Three-Jet Production
in Deep-Inelastic Scattering

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on behalf of the H1 Collaboration

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- **three-jet production: processes and variables**
- **recent H1 results and a comparison with pQCD in NLO**
- **summary and conclusions**

QCD Processes in the Hadronic Final State in DIS

- **event shape variables:**
  soft processes $\mathcal{O}(\alpha_s)$

- **inclusive jet and dijet production:**
  hard processes $\mathcal{O}(\alpha_s)$
  $\rightarrow$ determination of α_s and the gluon density

- **internal structure of jets in dijet production:**
  (hard +) soft processes $\mathcal{O}(\alpha_s^2)$

- **three-jet production:**
  hard processes $\mathcal{O}(\alpha_s^2)$
  more degrees of freedom
  QCD tests in greater detail

8 variables to study Three-Jet Production in DIS

- kinematics of lepton inclusive reaction: **2 variables** Q^2, x_{Bj}
- angular orientation of 3-jet system w.r.t. lepton plane ϕ
- subprocess: boson-parton $\rightarrow$ 3 massless jets

$(1+2 \rightarrow 3+4+5$ – jets ordered in energy in the 3-jet CM frame)

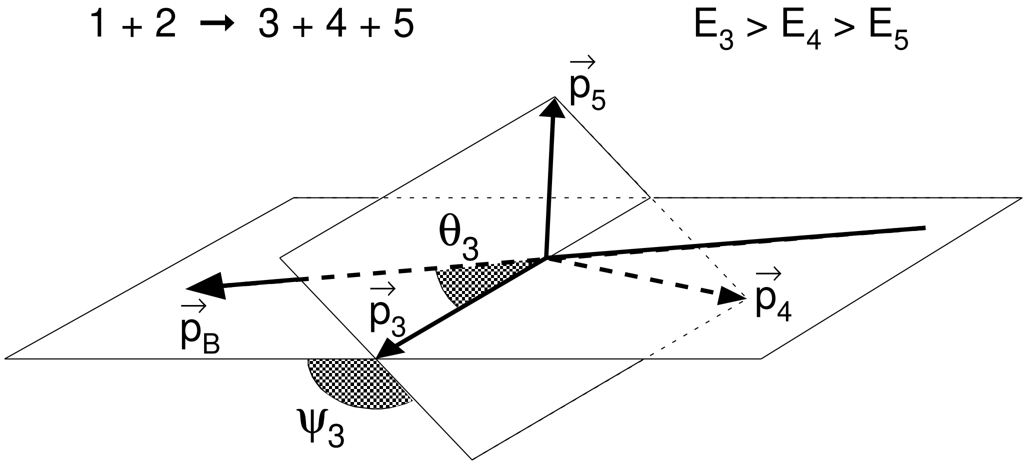
3-jet CM energy: $M_{3-\mathrm{jet}}$

$$X_3 = (2\,E_3)/M_{3\mathrm{jet}}$$
$$X_4 = (2\,E_4)/M_{3\mathrm{jet}}$$

$$\cos\theta_3 = \frac{\vec{p}_B \cdot \vec{p}_3}{|\vec{p}_B|\,|\vec{p}_3|}$$

$$\cos\psi_3 = \frac{(\vec{p}_3 \times \vec{p}_B)\cdot(\vec{p}_4 \times \vec{p}_5)}{|\vec{p}_3 \times \vec{p}_B|\ \ |\vec{p}_4 \times \vec{p}_5|}$$

three-jet center-of-mass frame:



measuring the inclusive 3-jet cross section in DIS

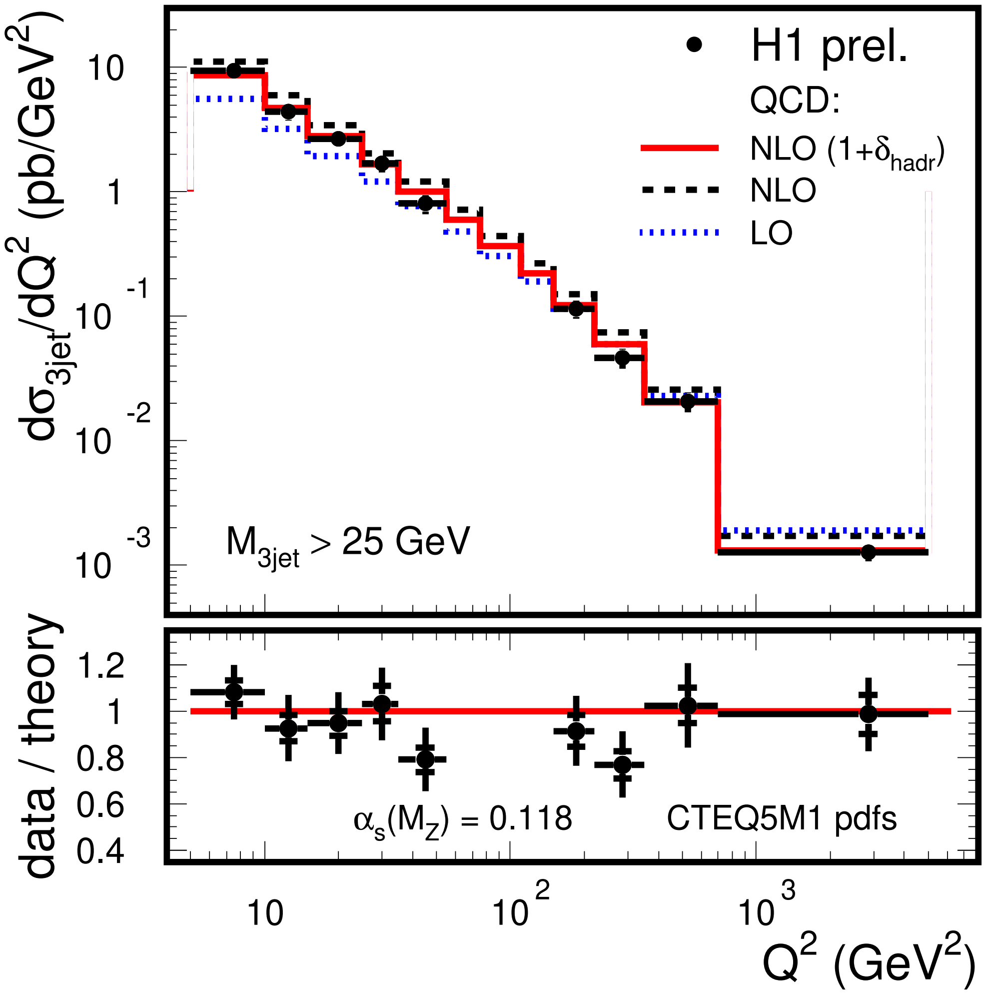
H1 e^+p data from 1995-97

analysis phase space:

$5 < Q^2 < 5000\,\mathrm{GeV}^2$
$0.2 < y < 0.6$

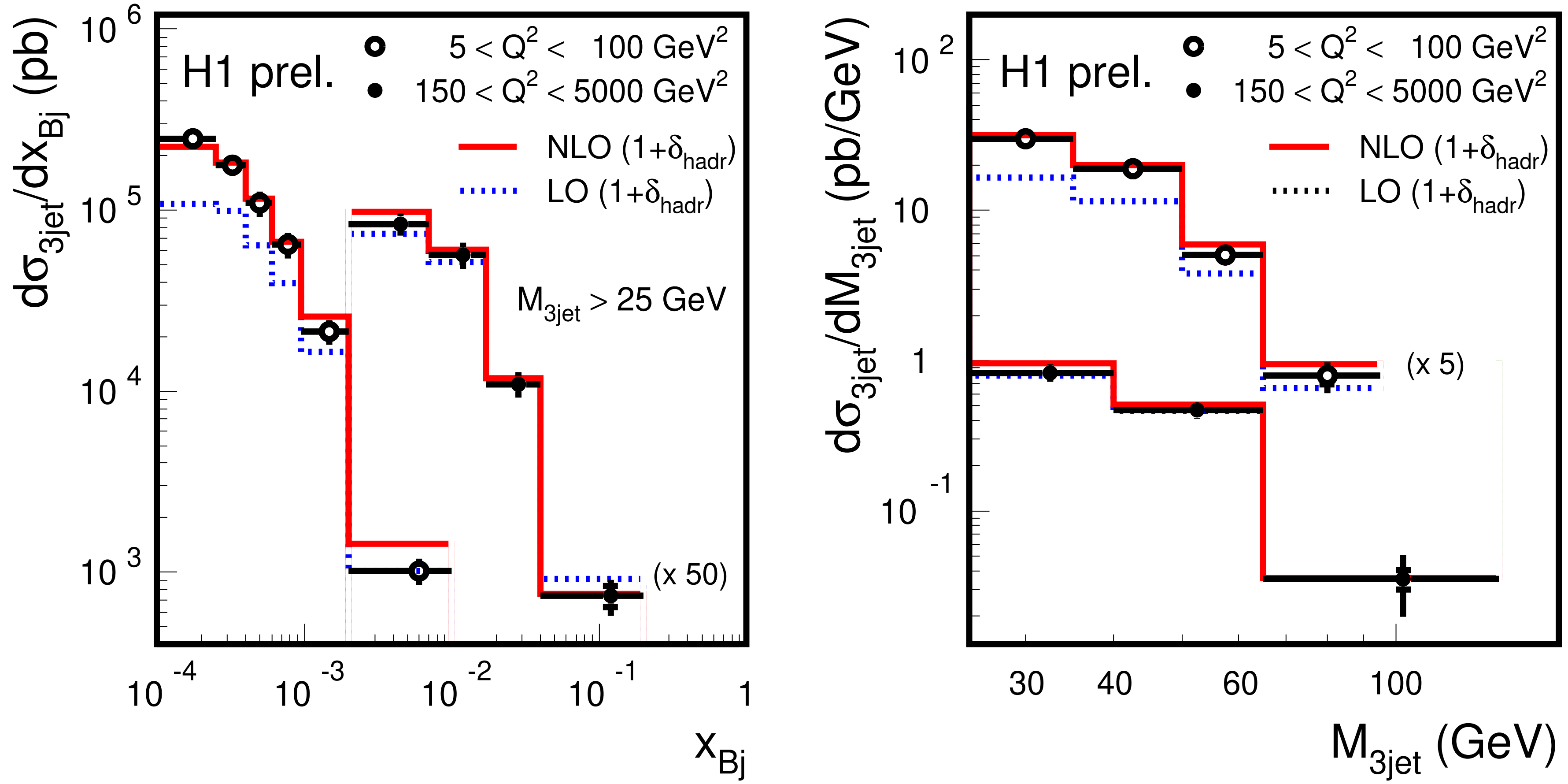
in Breit frame:
incl. $k_\perp$ algorithm

$-1 < \eta_{\text{jet lab}} < 2.5$
$E_{T,\,\text{Breit}} > 5\,\text{GeV}$
$M_{3-\text{jet}} > 25\,\text{GeV}$



theory curves: new NLO calculation by Z. Nagy, Durham **NLOJET**

3-jet cross section: Bjorken-x and invariant 3-jet mass



$\Rightarrow$ agreement over $10^{-4} < x_{\rm Bj} < 0.15$ and $25 < M_{\rm 3jet} < 140\,{\rm GeV}$

Jet Energy Fractions in the 3-Jet CM Frame

jet energy fractions:

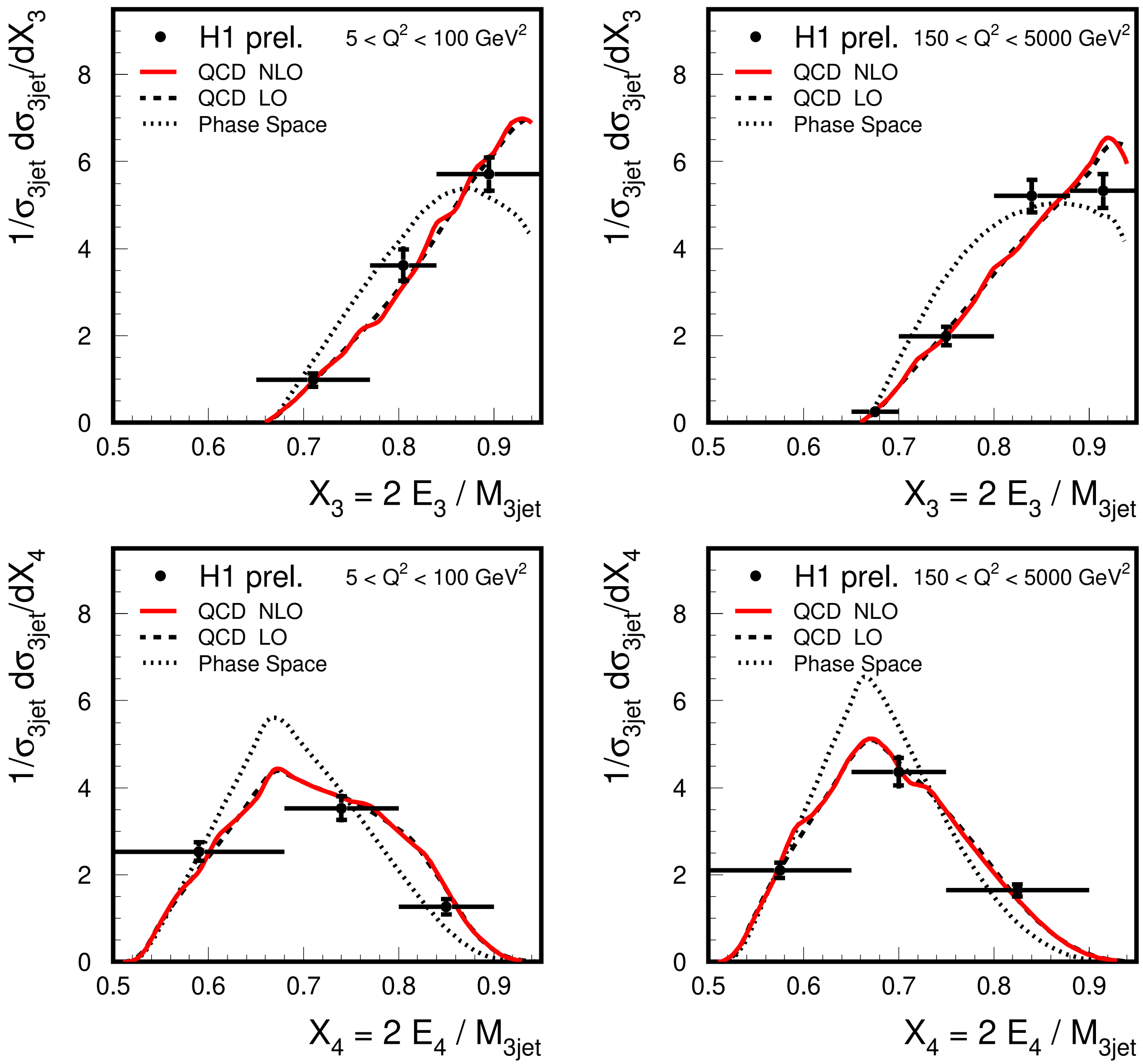
in 3-jet CM frame

$X_3 = (2\,E_3)/M_{\text{3jet}}$
$X_4 = (2\,E_4)/M_{\text{3jet}}$

add. cuts:

$X_3 < 0.95$
$|\cos\theta_3| < 0.8$

$M_{\text{3jet}} > 40\,\text{GeV}$
(only at $Q^2 < 100\,\text{GeV}^2$)



$\Rightarrow$ distributions dominated by phase space

Angular Jet Distributions in the 3-Jet CM Frame

angles:

in 3-jet CM frame

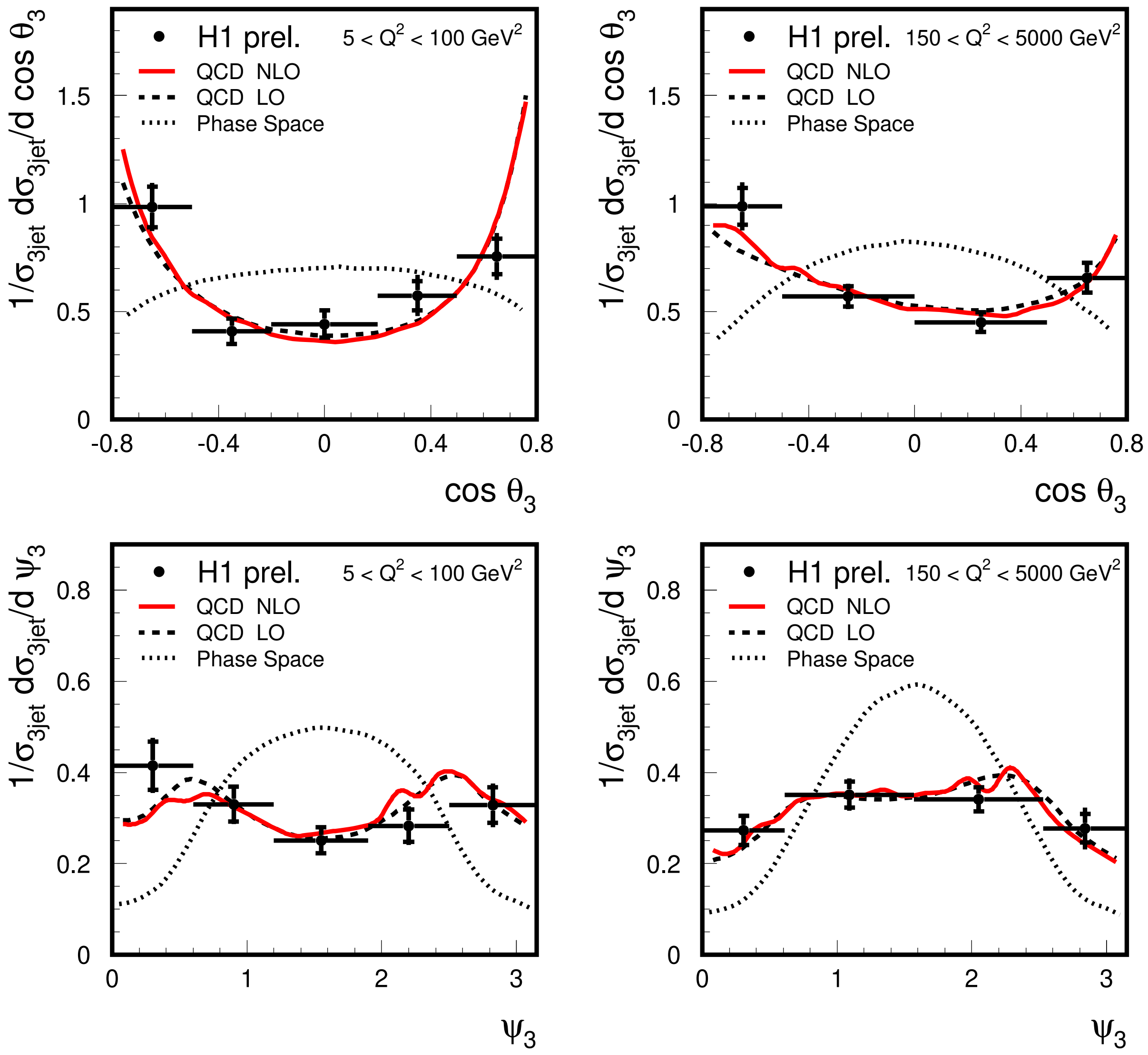
$$\cos\theta_3 = \frac{\vec{p}_B\cdot\vec{p}_3}{|\vec{p}_B|\;|\vec{p}_3|}$$

$$\cos\psi_3 = \frac{(\vec{p}_3\times\vec{p}_B)\cdot(\vec{p}_4\times\vec{p}_5)}{|\vec{p}_3\times\vec{p}_B|\quad|\vec{p}_4\times\vec{p}_5|}$$

add. cuts:

$X_3 < 0.95$
$|\cos\theta_3| < 0.8$

$M_{3\text{jet}} > 40$ GeV
(only at $Q^2 < 100\,\text{GeV}^2$)



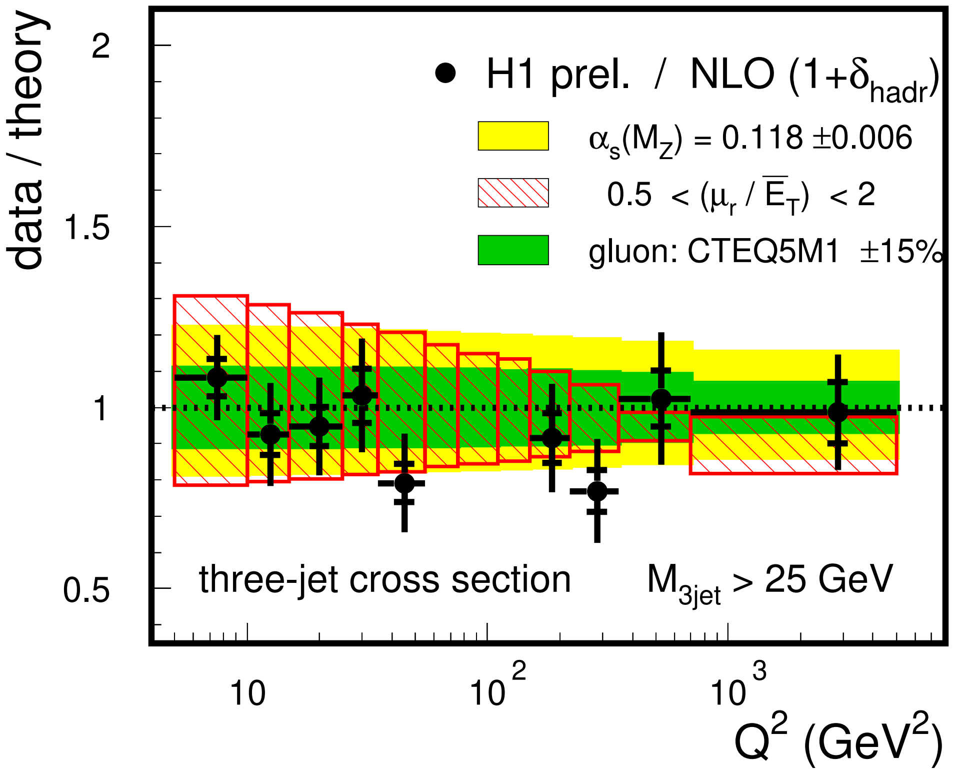
⇒ strong dynamic effects visible — typical QCD radiation pattern

theoretical uncertainties and experimental sensitivity

quantitative test: Q^2 dependence of three-jet cross section $\rightarrow \quad \sigma_{\text{3jet}} \propto \alpha_s^2$

compare:

experimental uncertainties
renormalization scale dependence
variation of gluon $\pm 15\%$
sensitivity to $\Delta\alpha_s(M_Z) = \pm 0.006$



consider:

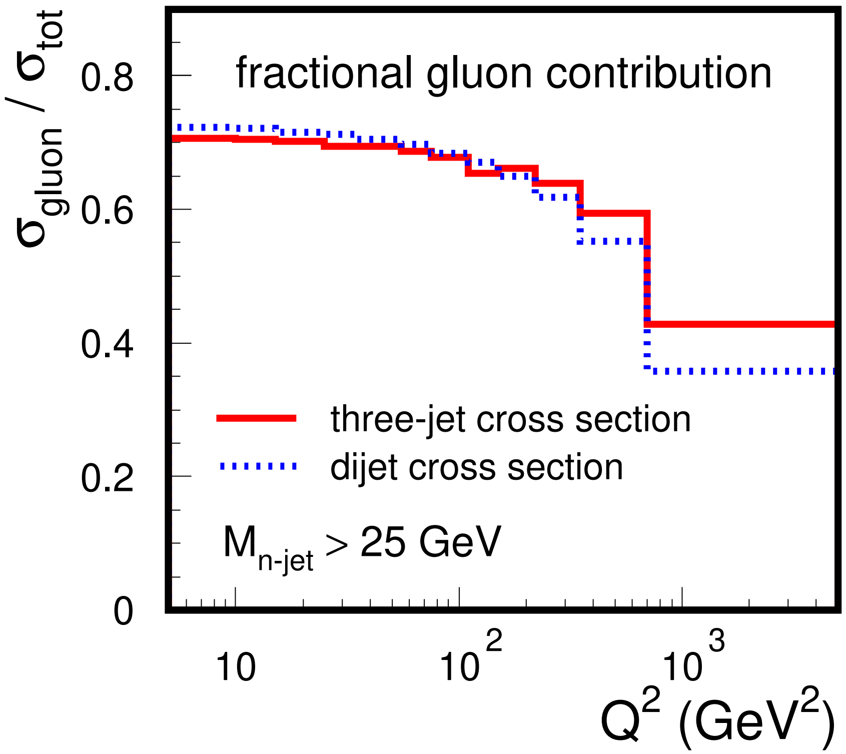
large hadronization corrections: 20%

$\Rightarrow$ at high Q^2:

renormalization scale depend. is smaller than variation $\Delta\alpha_s(M_Z) = \pm 0.006$
$\Rightarrow$ quantitative test of QCD + consistency with the world average value of α_s

fractional gluon contribution...

... to the three-jet and the dijet cross section



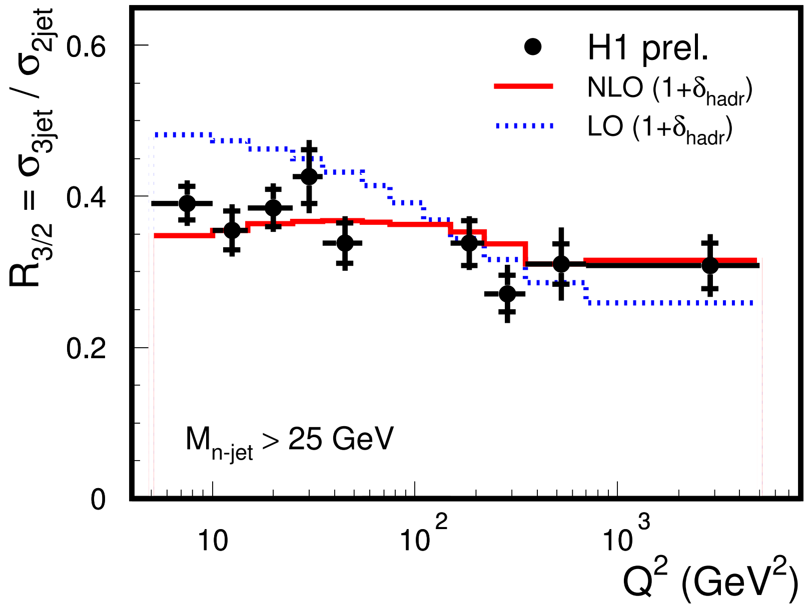
$\Rightarrow$ very similar fractions of gluon and quark induced processes

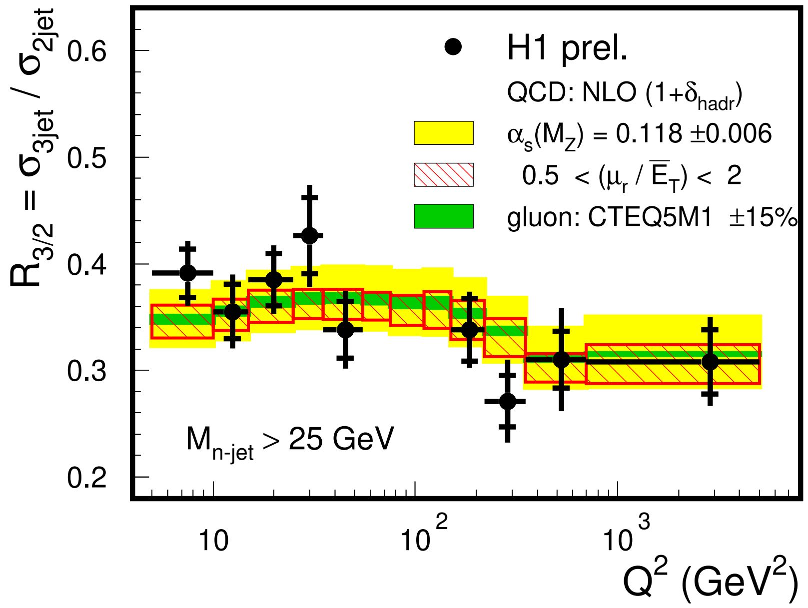
$\Rightarrow$ expect large cancellation of PDF uncertainties in ratio: $R_{3/2} = \sigma_{3\text{jet}}/\sigma_{2\text{jet}} \propto \alpha_s$

Ratio of 3-Jet and 2-Jet Cross Section: $R_{3/2} \propto \alpha_s$

measurement with same cut: $M_{\mathrm{n-jet}} > 25\,\mathrm{GeV}$
probe PDFs at same x $\Rightarrow$ cancellation of PDF uncertainties

comparing data with leading order and with next-to-leading order pQCD





$\Rightarrow$ NLO: significant change of shape + good agreement with data

$\Rightarrow$ small renormalization scale dependence over whole Q^2 range

Summary and Conclusion

- comprehensive measurements of three-jet observables in DIS over range $5 < Q^2 < 5000\,\mathrm{GeV}^2$ and $25 < M_{\mathrm{3jet}} < 140\,\mathrm{GeV}$
- new NLO calculation by Z. Nagy, Durham:
  $\Rightarrow$ **quantitative** test of QCD in three-jet production possible
- extension of QCD tests at HERA to $\mathcal{O}(\alpha_s^2)$
- Very good agreement between NLO prediction and data