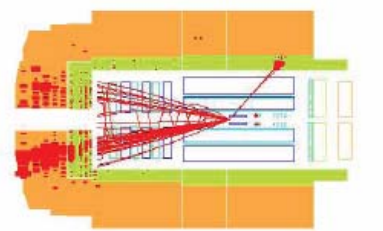
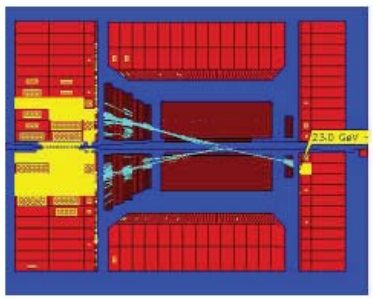
QCD studies through hadronic final states at HERA

Takahiro Matsumoto / KEK
On behalf of H1 and ZEUS collaborations



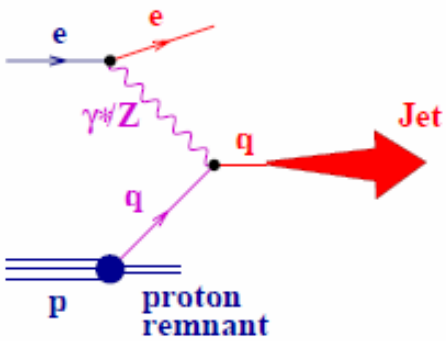


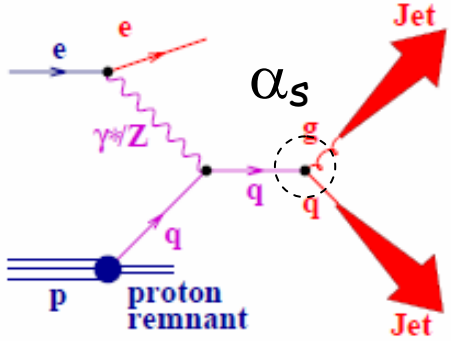
- scaled charged particle momentum distributions in DIS
- α_s from inclusive jet in DIS
- 3-jet in DIS for low x
- multi-jet production in γp
- antideuteron production in DIS

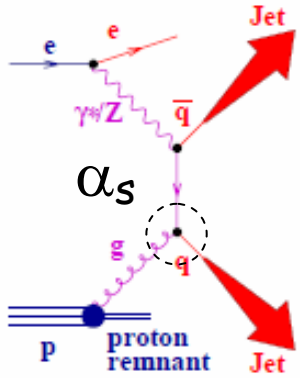
Lake Louise Winter Institute 2007, 24 February, 2007

Hadronic final states @HERA

Jet production at HERA







Cross section for HFS:

$$\sigma = \sum_{a=q,\bar{q},g} \int dx \cdot f_a(x,\mu_F,\alpha_s) \cdot \hat{d\sigma}_a(x,\mu_F,\mu_R,\alpha_s(\mu_R)) \cdot D(x_p,\mu_F,\alpha_s)$$

Parton distribution function of the proton

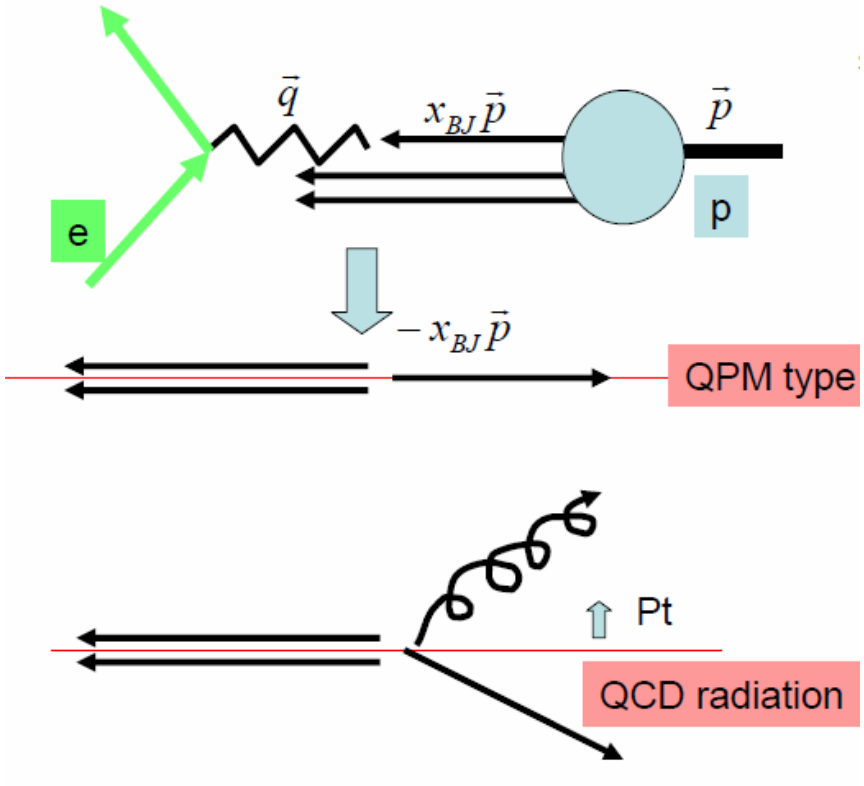
Cross section of the hard process

Fragmentation function

Regarded as hadronic correction
~ 1 + δ_{had}
in jet studies

This talk covers recent results on:
- fragmentation function
- hard process QCD (α_s, low x)
- other topics (multi-parton interaction, antideuteron)

Breit frame



Target region

[Proton remnants]

Current region

$$2x_{BJ}\ \vec{p}+\vec{q}=0$$

→ parton from proton (for the interaction) is back scattered with the same momenta

Breit frame has advantage for DIS jet analysis

- Current region can be compared to e^+e^- experiments
- Current quark and proton remnants are clearly separated
- Contributions from QCD radiation can be seen in high E_T jet

Jet algorithm

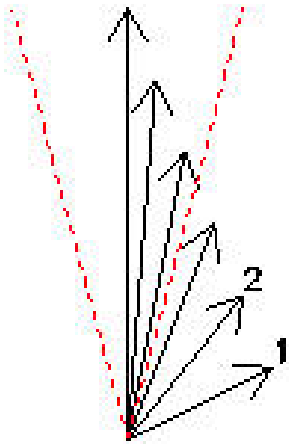
- Longitudinally invariant k_T algorithm
  - theoretically favored, no overlapping

For each Energy Flow Object, calculate:

$$d_{ii} = E_{T,i}^2 R^2$$ ← Radius parameter [usually set to 1]

$$d_{ij} = \min[E_{T,i}^2, E_{T,j}^2][\Delta\eta^2 + \Delta\phi^2]$$

*under Breit Frame



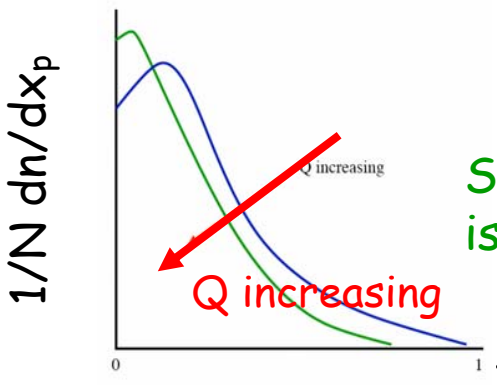
Order all d_{ii} and d_{ij}

If d_{ii} is minimum → i is regarded as jet

If d_{ij} is minimum → i and j are merged, further iteration

Scaled charged particle momentum distributions in DIS

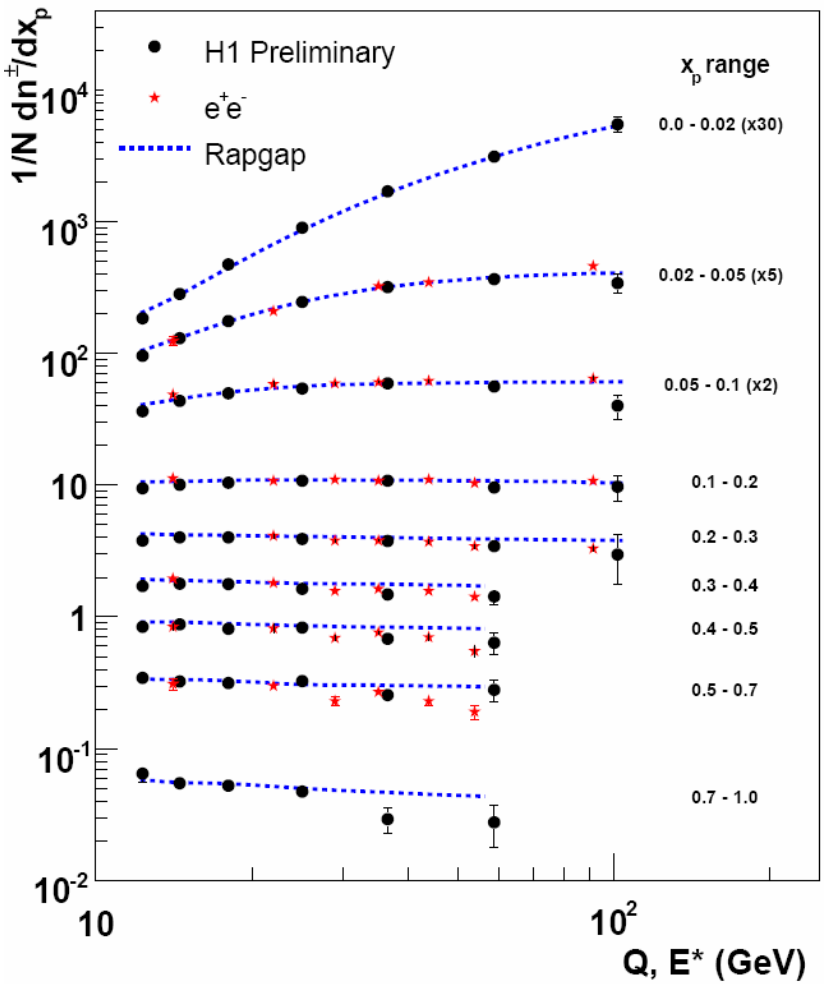
- For tracks in current region of Breit frame, define:
  - $x_p = p/(Q/2)$
- Measurements of dn/dx_p for $Q <\sim 100$ GeV and full x_p range



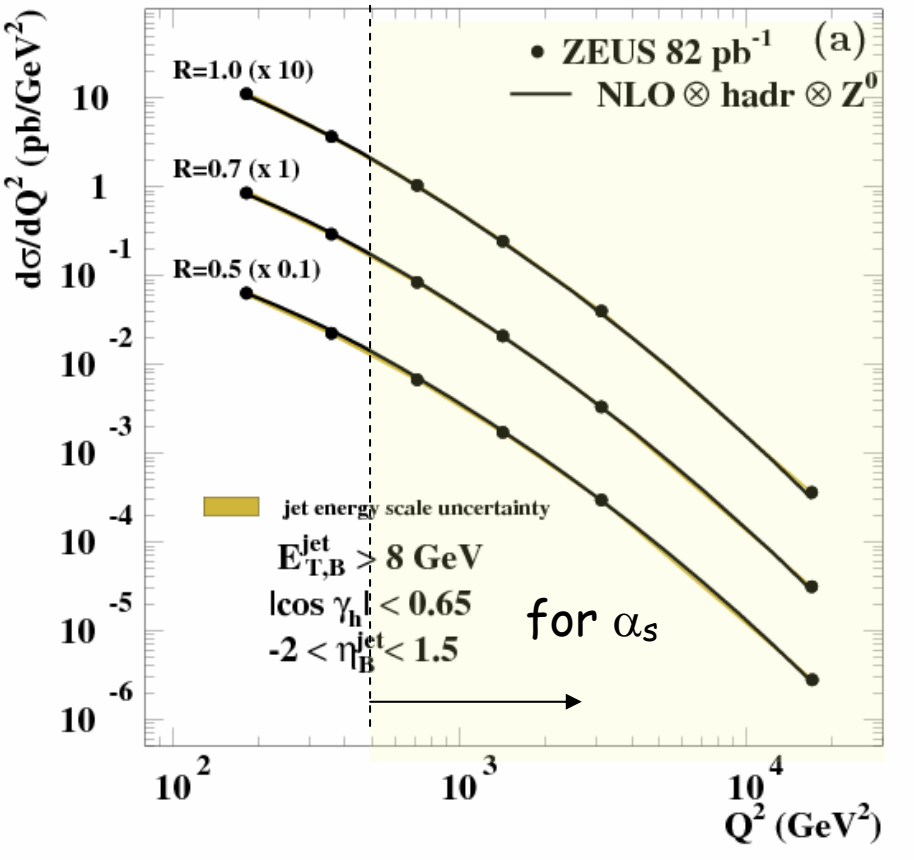
Scaling violation is clearly observed

Agreement with e^+e^- experiments, and RAPGAP(PS) MC tuned to e^+e^- → universality of quark fragmentation function

L = 44 pb^{-1} (2000)



Inclusive jet in DIS



NLO describes inclusive jets well

Agreement also for smaller radius (R=0.7,0.5)

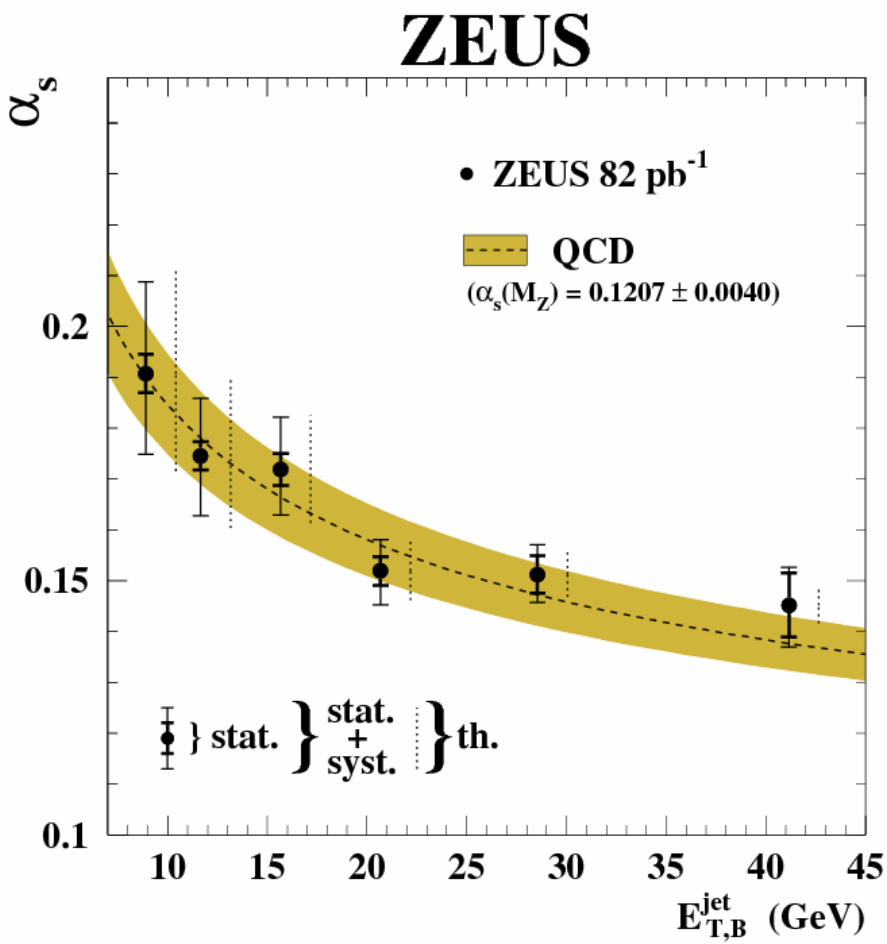
→ Interesting for studying jets from heavy particles

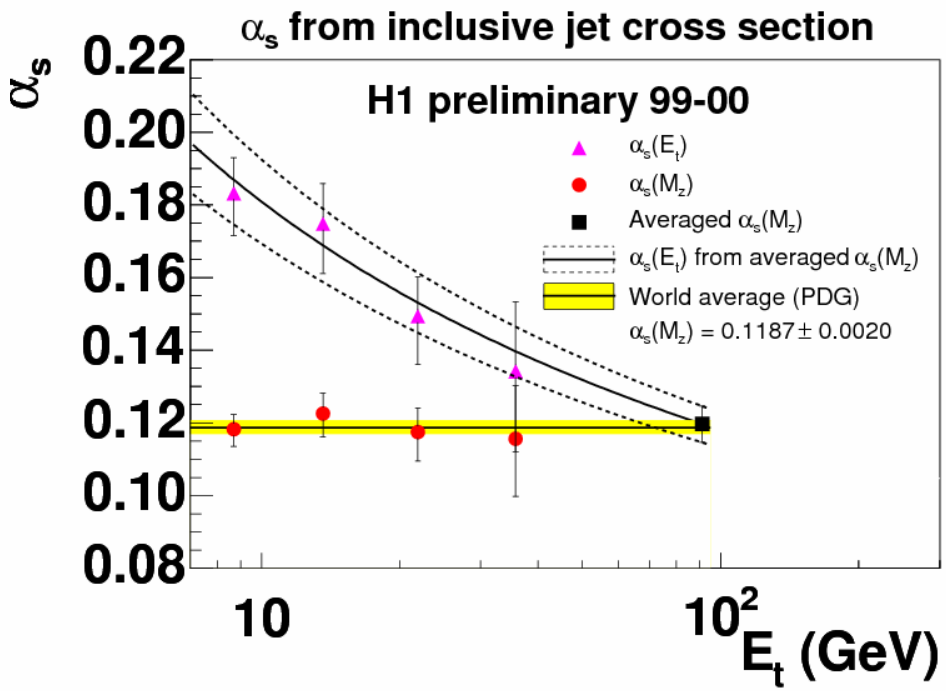
α_s extraction

$$[d\sigma / dQ^2(\alpha_s(M_Z))]_i = C_1^i \alpha_s(M_Z) + C_2^i \alpha_s{}^2(M_Z)$$

Small uncertainty of α_s
(main concern is theoretical part)
is obtained from Q^2>500GeV^2 and R=1

α_s running is clearly seen





$$\alpha_s(M_Z) = 0.1207 \pm 0.0014\ (\text{stat.})\ ^{+0.0030}_{-0.0028}\ (\text{exp.})\ ^{+0.0022}_{-0.0023}\ (\text{th.})$$

$$\alpha_s(M_Z) = 0.1197\ \pm 0.0016\ (\text{exp.})\ ^{+0.0046}_{-0.0048}\ (\text{th.})$$

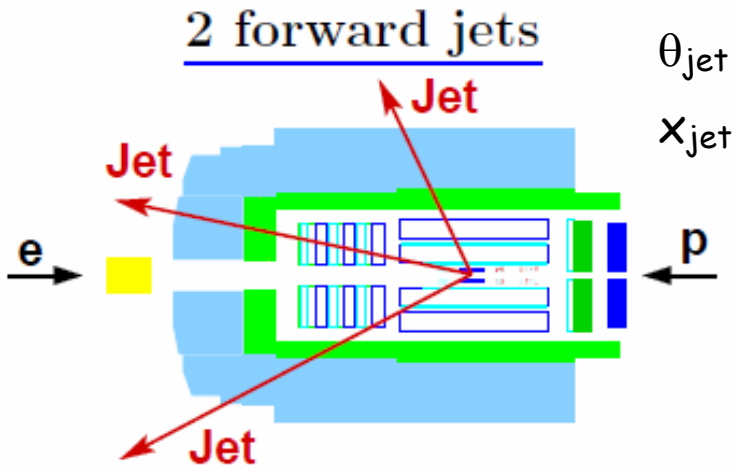
ZEUS (DESY-06-241)

H1prelim-05-133

Consistent with PDG'2006: $\alpha_s(M_Z)$ = 0.1176 ±0.002

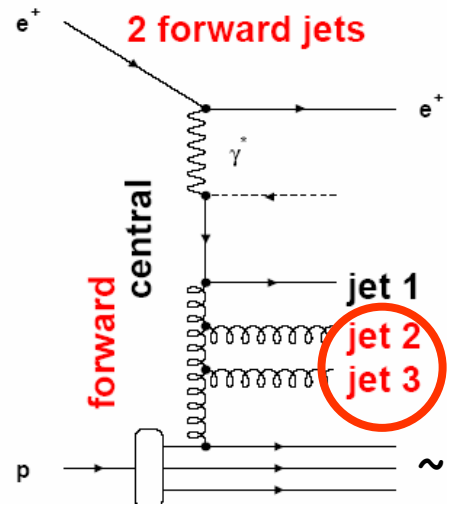
3-jet in DIS for low x

- Low x DIS
  - DGLAP (k_T ordering) may be insufficient to describe g radiation
- 3-jet in DIS
  - Low Q^2: $5 < Q^2 < 80\ GeV^2$
  - Low x: $10^{-4} < x < 10^{-2}$
  - 2 jets in forward
    - Sensitive to g radiation
- Fixed order QCD prediction, $O(\alpha_s^3)$ is greatly improved from $O(\alpha_s^2)$, but still discrepancy exists at small x
  →Unordered gluon radiation would play a significant role

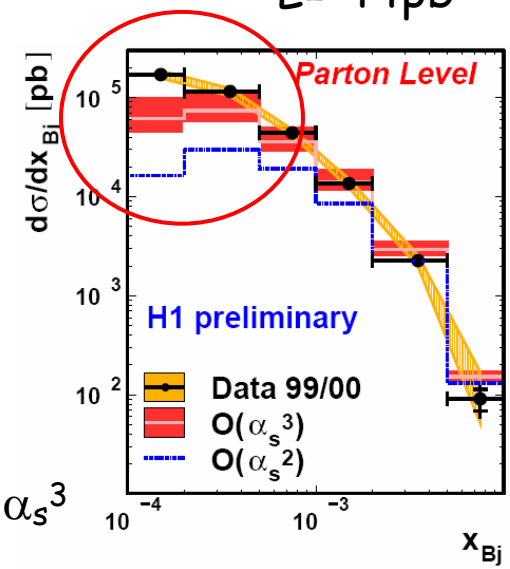


$\theta_{jet} < 20°$

$x_{jet} = E_{jet}^*/E_{p,beam} > 0.035$



L= 44pb^{-1}

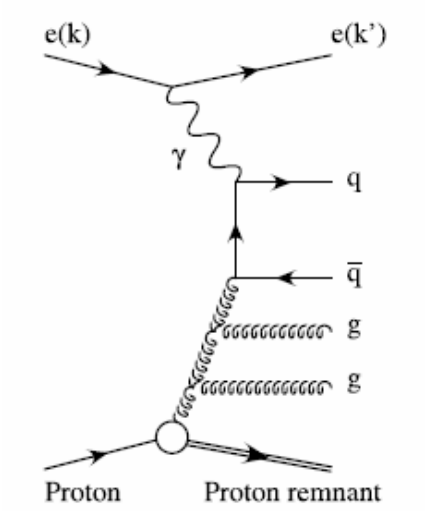


(usually 3-jet: ~α_s^2)

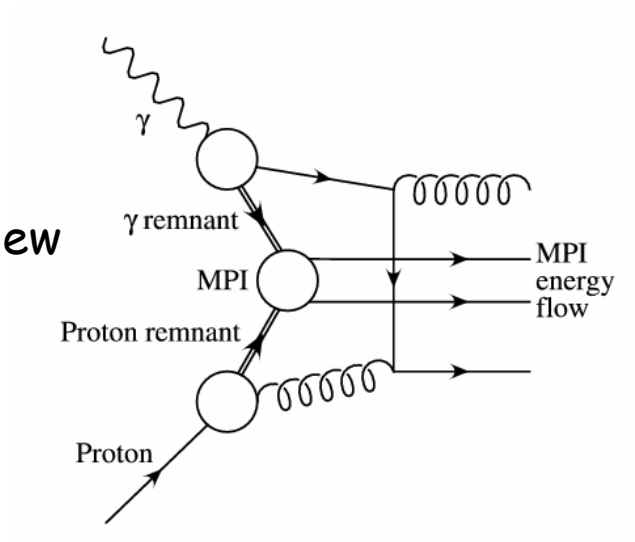
Four jets in photoproduction

4jet direct
(tree level)

$O(\alpha\alpha_s^3)$



Schematic view
of MPI



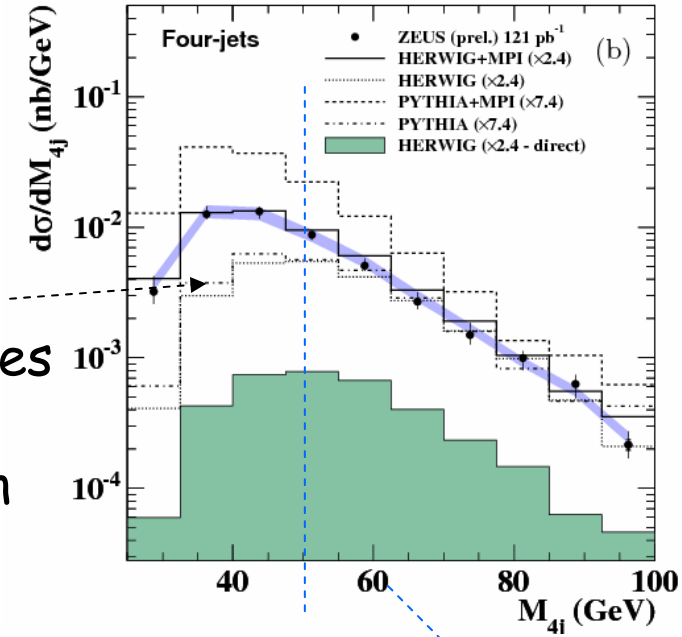
Multi-jet at HERA

- Test of pQCD
  in higer orders of α_s
- Can adjust multi-parton
  interaction model to
  agree with data

  → related to LHC
  (underlying event)

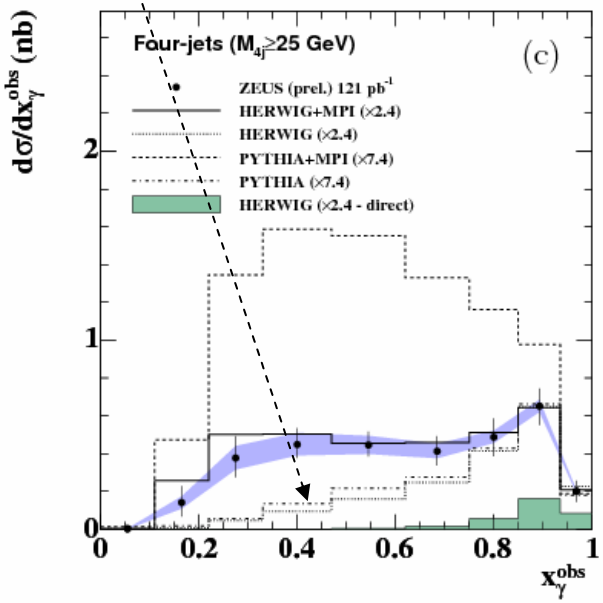
ZEUS (prel.)
121 pb^{-1}

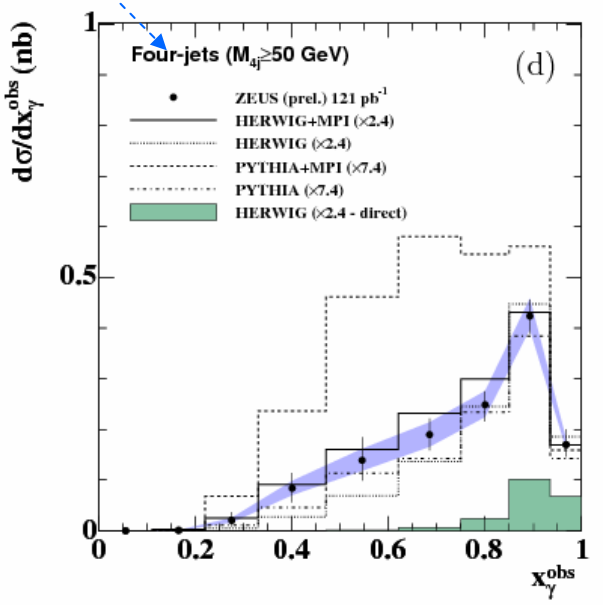
MC without MPI underestimates the data in low M_{nj} region



First observation of 4 jets in photoproduction

HERWIG with tuned MPI describes the data well





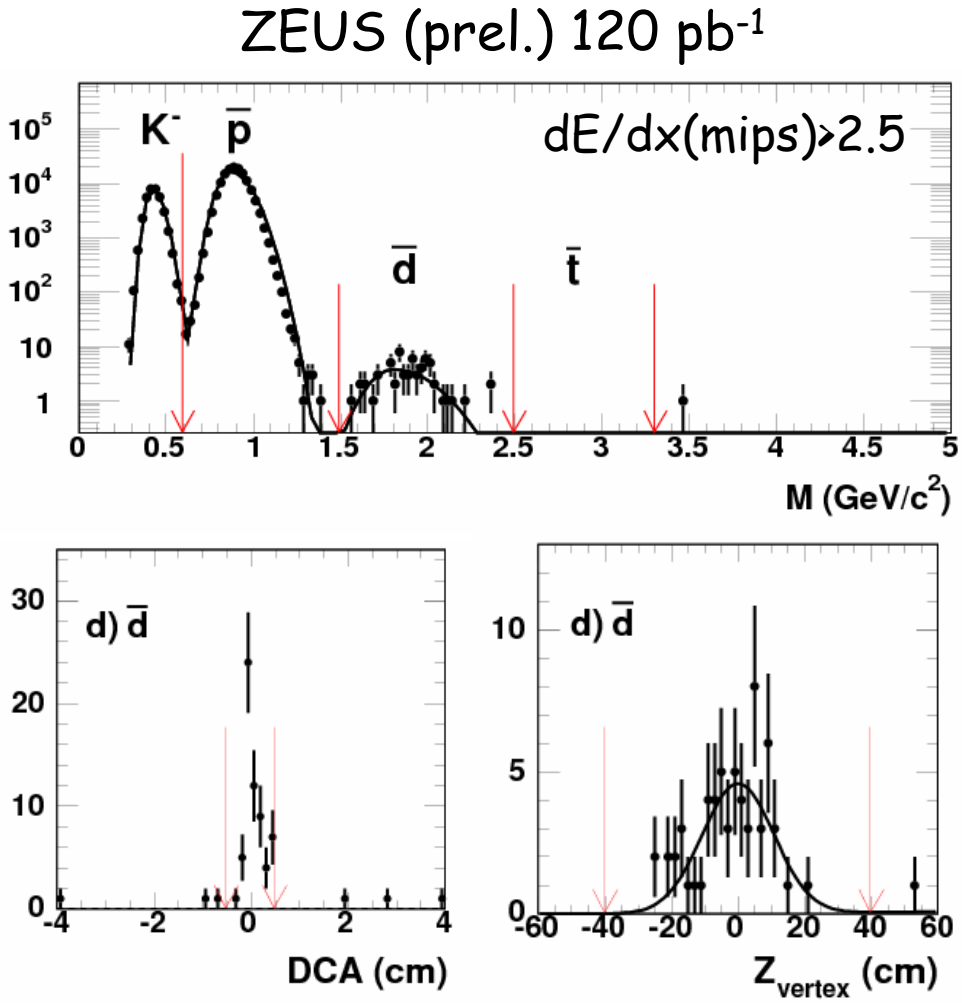
$$x_\gamma^{obs} = \frac{\sum_{i=1}^{n} E_{T,i}^{jet} \exp(-\eta_i^{jet})}{2yE_e}$$

Fraction of the photon's momentum exchanged in the interaction

Antideuteron production in DIS

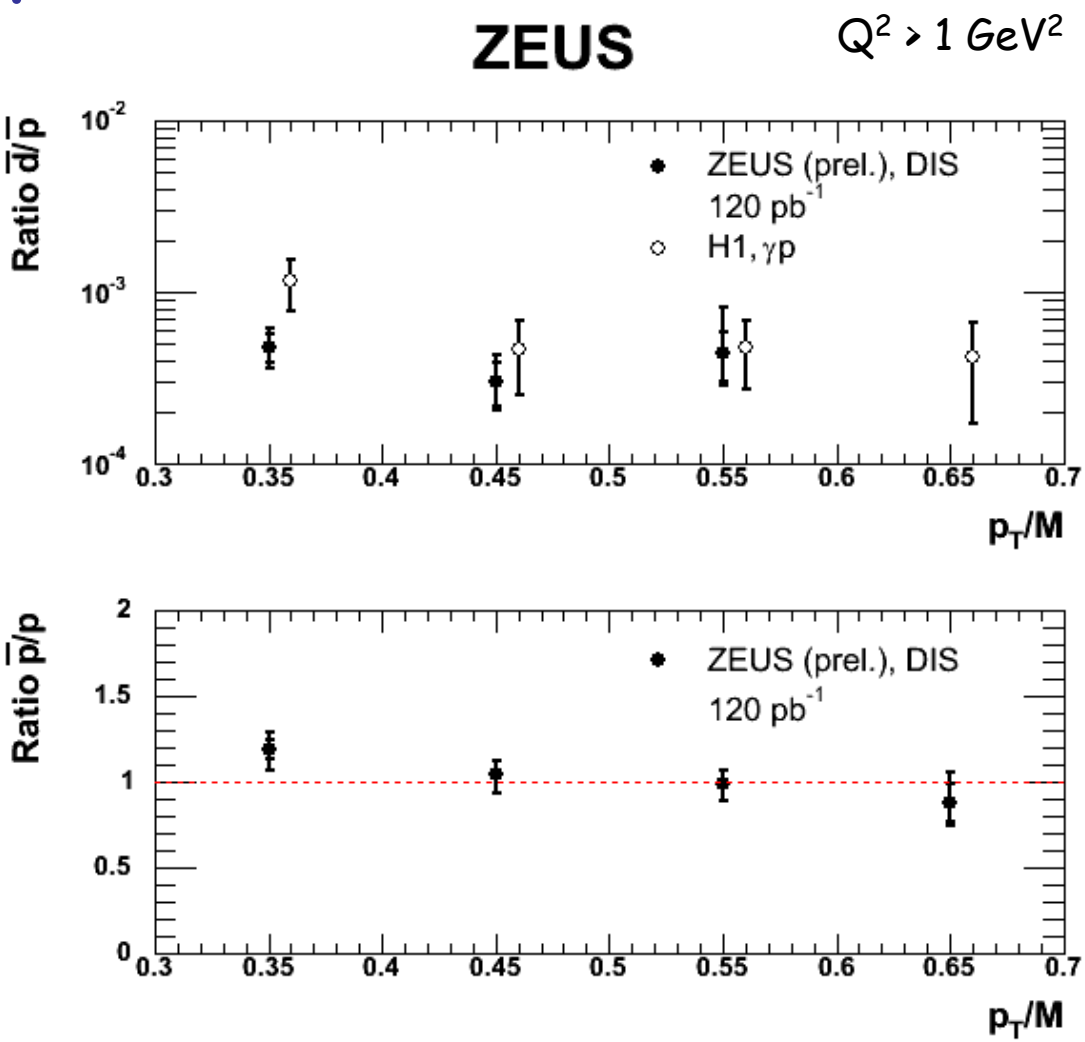
$Q^2 > 1\ GeV^2$

- Antideuteron production:
  - Studied in nuclear experiments (PHENIX etc.), but not well known for elementary particle collisions
- Search in DIS first time
  - Mass was calculated from dE/dx, p
  - Also use DCA to beam spot, Z_{vtx}
- First observation of antideuteron in DIS
  - $N(\bar{d}) = 61 \pm 8$



$\bar{d}/\bar{p}$, $\bar{p}/p$ ratios in DIS

- Ratios were measured after correction of efficiency for tracking and dE/dx cut
- $\bar{d}/\bar{p} \sim 5 \times 10^{-4}$
  - Consistent with γp(H1), also for Υ(1S)(ARGUS), pp
  - But $\bar{d}$ production is suppressed in e^+e^-
- $\bar{p}/p \sim 1$
  - Asymmetry is not observed



$0.3 < p_T/M < 0.7$, $|y| < 0.4$

Summary

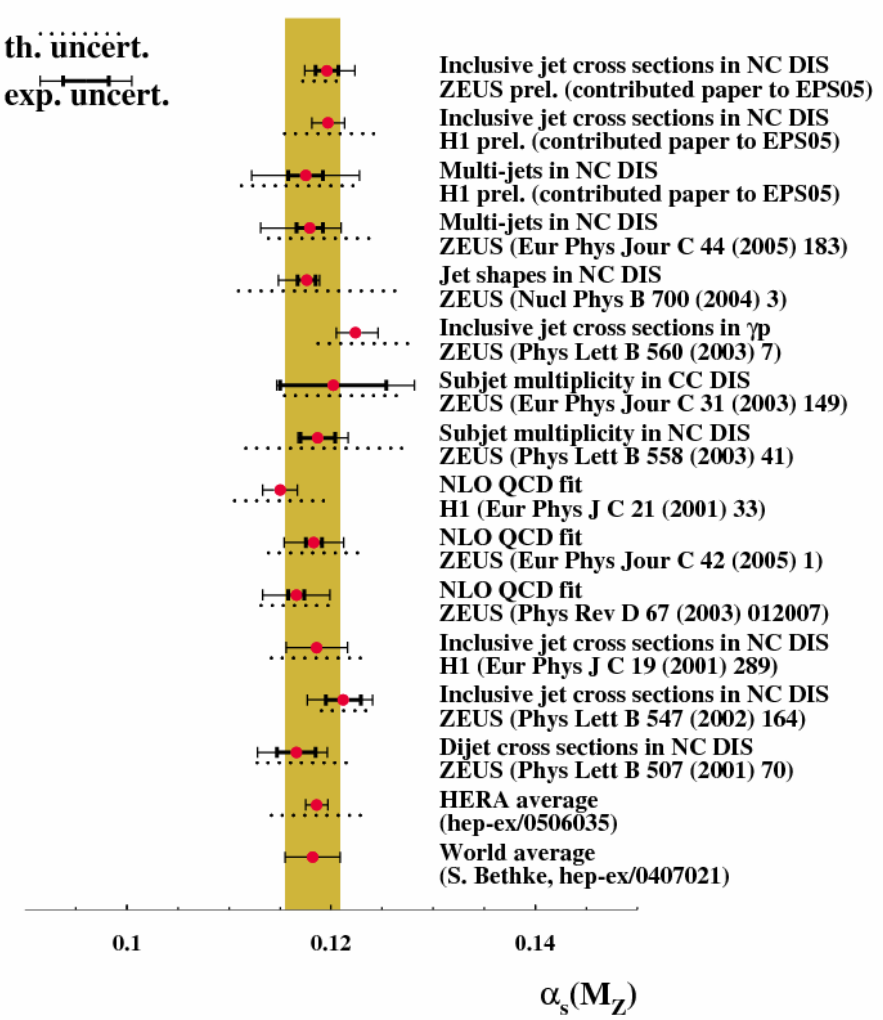
Selected topics on recent results from
hadronic final states at H1 and ZEUS were presented

Hadronic final states allow various tests on QCD !

- Scaled momentum in DIS in wide kinematic range
  → validation of fragmentation function
- Inclusive jet at high Q^2 DIS
  → measurements of strong coupling constant α_s
- 3-jet in low Q^2 DIS
  → QCD at low x
- First observation of 4-jet in photoproduction
  → tuning of multi-parton interaction model
- First observation of antideuteron in DIS
  → understanding of hadronization, coalescence

Backup

α_s measurements at HERA



α_s running