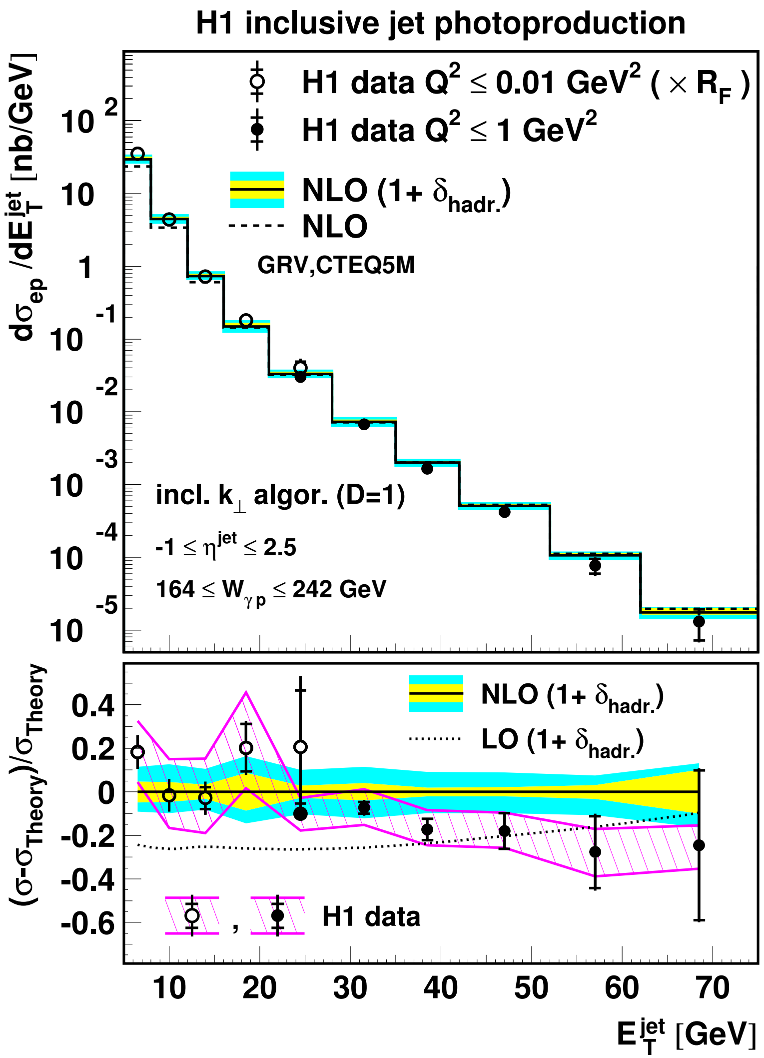
Theoretical models:

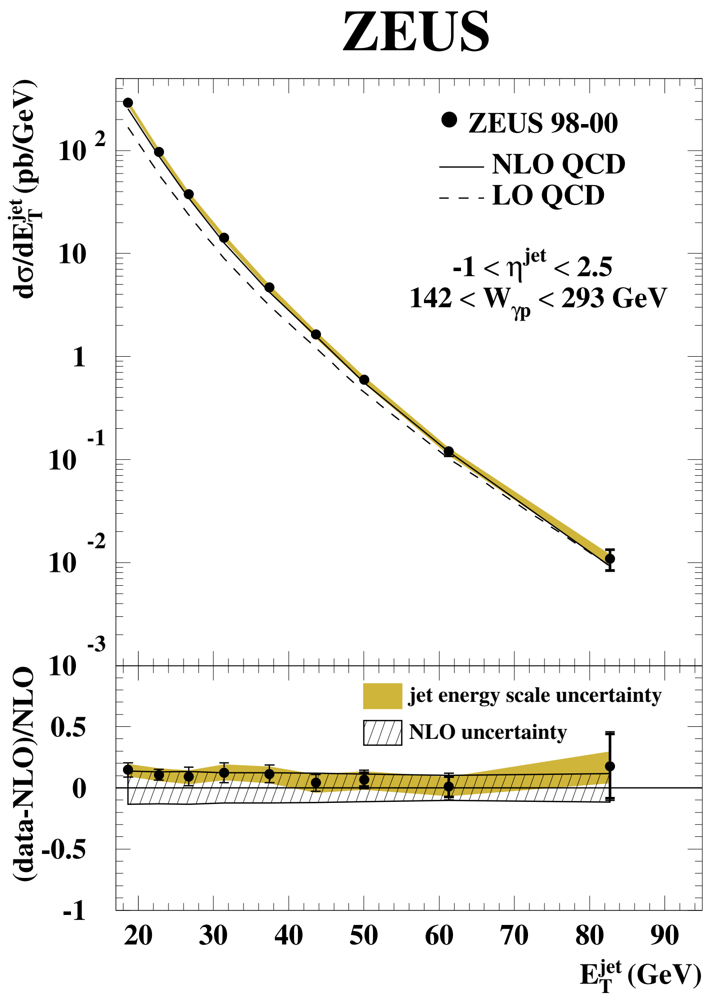
- Inputs:
  - PDF's of proton, global fits to DIS, hh data
  - PDF's of photon, usually from $\gamma\gamma$
  - Perturbative QCD
- Leading order + Parton Shower models:
  - hadronization done in model
  - predictions on hadron level, possible to compare directly to data
- NLO calculations:
  - calculations up to fixed order in α_S
  - predictions on parton level
  - $\Rightarrow$ before comparing to data, NLO is corrected for hadronization effects (Estimated by LO+PS models)

Experimental conditions:

- Q^2 ranges:
  - tagged photoproduction ($Q^2 \leq 10^{-2} GeV^2$)
  - un-tagged photoproduction ($Q^2 \leq 1 GeV^2$)
  - low Q^2 region ($Q^2 \geq 2 GeV^2$)
- W: up to $280\ GeV$
- frame: γp or LAB
- jet algorithm: inclusive k_T
- corrections: data are corrected to hadron level using LO+PS models and detector simulation

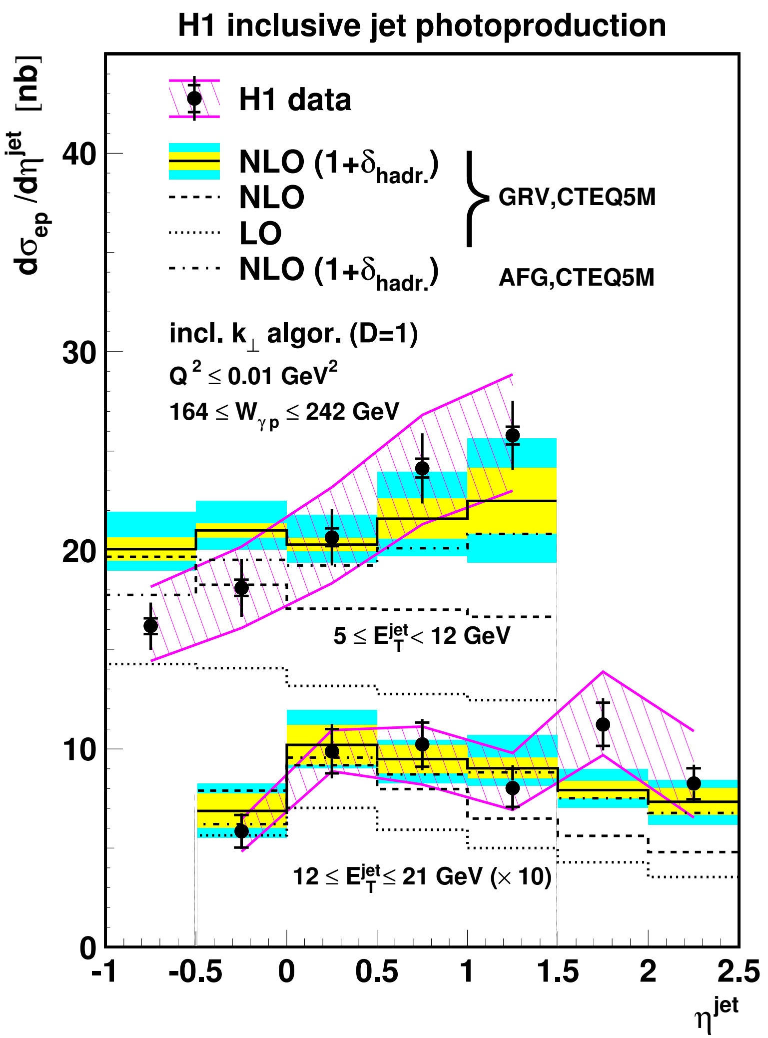
Inclusive jets in photoproduction: H1 and ZEUS

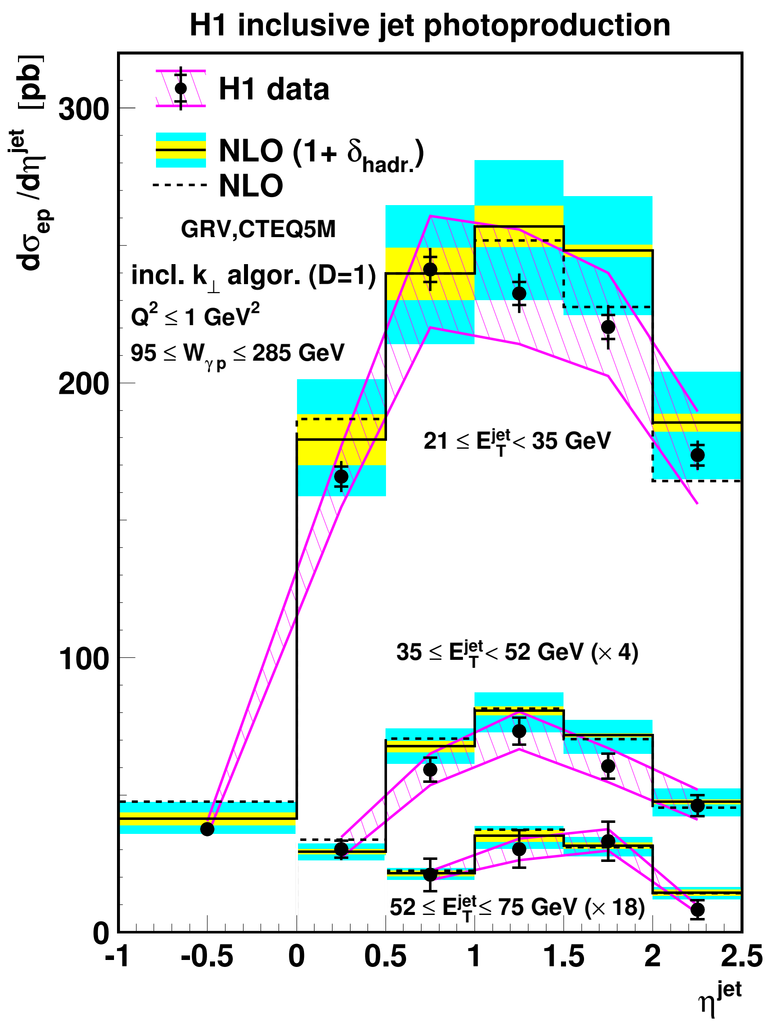




Good agreement with NLO over six orders of magnitude, dominant uncertainty due to theory

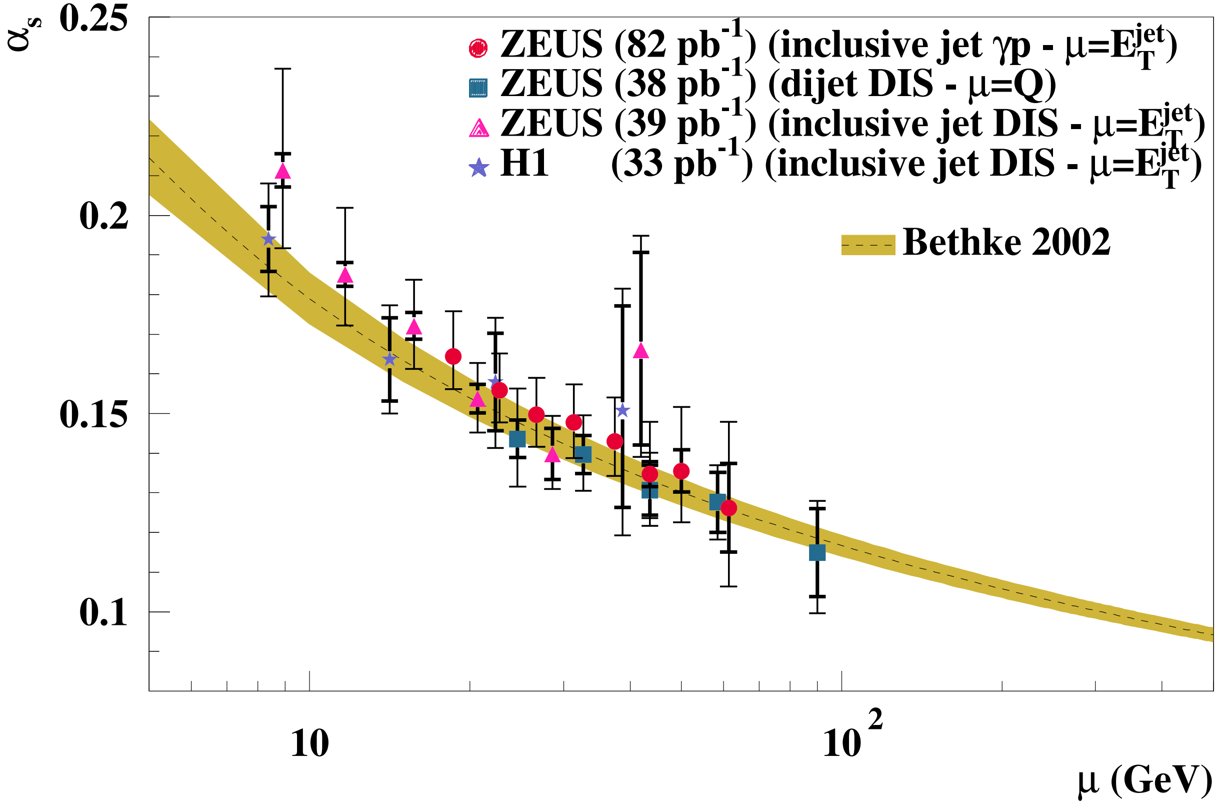
Inclusive jets in photoproduction: H1





Low E_T: hadronization and underlying event corrections become substantial

Inclusive jets in photoproduction: H1 and ZEUS



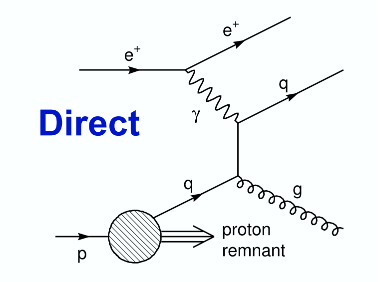
Good agreement with expected running of α_S

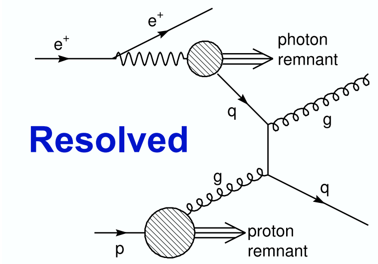
Consistent and competitive measurement of α_S between HERA and LEP

More details in talk by Adam Everett

Dijets in photoproduction and at low Q^2

- Advantages of dijets:
  - more differential quantities
  - Allows to estimate fraction of photon energy going into hard interaction:





$$x_\gamma = \frac{\sum_{jets}(E_j^* - p_z)}{\sum_{hadrons}(E^* - p_z^*)}$$

- Interesting questions:
  - photoproduction: ($Q^2 \Rightarrow 0$) photon behaves as hadron (= has resolved part)
  - DIS: ($Q^2 \Rightarrow \inf$) photon is pointlike
  - ? What happens in transition region?
  - ? Where is the transition region? (Q^2, E_T , . . .)

Dijets in photoproduction and in DIS : ZEUS

NLO:

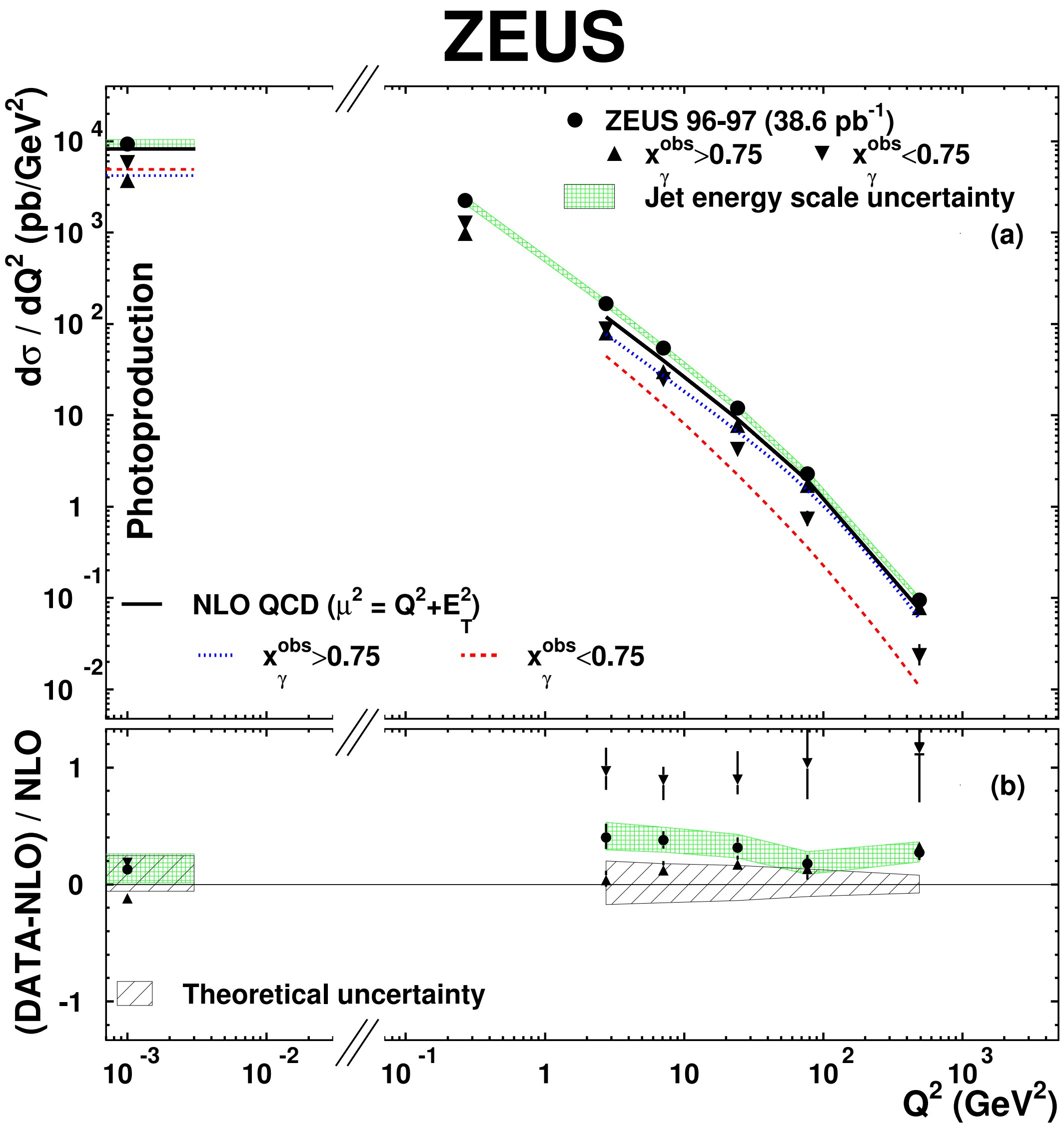
- photoproduction: direct+resolved
- DIS: direct

Comparison with data:

⇒ NLO underestimates cross section

⇒ $x_\gamma > 0.75$ looks OK

⇒ discrepancy located in region $x_\gamma < 0.75$



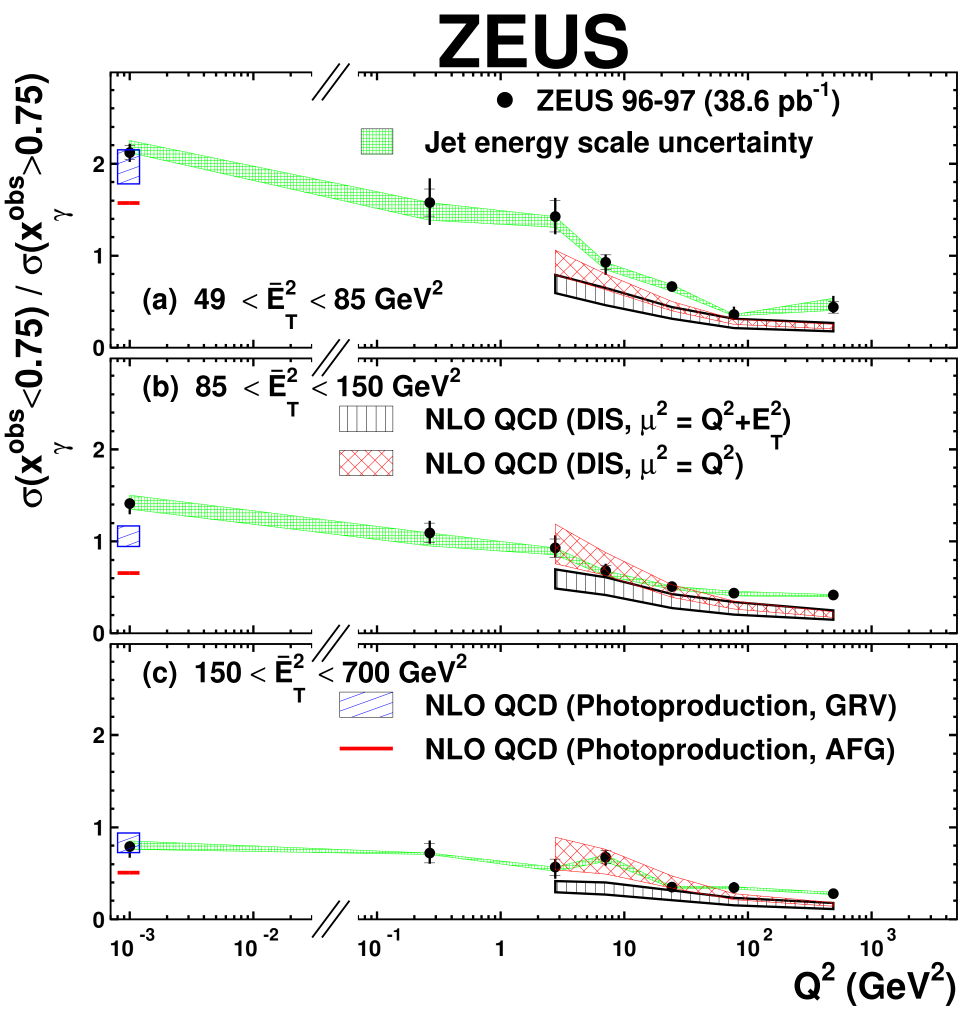
Dijets in photoproduction and in DIS: ZEUS

Cross section as a function of R:

- $R = \frac{\sigma(x_\gamma^{obs}<0.75)}{\sigma(x_\gamma^{obs}>0.75)}$
- advantage:correlated theoretical and experimental uncertainties cancel

Comparison of data with theory:

- discrepancy goes up to rather high Q^2
- most remarkable at low E_T
- using Q^2 as a scale instead of $Q^2 + E_T^2$ improves at low Q^2

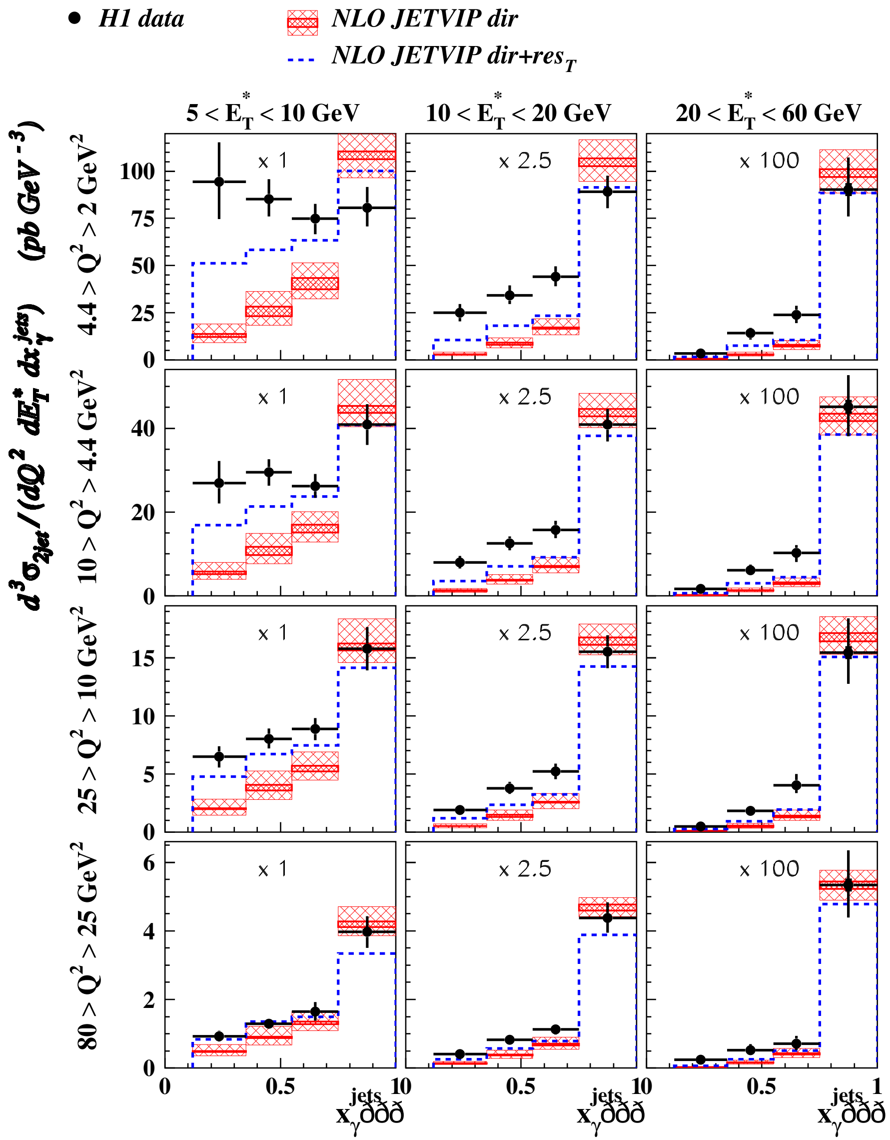


Missing higher orders (at low Q^2 could be included using concept of resolved virtual photon).

Dijets at low Q^2 : H1

Triple differential cross section as a function of x_γ:

- direct NLO underestimates cross section for low x_γ, Q^2 and E_T
- inclusion of resolved component of transverse virtual photon to NLO improves the description of the data
- still not enough!



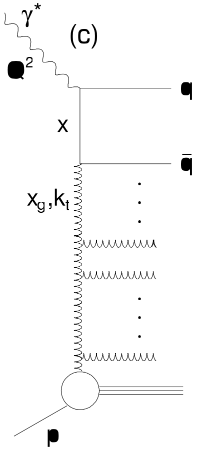
Dijets at low Q^2 : H1

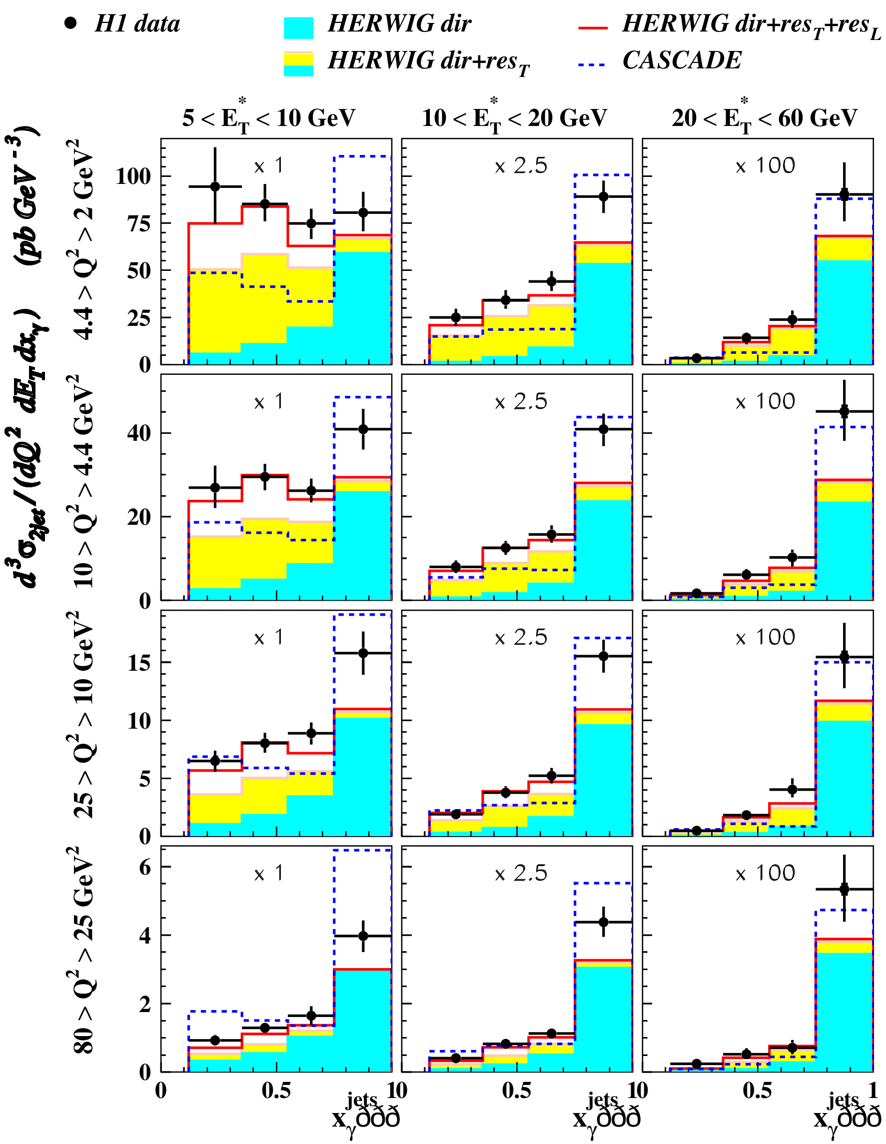
HERWIG(LO+PS+Had):

- direct photon calculation underestimates cross section
- including resolved transverse component improves situation
- good agreement with data after adding resolved longitudinal component

CASCADE(CCFM evolution):

- no k_T ordering (angular ordering)
- un-integrated gluon density

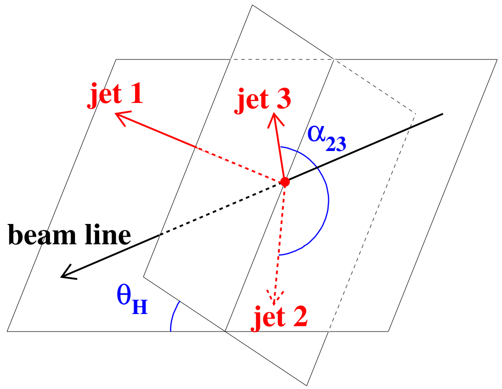


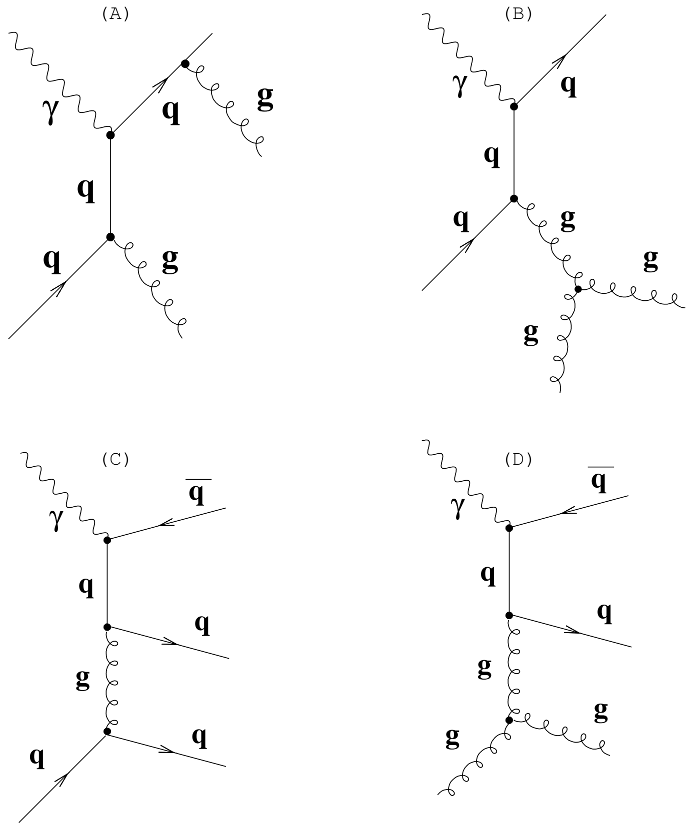


- reasonable (but not perfect) agreement
- no structure of virtual photon

Three jets in photoproduction: ZEUS

- Are there any three-jet observables sensitive to a structure of underlying gauge group ?
- Experimental study: cross section as a function of angles θ_H,α_{23},β_{KSW}:





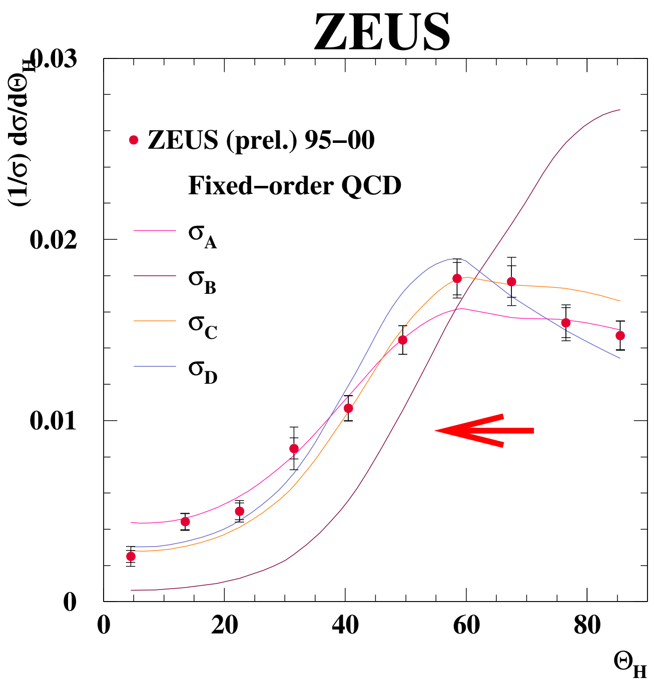
  - β_{KSW}: (Körner-Schierholz-Willrodt)

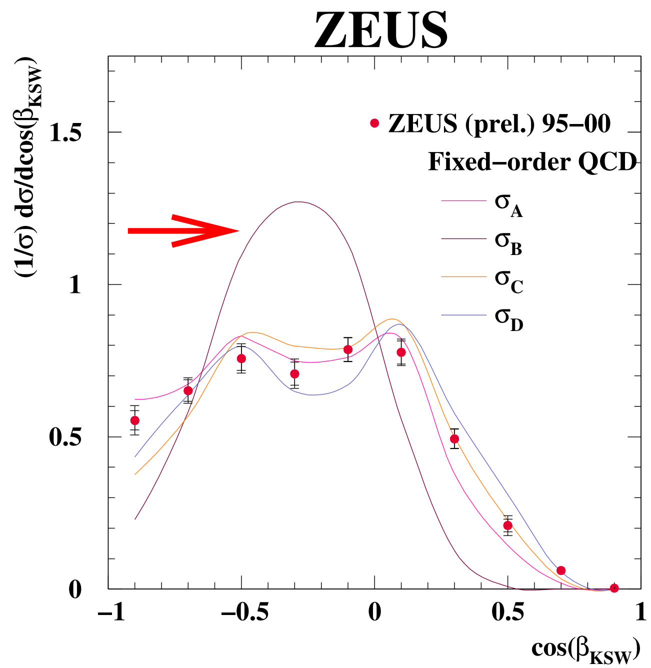
    $\cos\beta_{KSW} = cos\frac{1}{2}(\angle[p_1 \times p_3, p_2 \times p_B] + \angle[p_1 \times p_B, p_2 \times p_3])$

- Select predominantly direct events

LO: $\sigma_{ep\to 3jets} = C_F^2.\sigma_A + C_F C_A.\sigma_B + C_F T_F.\sigma_C + T_F C_A.\sigma_D$

Three jets in photoproduction: ZEUS - Shape of individual terms





- Look at shape of individual terms
- Part of triple-gluon contribution (term B) has different shape
- sensitive to color configurations!

SU(3) predicts relative rates of terms:

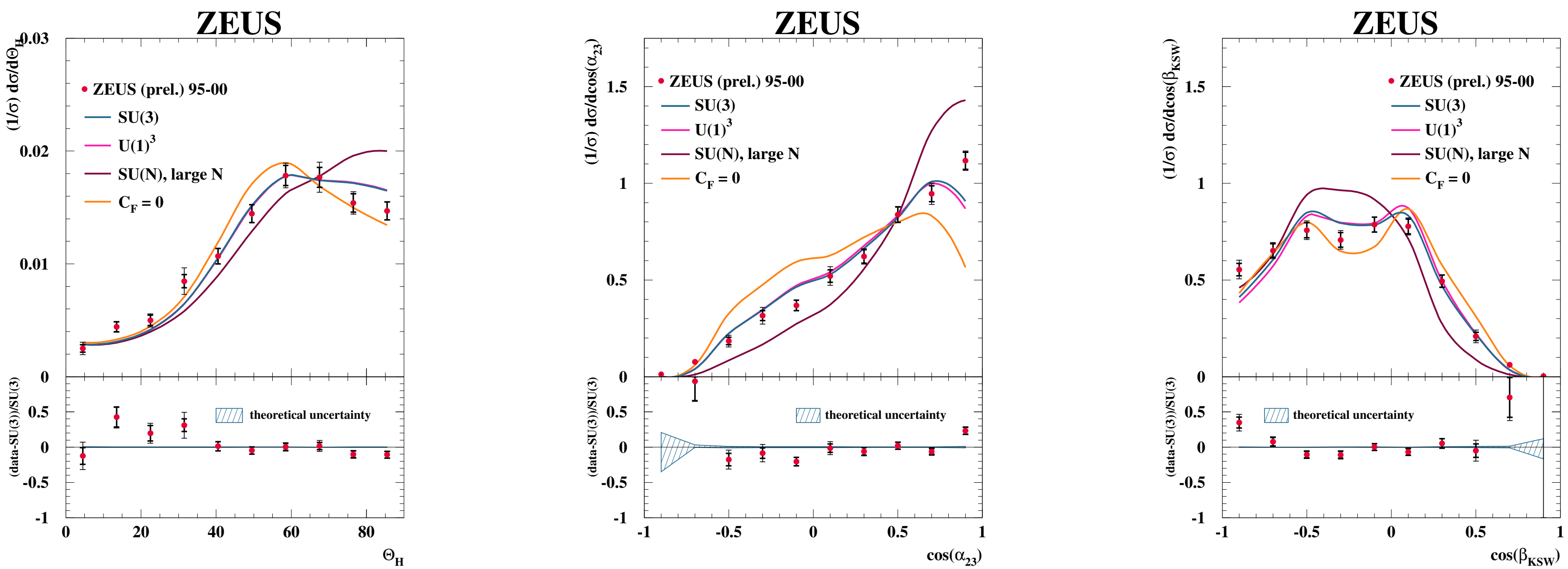
A: 13%

B: 10% (triple gluon in q-induced event !)

C: 45%

D: 32% (triple gluon in g-induced event)

Three jets in photoproduction : ZEUS - Comparison with data



- Terms combined according to predicted probabilities:
- $SU(3)$ in good agreement with data
- $SU(N)$ for large N does not describe the data
- $C_F = 0$: the same story
- Not possible (yet) to discriminate between $SU(3)$ and Abelian theory

Conclusions

- Cross sections for inclusive jets in good agreement with theory

$\longrightarrow$ Allow to extract α_S

- Dijets probe the structure of real and virtual photon

$\longrightarrow$ theory does not describe data at low Q^2 and x_γ
$\longrightarrow$ higher orders needed (resolved virtual photon)

- Three jet events allow to look at structure of gauge group describing strong interactions

Interesting field, still large room for experimental and theoretical studies !