Three-Jet Production in Deep-Inelastic Scattering

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on behalf of the

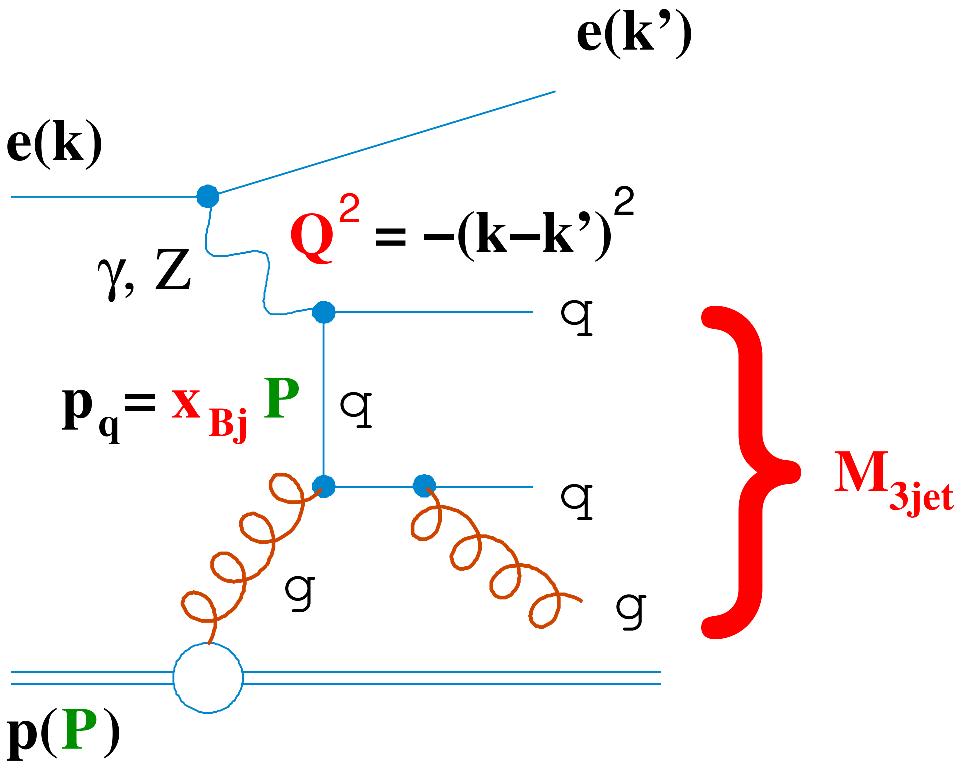
Collaboration

Motivation

- previous measurements of inclusive jet and dijet production:
  directly sensitive to $\mathcal{O}(\alpha_s)$ in LO QCD
  $\Rightarrow$ determination of α_s and gluon density in proton using NLO calculations
- three-jet cross section in DIS: directly sensitive to $\mathcal{O}(\alpha_s^2)$ in LO QCD
  – higher sensitivity to α_s
  – greater number of degrees of freedom
  $\Rightarrow$ QCD tests in more detail
- in this talk:
  – differential measurements of three jet cross sections in neutral current DIS
  – measurements of shapes of angular jet distributions which are sensitive to dynamic effects
  – comparison with NLO QCD $\mathcal{O}(\alpha_s^3)$
  $\Rightarrow$ published for the first time: Phys. Lett. B517: 47-58, 2001

Variables

neutral current DIS:



- cross section as function of Q^2, $x_{\rm Bj}$, $M_{\rm 3jet}$
- partonic subprocess $1+2 \longrightarrow 3+4+5$

  for massless jets:

  fully described by Q^2, $x_{\rm Bj}$ and 6 further variables constructed from energies and momenta of jets
- $R_{3/2} = \sigma_{\rm 3jet}/\sigma_{\rm 2jet}$ as a function of Q^2

kinematic range: $5 < Q^2 < 5\,000\,{\rm GeV}^2$

$25 < M_{\rm 3jet} \lesssim 140\,{\rm GeV}$

Event Selection

e^+ in LAr:

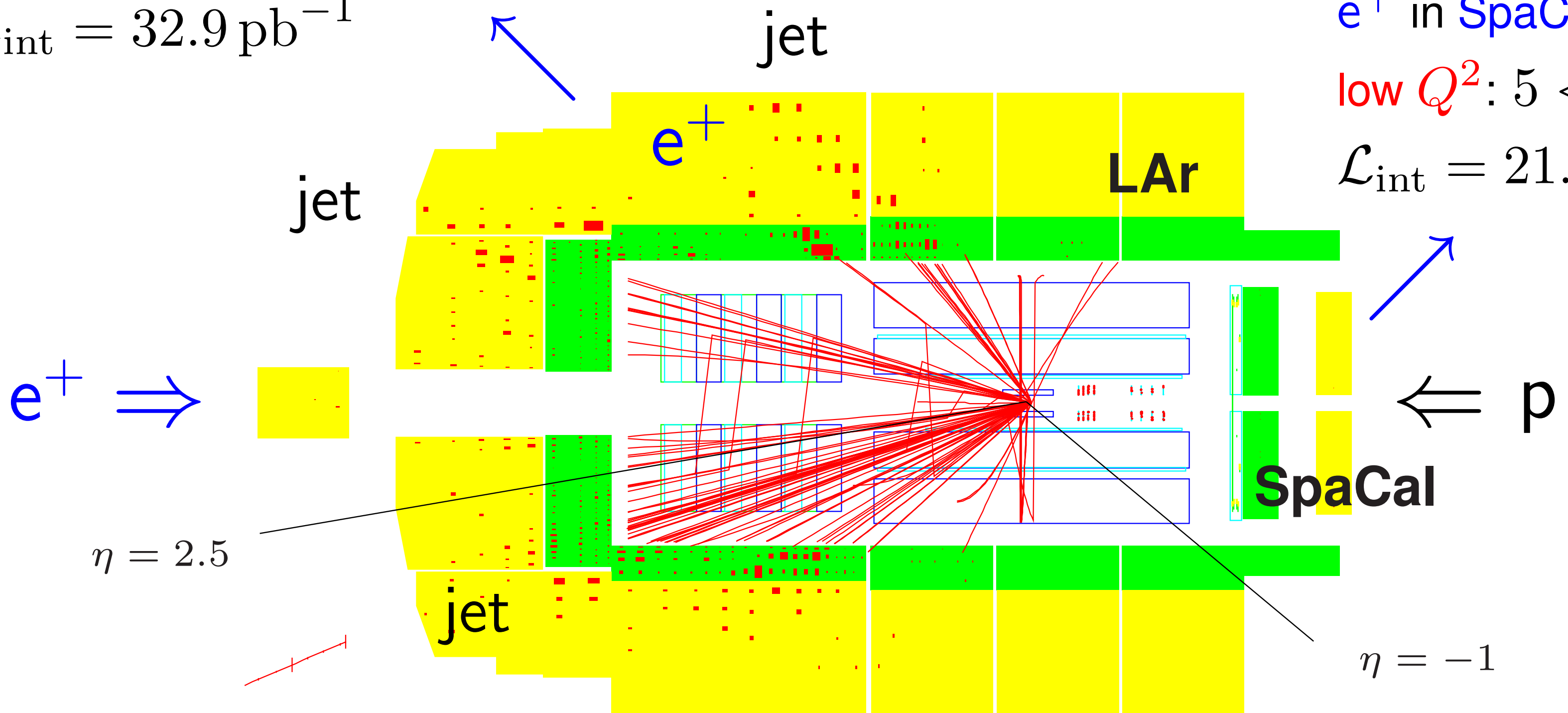
high Q^2: $150 < Q^2 < 5\,000\,\mathrm{GeV}^2$

$\mathcal{L}_{\mathrm{int}} = 32.9\,\mathrm{pb}^{-1}$

e^+ in SpaCal:

low Q^2: $5 < Q^2 < 100\,\mathrm{GeV}^2$

$\mathcal{L}_{\mathrm{int}} = 21.1\,\mathrm{pb}^{-1}$



- $0.2 < y = Q^2/(s\,x_{\mathrm{Bj}}) < 0.6$

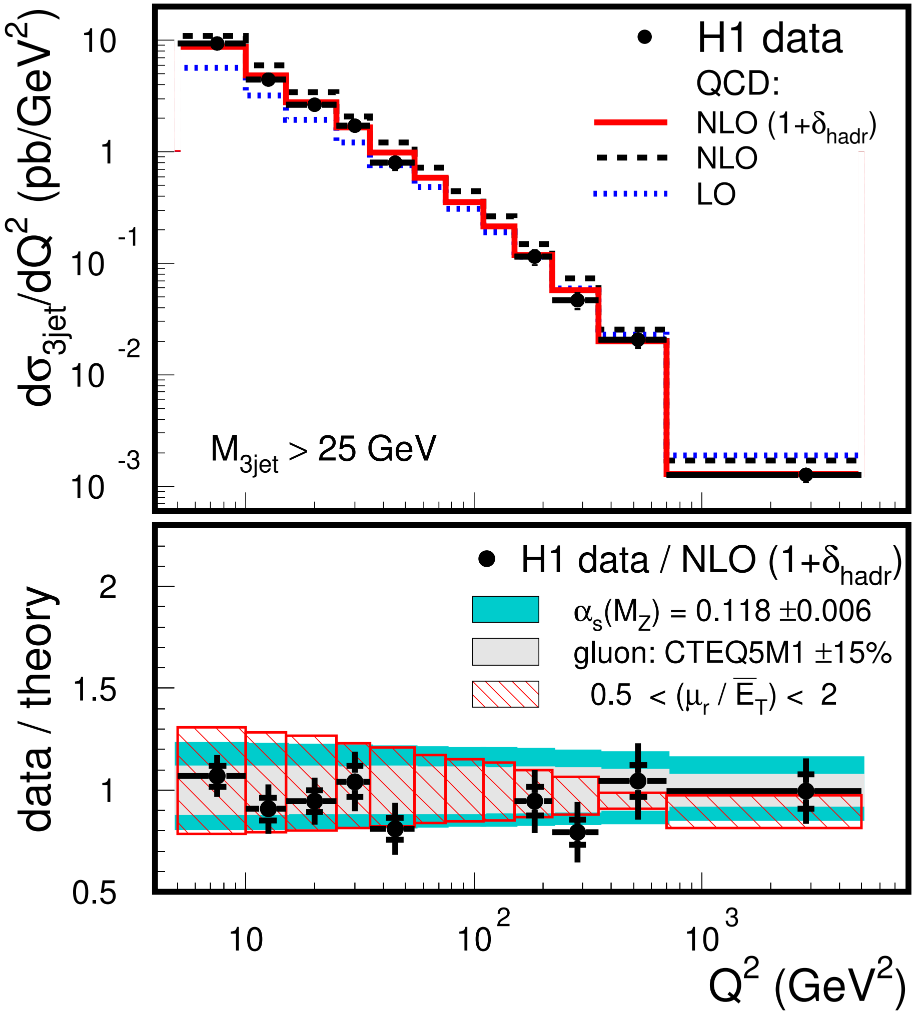
CM energy: $\sqrt{s} = 300\,\mathrm{GeV}$

in Breit frame:

- inclusive $k_\perp$ clustering algorithm
- $-1 < \eta_{\mathrm{jet,lab}} < 2.5$
  $E_T > 5\,\mathrm{GeV}$
  $M_{3\mathrm{jet}} > 25\,\mathrm{GeV}$

H1 e^+p data from 1995 – 97

3-Jet Cross Section as Function of Q^2



- theory curves:

  NLO calculations by Nagy, Trocsanyi

  (Phys. Rev. Lett. 87: 082001, 2001):

  NLOJET

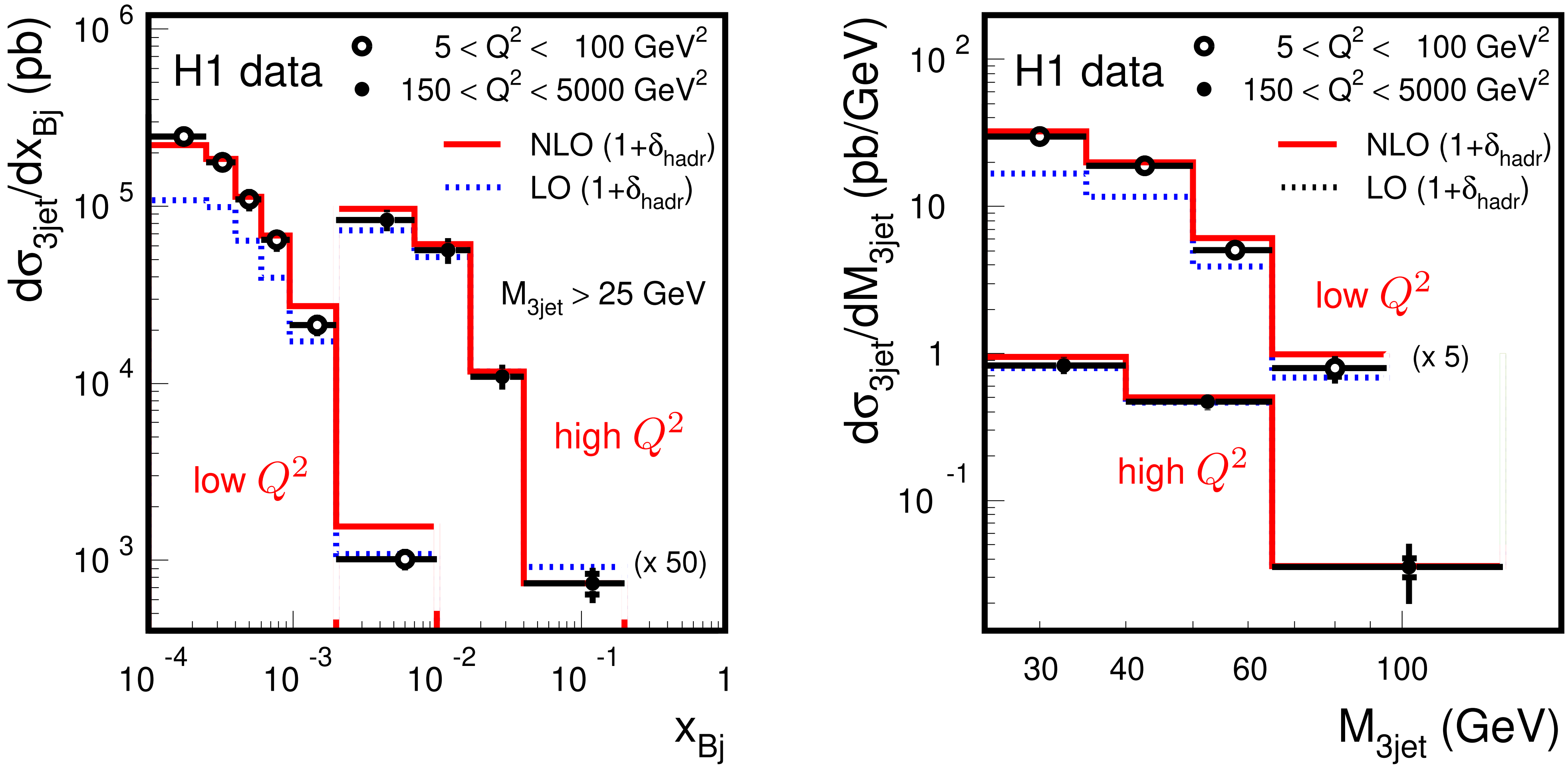
- hadronization corrections δ_{hadr}:

  relative change of an observable before and after hadronization

- theoretical uncertainties:
  - value of α_s
  - parton density functions of proton (especially gluon density)
  - renormalization scale dependence

$\Rightarrow$ NLO prediction gives good description of data over whole range of Q^2 (LO does not)

3-Jet Cross Section as Function of x_{Bj} and M_{3jet}



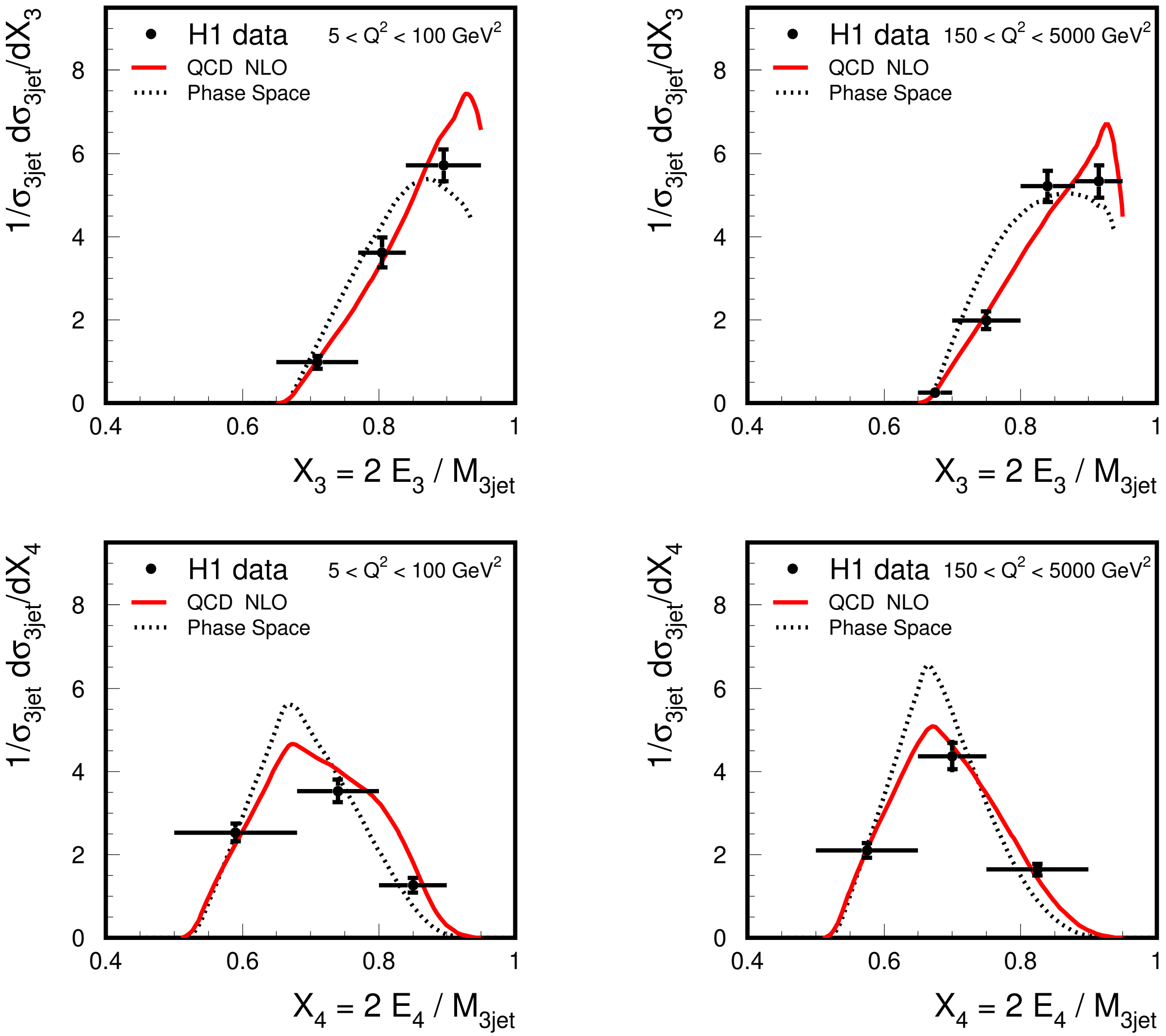
$\Rightarrow$ NLO calculation gives good description of data over range

$$10^{-4} < x_{\mathrm{Bj}} < 0.2 \text{ and } 25 < M_{\mathrm{3jet}} < 140\,\mathrm{GeV}$$

(LO does not)

Jet Energy Fractions in 3-Jet CM Frame

low Q^2 high Q^2



$$\underline{1+2 \rightarrow 3+4+5}$$

$$E_3 > E_4 > E_5$$

$$X_3 = 2\,E_3/M_{3\mathrm{jet}}$$

$$X_4 = 2\,E_4/M_{3\mathrm{jet}}$$

- additional cuts:

$$X_3 < 0.95$$

$$|\cos\theta_3| < 0.8$$

$$M_{3\mathrm{jet}} > 40\,\mathrm{GeV}$$

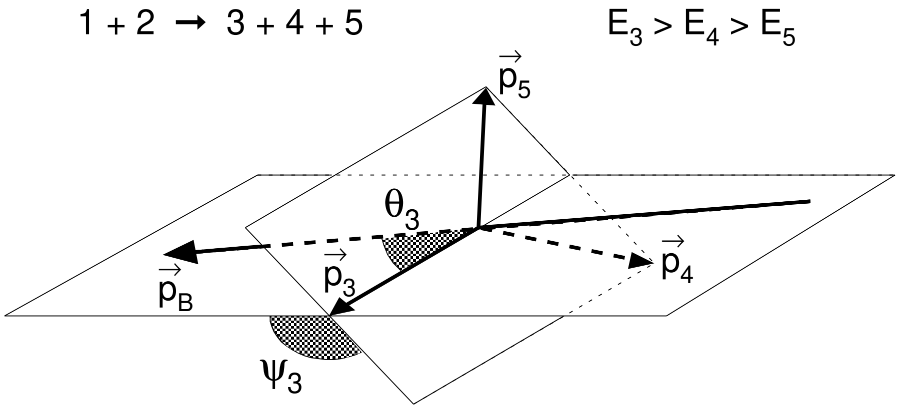
$$(\text{ only for } Q^2 < 100\,\mathrm{GeV}^2 \;)$$

$\Rightarrow$ NLO corrections negligible

$\Rightarrow$ distributions dominated by phase space

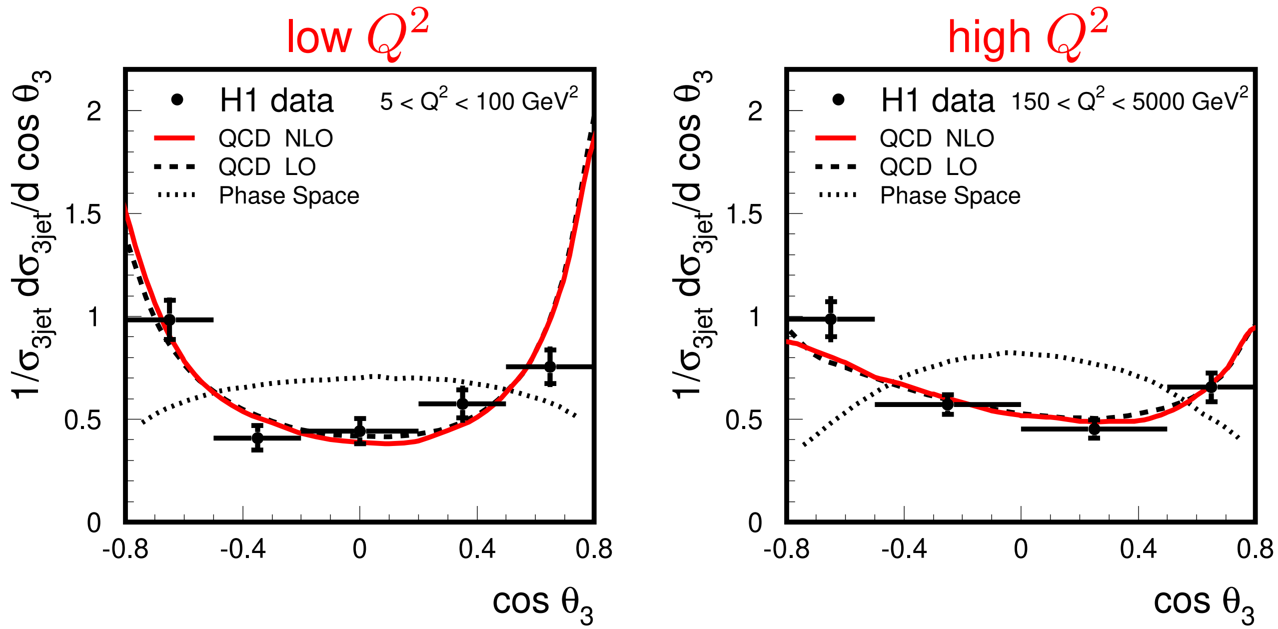
Angular Distributions of $\cos\theta_3$

three-jet center-of-mass frame:



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

$\vec{p}_B$: direction of the proton beam



- additional cuts:

$$\begin{array}{rcl} X_3 & < & 0.95 \\ |\cos\theta_3| & < & 0.8 \\ M_{3\text{jet}} & > & 40\,\text{GeV} \\ (\text{ only for } Q^2 & < & 100\,\text{GeV}^2\ ) \end{array}$$

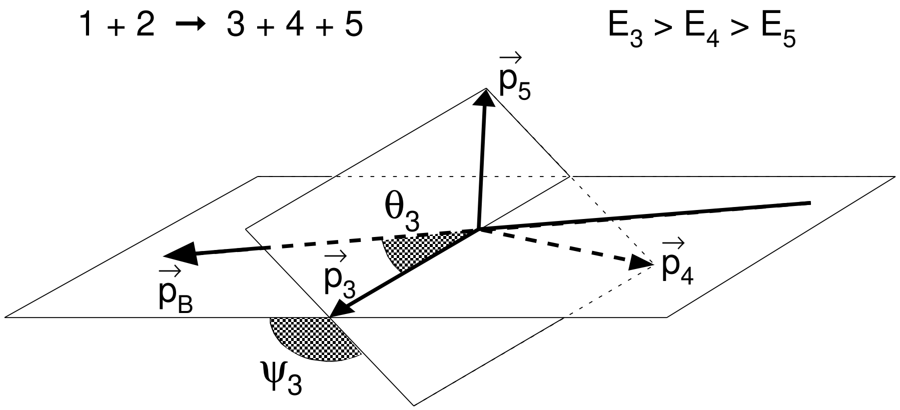
⇒ NLO QCD gives good description of data

⇒ shapes almost unaffected by NLO corrections

⇒ strong dynamic effects visible

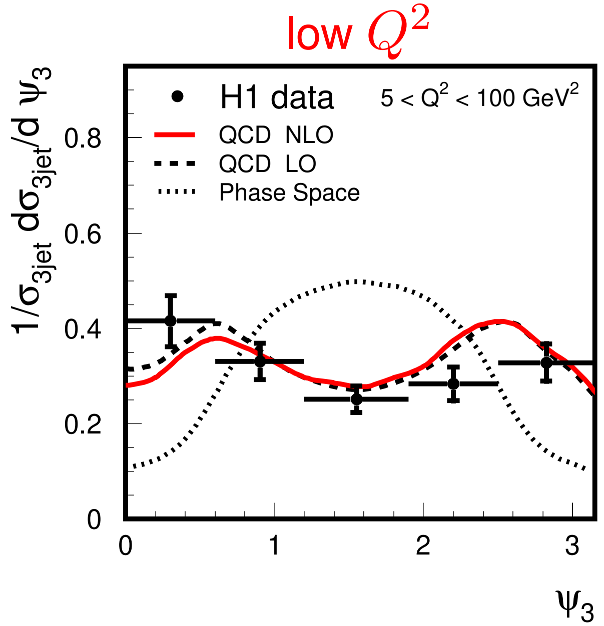
Angular Distributions of ψ_3

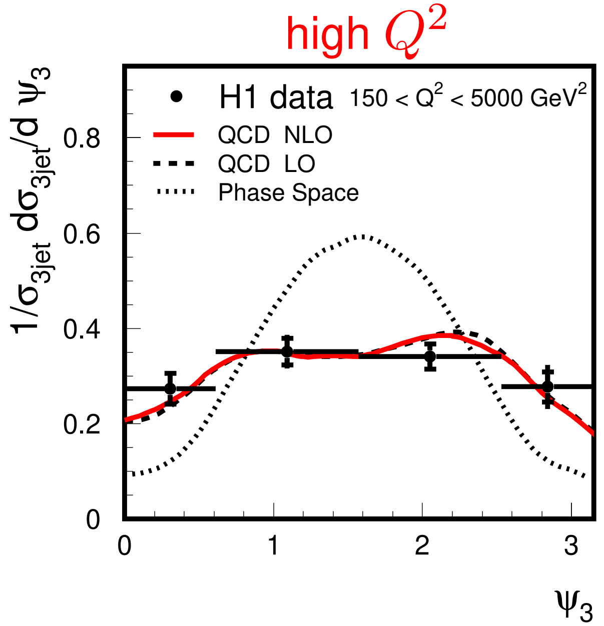
three-jet center-of-mass frame:



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

$\vec{p}_B$: direction of the proton beam





- additional cuts:

$$X_3 < 0.95$$
$$|\cos\theta_3| < 0.8$$
$$M_{3\mathrm{jet}} > 40\,\mathrm{GeV}$$
$$(\text{ only for } Q^2 < 100\,\mathrm{GeV}^2\ )$$

$\Rightarrow$ NLO QCD gives good description of data

$\Rightarrow$ shapes almost unaffected by NLO corrections

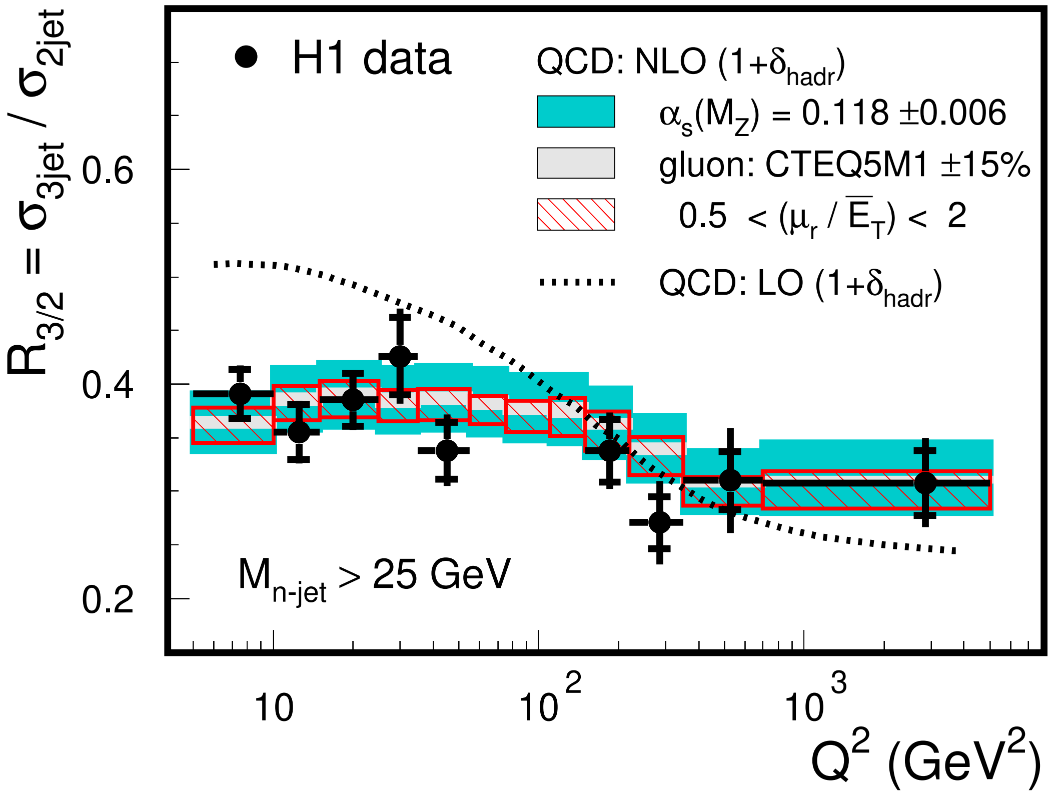
$\Rightarrow$ typical QCD radiation pattern (qualitative agreement with $\bar{p}p$ and γp)

$R_{3/2} = \sigma_{3\mathrm{jet}}/\sigma_{2\mathrm{jet}}$ as Function of Q^2

some experimental and theoretical uncertainties cancel to a large extent

$\Longrightarrow$

- NLO: significant change of shape
  $\Rightarrow$ good agreement with data
- both cross sections are dominated by gluon induced processes:
  $R_{3/2}$ almost insensitive to variations of gluon density in proton
- renormalization scale dependence smaller than variation $\Delta\alpha_s(M_Z) = \pm 0.006$
- for world average $\alpha_s(M_Z) = 0.118$:
  consistency between NLO calculations and data



Summary

- measurements of 3-jet observables in DIS over range $5 < Q^2 < 5\,000\,\mathrm{GeV}^2$ and $25 < M_{\mathrm{3jet}} \lesssim 140\,\mathrm{GeV}$
- extension of QCD tests at HERA to $\mathcal{O}(\alpha_s^2)$ in LO QCD
- comparison with NLO QCD $\mathcal{O}(\alpha_s^3)$

$\Rightarrow$ good agreement between NLO prediction and data