DIS production of inclusive hadrons with large p_T at NLO

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Contents

[1] B.A.K., G. Kramer, M. Maniatis, Nucl. Phys. **B711** (2005) 345.
[2] C. Adloff et al., Phys. Lett. **B462** (1999) 440; A. Aktas et al., Eur. Phys. J. **C36** (2004) 441.
[3] M. Derrick et al., Z. Phys. **C70** (1996) 1.

1. Introduction

Motivation for NLO:

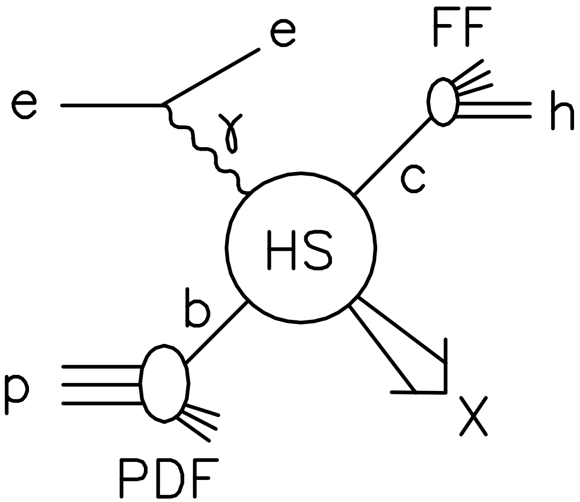
- Reduction of renormalization and factorization scale dependence.
- Sizeable effects, e.g. due to opening of new partonic production channels.
- Test of DGLAP scaling violations and universality of FFs (factorization theorem of QCD-improved parton model).
- High-statistics data from HERA II.

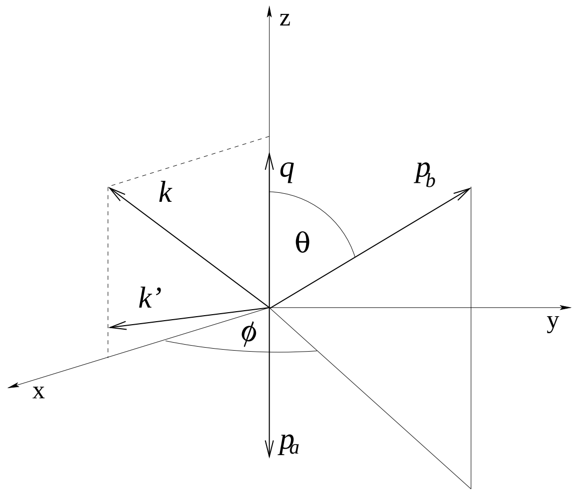
Other NLO calculations:

- P. Büttner, PhD thesis, University of Hamburg, 1999, Report No. DESY-THESIS 1999-004 transverse γ^* only, phase-space slicing.
- P. Aurenche, R. Basu, M. Fontannaz, R.M. Godbole, Eur. Phys. J. C 34 (2004) 277 based on DISENT, w/o Furry terms, phase-space slicing.
- A. Daleo, D. de Florian, R. Sassot, Phys. Rev. **D71** (2005) 034013 see previous talk.

2. LO results

A. Mendez, Nucl. Phys. **B145** (1978) 199.





$$e^-(k) + p(P) \to e^-(k') + h(p) + X \qquad \gamma^*(q) + a(p_a) \to b(p_b) + X$$

$$S = (P + k)^2 \qquad s = (p_a + q)^2$$

$$\overline{x} = x_{\mathrm{B}} = Q^2/(2P \cdot q) \qquad x = Q^2/(2p_a \cdot q)$$

$$\overline{y} = P \cdot q/P \cdot k = \qquad y = p_a \cdot q/p_a \cdot k$$

$$\overline{z} = P \cdot p/P \cdot q \qquad z = p_a \cdot p_b/p_a \cdot q$$

$$\frac{d^3\sigma^h}{d\overline{x}\,dy\,d\overline{z}} = \sum_{ab} \int_{\overline{x}}^{1} \frac{dx}{x} \int_{\overline{z}}^{1} \frac{dz}{z} F_a^p(\overline{x}/x, \mu_i) \frac{d^3\sigma^{ab}}{dx\,dy\,dz} D_b^h(\overline{z}/z, \mu_f)$$

$$\frac{d^3\sigma^{ab}}{dx\,dy\,dz} = \frac{\alpha^2}{8\pi} \left(\frac{y^2 - 2y + 2}{2yQ^2} H_T^{ab} + 2\frac{y^2 - 6y + 6}{y^3 s^2} H_L^{ab} \right)$$

where $H_T^{ab} = -g^{\mu\nu} H_{\mu\nu}^{ab}$, $H_L^{ab} = p_a^\mu p_a^\nu H_{\mu\nu}^{ab}$.

Subprocesses:

$$\gamma^* + q \to q + g$$
$$\gamma^* + q \to g + q$$
$$\gamma^* + g \to q + \overline{q}$$

where $q = q_1, \overline{q}_1, \ldots, q_{n_f}, \overline{q}_{n_f}$.

3. NLO calculation: (a) Virtual corrections

- Interference of tree-level and one-loop matrix elements.
- Self-energy, triangle, and box diagrams.
- 2-, 3-, and 4-point tensor integrals.
- Reduction to scalar integrals using Passarino-Veltman algorithm.
- UV and IR singularities extracted in dimensional regularization.
- Analytic results in agreement with D. Graudenz, Phys. Rev. **D49** (1994) 3291.

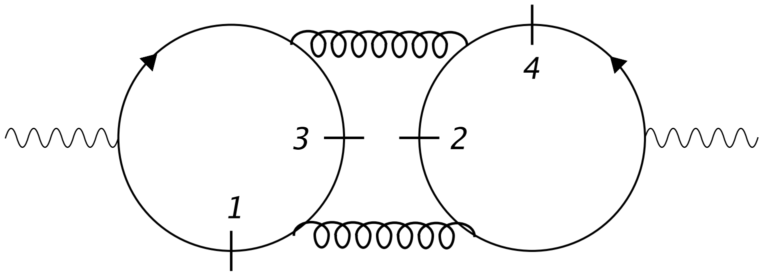
(b) Real corrections

$$
\begin{aligned}
\gamma^* + q &\to q + g + g \\
\gamma^* + q &\to g + q + g \\
\gamma^* + g &\to q + \overline{q} + g \\
\gamma^* + g &\to g + q + \overline{q} \\
\gamma^* + q &\to q + q + \overline{q} \\
\gamma^* + q &\to \overline{q} + q + q \\
\gamma^* + q &\to q + q' + \overline{q}' \\
\gamma^* + q &\to q' + \overline{q}' + q
\end{aligned}
$$

where $q, q' = q_1, \overline{q}_1, \ldots, q_{n_f}, \overline{q}_{n_f}$ with $q \neq q'$.

- Consider corresponding subprocesses of e^+e^- annihilation via a virtual photon.
- Analytic results in agreement with R.K. Ellis, D.A. Ross, A.E. Terrano, Nucl. Phys. **B178** (1981) 421.
- Exploit crossing symmetry.

Furry terms



- Furry cancellation if on-shell quarks in one of the loops are untagged, e.g. in e^+e^- annihilation or $ep \to j + X$ in DIS.
- Cancellation hindered in $ep \to h + X$ if tagged quarks are in different loops and PDFs or FFs are different for quarks and antiquarks.

4. Phenomenology

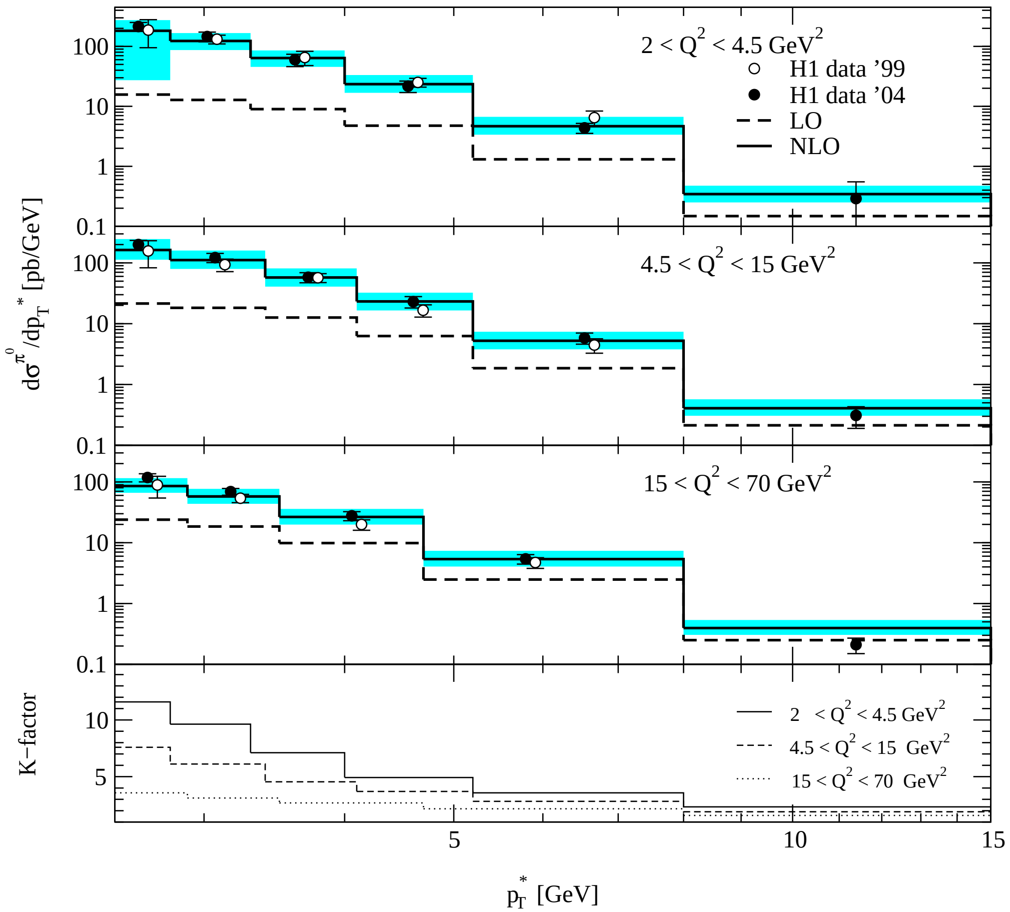
Input:

- p PDFs: CTEQ6M (CTEQ6L1) w/ $\Lambda_{\mathrm{QCD}}^{(5)} = 226$ MeV (165 MeV) at NLO (LO)
- $\pi^\pm, K^\pm, p/\overline{p}$ FFs: KKP

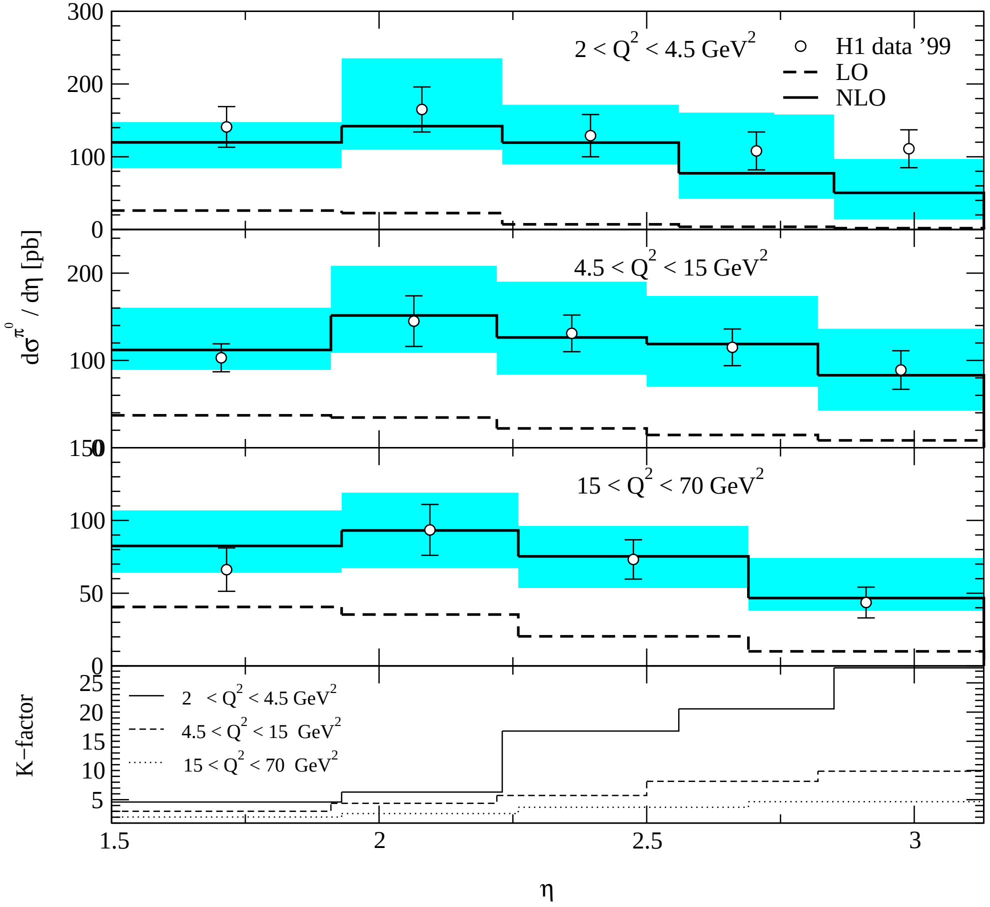
$$D_a^{\pi^0}(x,\mu_f) = \frac{1}{2} D_a^{\pi^\pm}(x,\mu_f)$$
$$D_a^{h^\pm}(x,\mu_f) = D_a^{\pi^\pm}(x,\mu_f) + D_a^{K^\pm}(x,\mu_f) + D_a^{p/\overline{p}}(x,\mu_f)$$

- $\mu_r^2 = \mu_i^2 = \mu_f^2 = \xi[Q^2 + (p_T^*)^2]/2$ with $0.5 < \xi < 2$
- H1: 5.8 and 21.2 pb^{-1} at $\sqrt{S} = 301$ GeV from 1996 and 1996/1997
  DIS range: $0.1 < y < 0.6$, $2 < Q^2 < 70$ GeV^2
  acceptance cuts: $p_T^* > 2.5$ and 3.5 GeV, $5^\circ < \theta < 25^\circ$, $x_E = E_h/E_p > 0.01$
- ZEUS: 0.55 pb^{-1} at $\sqrt{S} = 296$ GeV from 1993
  DIS range: $10 < Q^2 < 160$ GeV^2, $75 < W < 175$ GeV
  acceptance cut: $x_F = 2p_L^*/W > 0.05$

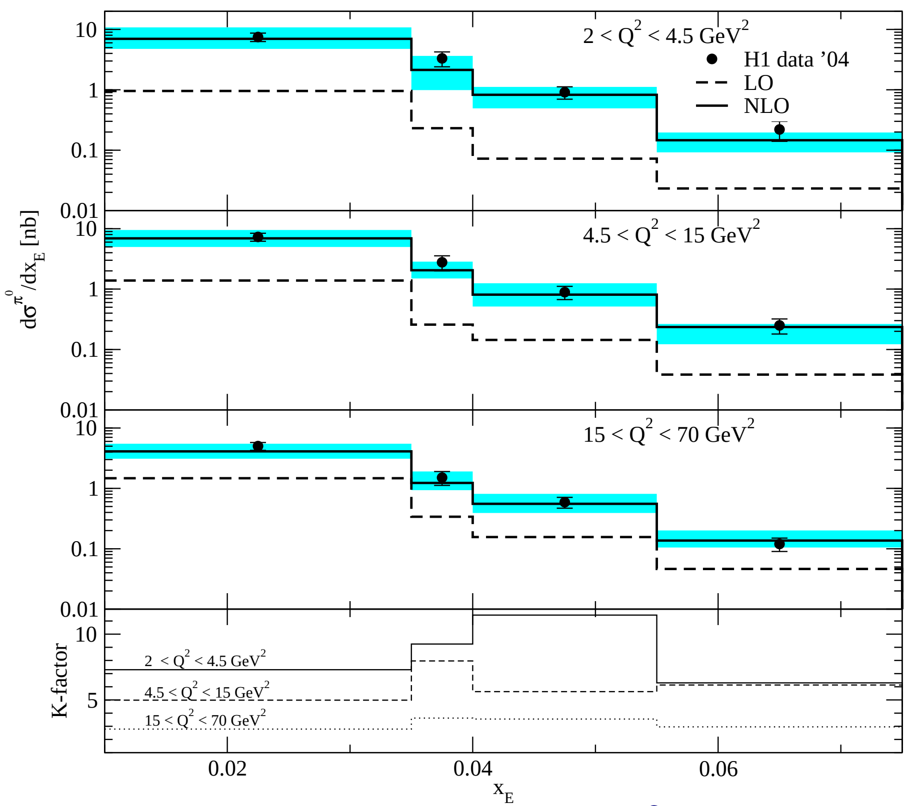
(a) π^0 mesons in the forward region (H1)



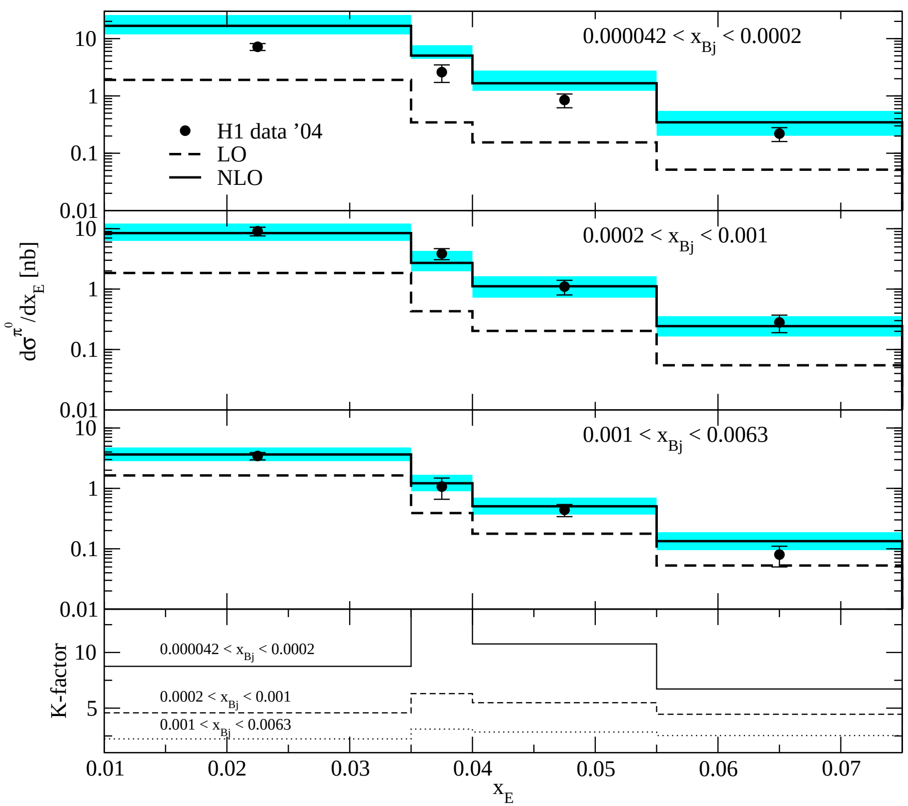
p_T^*



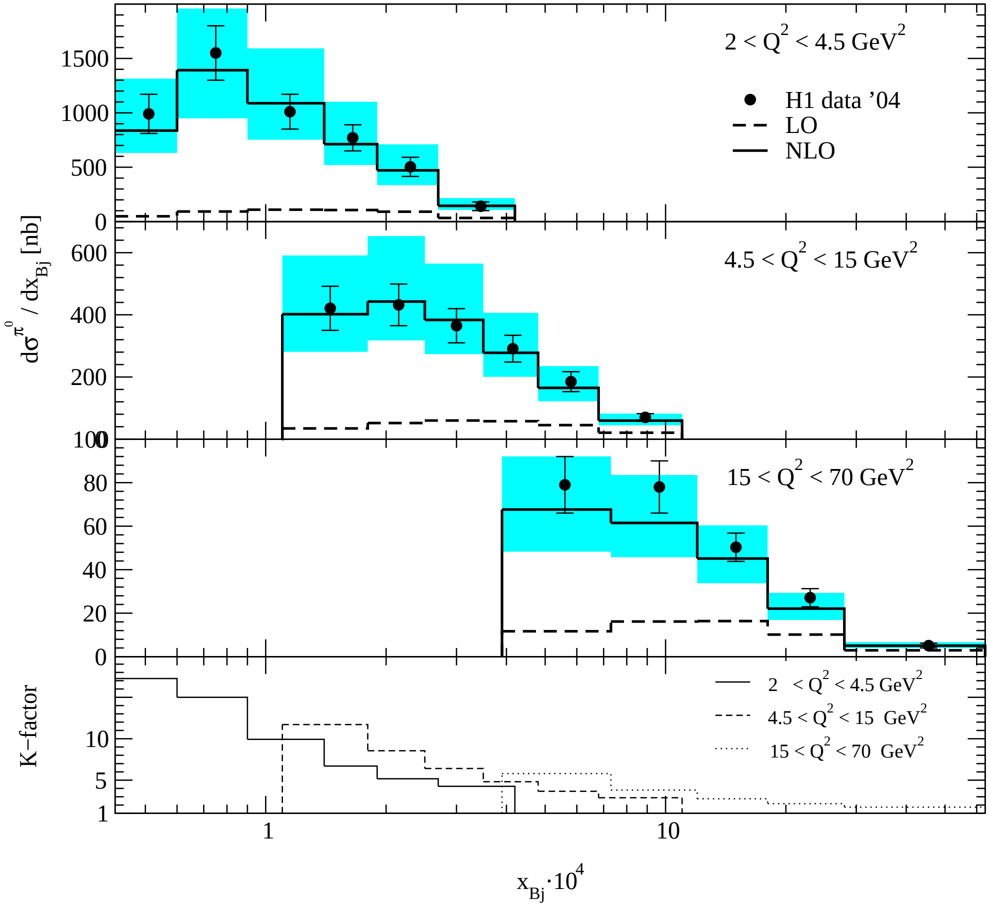
$\eta = -\ln\tan(\theta/2)$



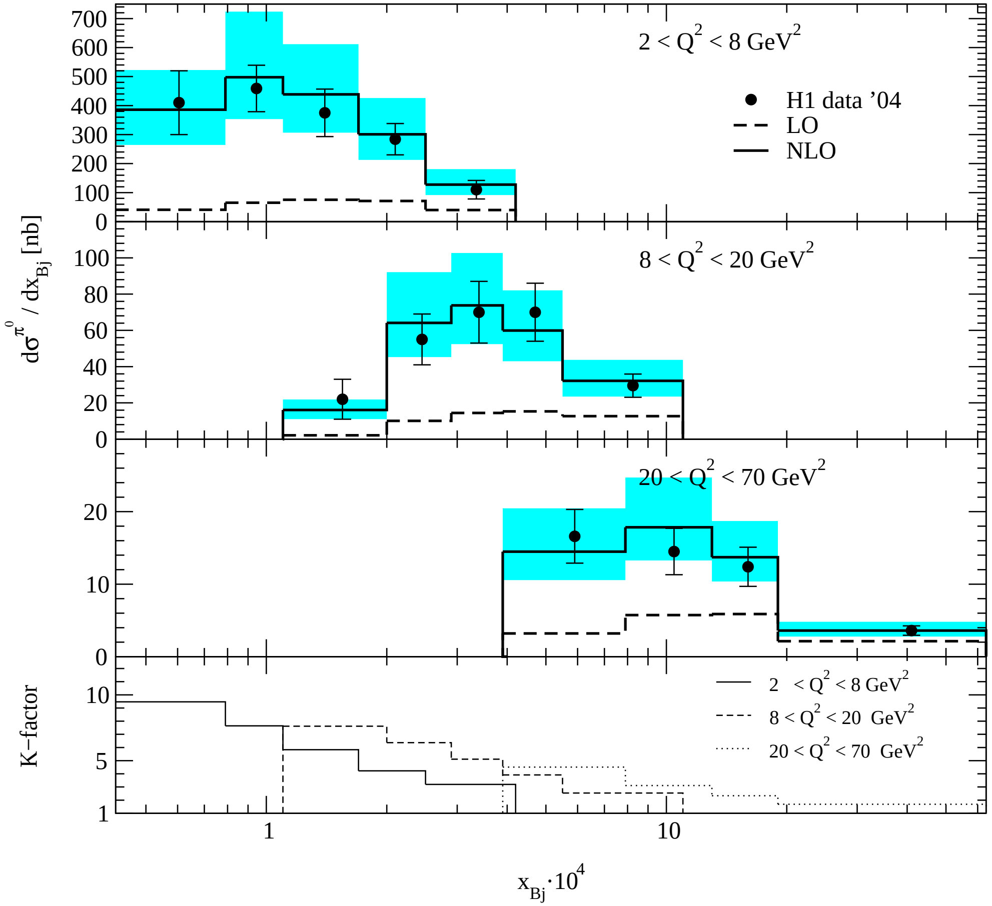
x_E (in bins of Q^2)



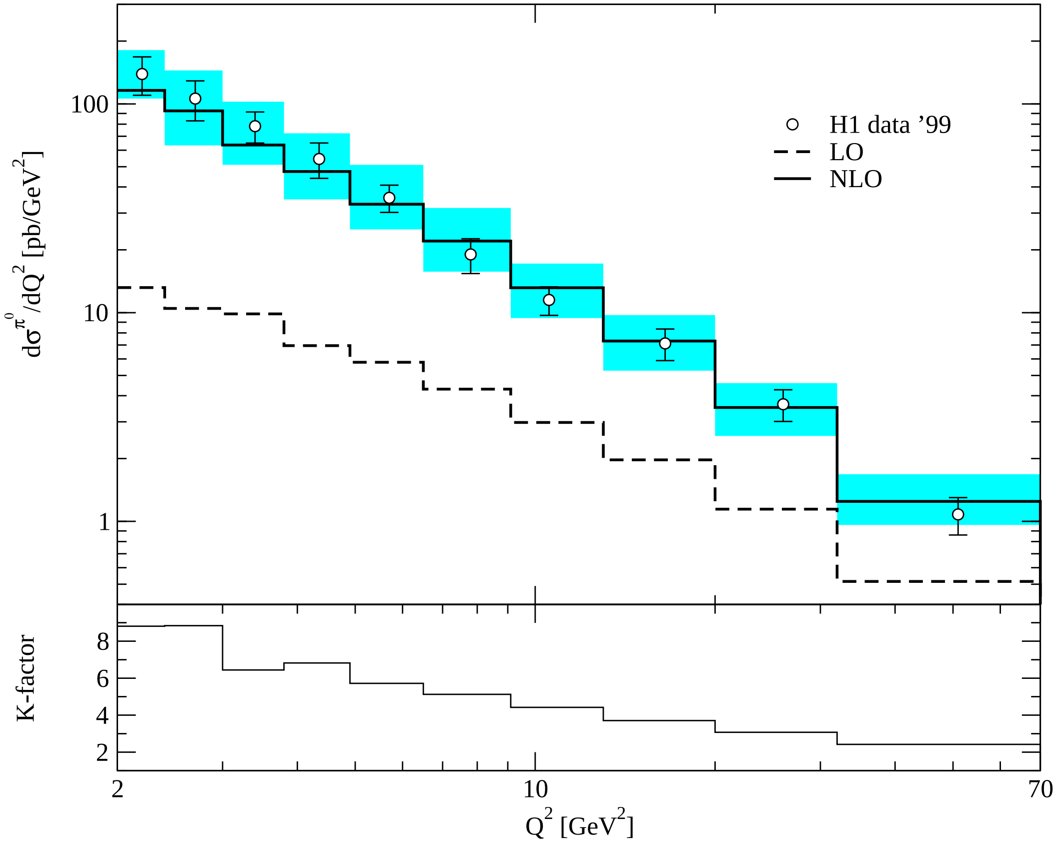
x_E (in bins of x_B)



$10^4 \times x_B \;\; (p_T^* > 2.5$ GeV)



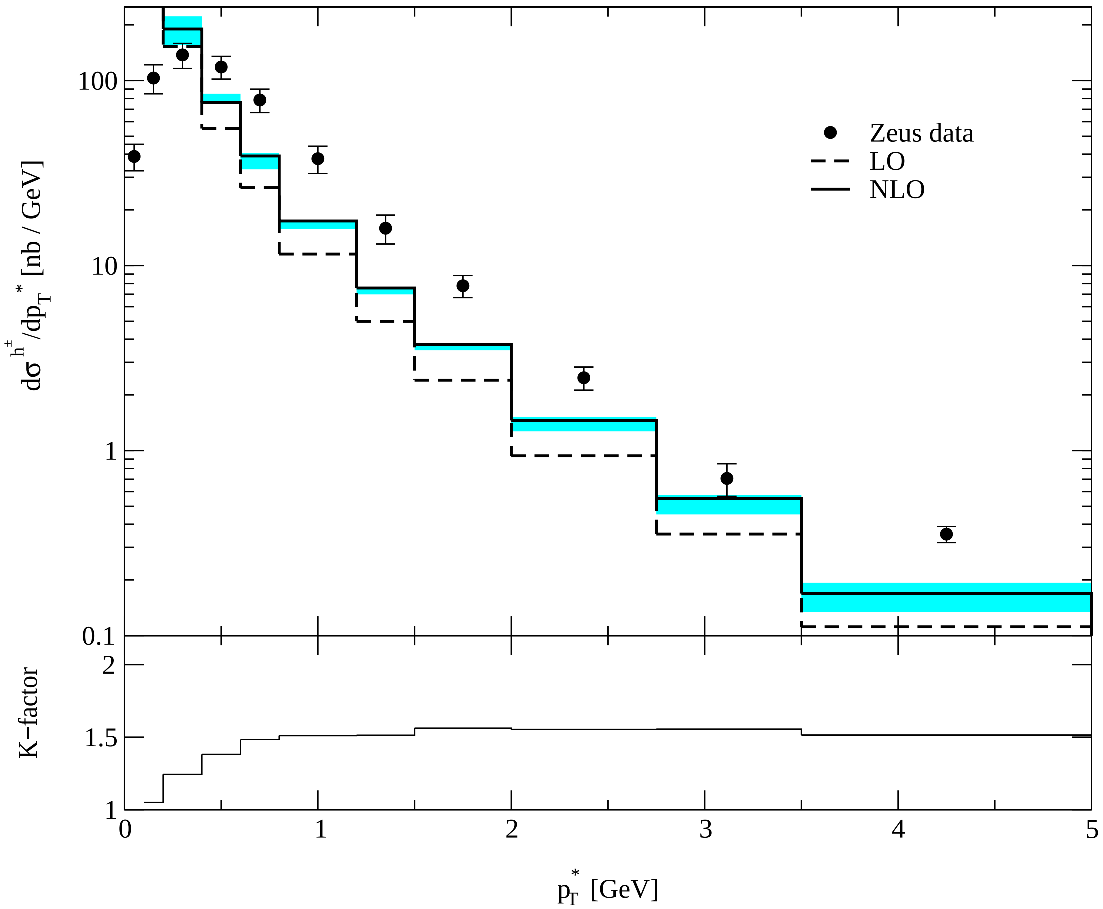
$10^4 \times x_B \;\; (p_T^* > 3.5$ GeV)



H1 data ’99
LO
NLO
100
10
1
dσ^π0/dQ^2 [pb/GeV^2]
K-factor
8
6
4
2
2
10
70
Q^2 [GeV^2]

Q^2

(b) Charged hadrons in the current-jet region (ZEUS)



p_T^*

5. Summary and outlook

- LO prediction generally far too low in normalization and with deviating shape.
- NLO prediction nicely agrees with H1 data on forward π^0's, but sizeable K factor and considerable theoretical uncertainty.
- Test of scaling violations and universality of FFs.
- Expect deviations for:
  - $Q^2 \longrightarrow 0$: photoproduction limit, resolved photons important, especially at small p_T^* and/or θ.
  - $\theta \longrightarrow 0$ (or $\eta \longrightarrow \infty$ or $x_F \longrightarrow -1$): hadron h close to proton remnant $\leadsto$ fracture functions.
  - $x_B \longrightarrow 0$: BFKL dynamics. But no convincing case yet, see also forward-jet electroproduction (E. Gallo's talk).
  - $p_T^* \longrightarrow 0$: collinear singularities $\leadsto$ take $\gamma^* q \longrightarrow q$ as LO subprocess.
- Need NNLO prediction to reduce theoretical uncertainty.
- For D and B electroproduction, include mass effects w/o spoiling factorization $\leadsto$ general-mass variable-flavour-number scheme.