Recent Jet Results and Precision α_s Measurements from HERA

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on behalf of the H1 and ZEUS collaborations

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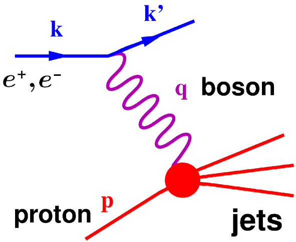
Deep Inelastic Scattering at HERA

Kinematic variables:

- $\sqrt{s} = 318 GeV$: *ep* center of mass energy.
- $Q^2 = -(k - k')^2$: Virtuality of boson
- $x = \frac{Q^2}{p\dot{q}}$: in QPM, parton's fraction of p
- $y = \frac{Q^2}{sx}$: Inelasticity parameter



Jet production in DIS at HERA sensitive to:

- **proton PDFs**
- non-perturbative effects
  - Multiple interactions & underlying event.
- **strong coupling constant at many scales.**
  - If >1 jet, **each** data point is measurement of α_s!

Jet Finding

Jet finding using k_T cluster algorithm

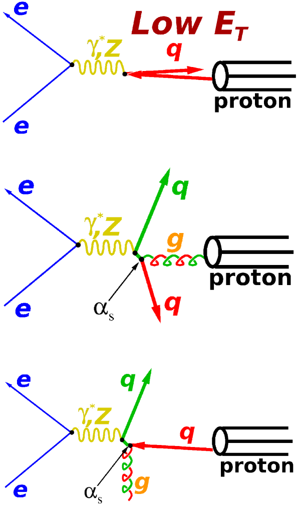
- $d_{ij} = \left(min\left(E_T^i, E_T^j\right)\right)^2 \times \left(\Delta\eta_{ij}^2 + \Delta\phi_{ij}^2\right)$

Born level has $E_T = 0$ in
boson-quark collinear frame:

- Hadronic center of mass frame (HCM)
  - Center of mass of γ/Z^0-q system
- Breit frame
  - Exchanged boson spacelike
  - Struck quark in Born level has $\vec{p}_i = -\vec{p}_f$

In these frames lowest order contribution proportional to α_s.

Allows **direct** QCD measurements.



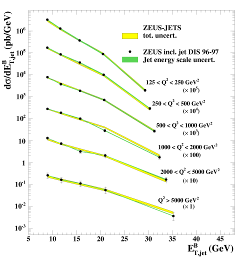
ZEUS Jet Data and proton PDF Fits

Inclusion of ZEUS jet data **reduces proton PDF uncertainty**

- Greatest improvement on **gluon PDF** $.01 < x < .04$

Jet data included:

- High Q^2: netural current inclusive jet production
- Low Q^2: dijets in photoproduction



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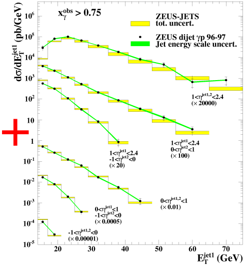
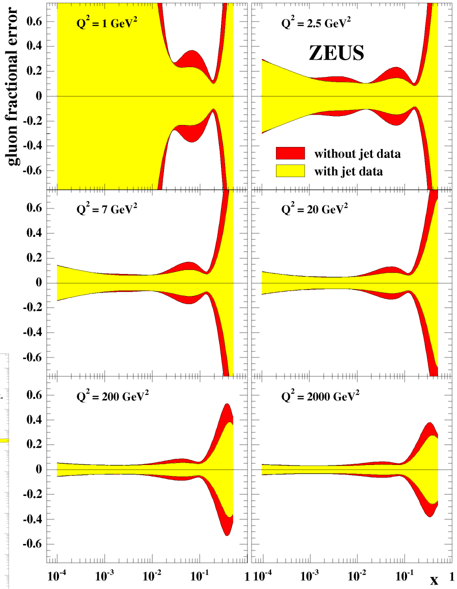
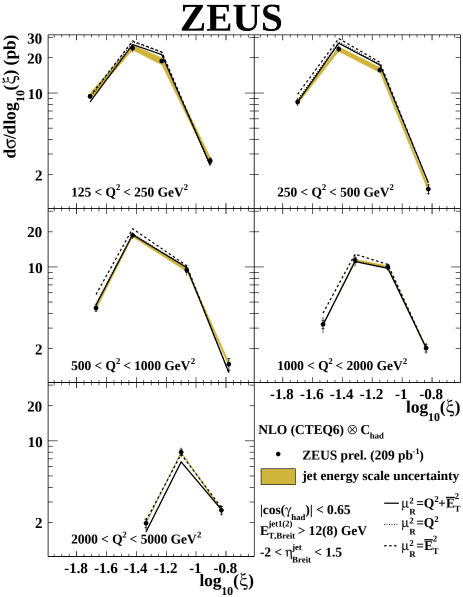


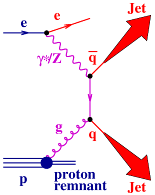




4.4× **Statistical increase** over previous ZEUS study

- $125 GeV^2 < Q^2 < 5000 GeV^2$
- $E_T^{jet1(2)} > 12(8) GeV$
- Measure cross sections in bins of Q^2 and ξ
  - $\xi = x\left(1 + \frac{M^2_{jets}}{Q^2}\right)$

PDF uncertainty dominant in many bins, designed for **gluon PDF** fit.

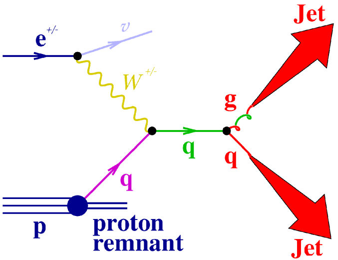


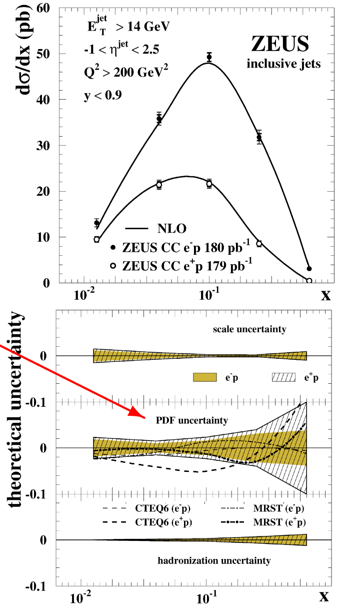
Charged Current Multijets at ZEUS

- uses $359 pb^{-1}$ **polarized** $e^{\pm}p$ data
- $Q^2 > 200 GeV^2$
- $E_T^{jet1(2,3)} > 14(5) GeV$ lab frame.
- $W^{-(+)}$ couples primarily to $u(d)$

Conclusions:

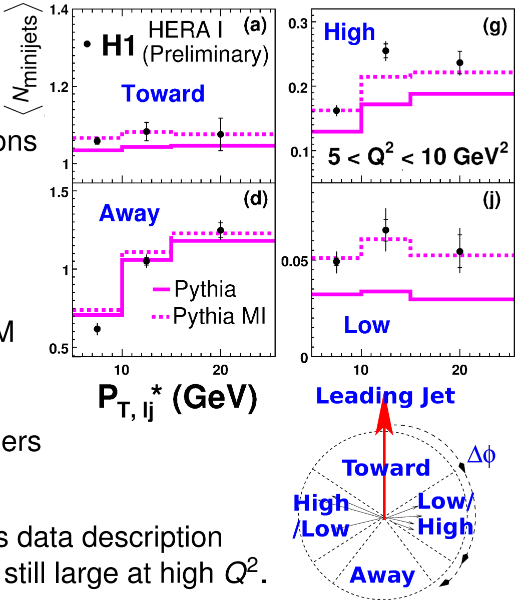
- Including can **constrain** *d*-PDF





Understanding **hard scattering** requires understanding of **non-perturbative backgrounds**

- **Multiple interactions** in regions transverse to leading jet?
- Neutral current sample
- $5 GeV^2 < Q^2 < 100 GeV^2$
- Leading jet: $p_T^{jet} > 5 GeV$ HCM
- **Minijet**: $p_T^{jet} > 3 GeV$ HCM
- PYTHIA vs PYTHIA+MI & others

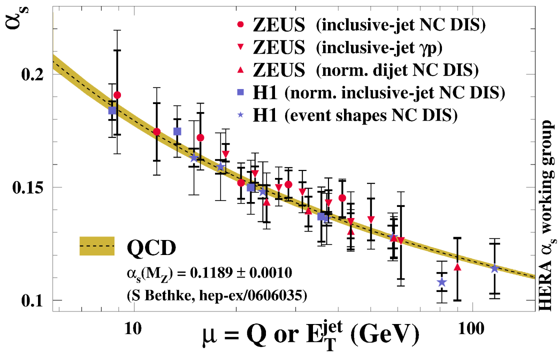


Conclusions:

- Addition of MI to MC improves data description at low Q^2, but disagreements still large at high Q^2.

H1 and ZEUS extracted α_s at scales spanning over 100 GeV, using a variety of observables.

- Structure functions
- Event shapes
- Jet production rates
- Jet substructure



Previous H1 & ZEUS combined α_s measurement (2004)

- 11 separate measurements: Small exp uncertainty, large theor.

Goals of **NEW 2007 combined α_s extraction**:

- **H1**: Minimize **experimental** uncertainties
- **ZEUS**: Minimize **theoretical** uncertainties

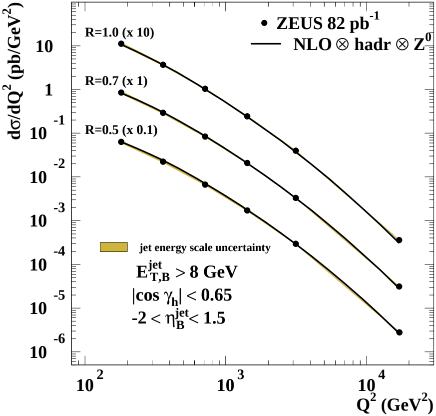
Result: Minimized **combined** uncertainty

Jet-radius dependence of inclusive-jet cross sections in DIS

- k_t cluster algorithm uses R parameter, acts as a jet radius:

$$d_{ij} = \left(min\left(E_T^i, E_T^j\right)\right)^2 \times \left(\Delta\eta_{ij}^2 + \Delta\phi_{ij}^2\right)$$

$$d_{ii} = \left(E_T^i\right)^2 \times R^2$$



- Neutral current selection
- $Q^2 > 125 GeV^2$
- Jets found in breit frame
- $E_{T,B} > 8 GeV$
- Jet production dependence on R studied for $R = .5, .7, 1.$
- Data well described by NLO

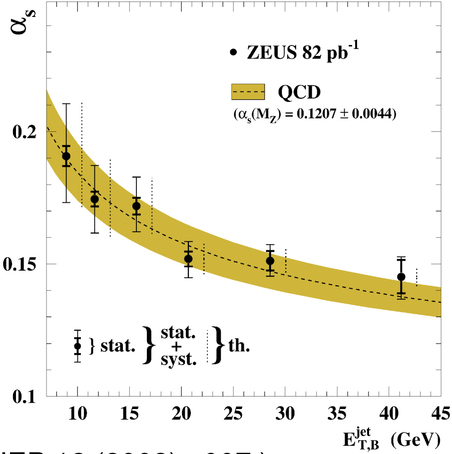
ZEUS Extraction of α_s (2/2)

For extraction of α_s:

- Restricted $Q^2 > 500 GeV^2$
- Use standard value $R = 1$
- χ^2 fit to $d\sigma/d(Q^2)$.

$$\alpha_s(M_Z) = 0.1207 \pm 0.0014\,(\text{stat.})\,{}^{+0.0035}_{-0.0033}\,(\text{exp.})\,{}^{+0.0022}_{-0.0023}\,(\text{th.})$$

Observed running agrees with extracted value

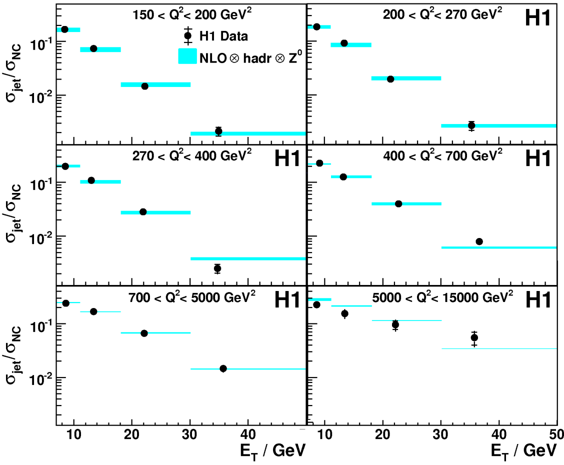


Major uncertainty sources:

- Jet energy: 2%
- Hadronization: 0.8%
- Terms beyond NLO: 1.5%
  (as per Jones et. al. JHEP 12 (2003) p007)
- PDFs: 1%

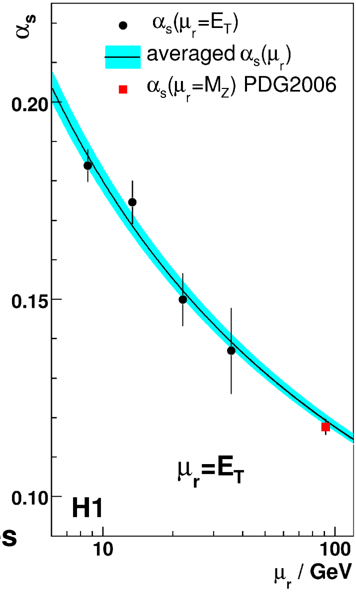
Measurement of inclusive jet production in DIS at high Q^2 and determination of the strong coupling

- $150 GeV^2 < Q^2 < 15,000 GeV^2$
- NC Selection
- Jets found in Breit frame
- $7 GeV < E_T^{Lab} < 50 GeV$
- Extracted $\alpha_s(M_Z)$ from fit to **24 data points** of $\frac{d^2\sigma_{JETS}}{dQ^2 dE_T} / \frac{d^2\sigma_{NC}}{dQ^2 dE_T}$.
- **Ratio** of cross sections cancels luminosity uncertainty, reduces scale uncertainty
- Data well described by NLO



Extraction of α_s

- $\alpha_s(M_Z) = 0.1193 \pm 0.0014(exp.)$ $^{+0.0047}_{-0.0030}(th.)$ $\pm 0.0016(pdf)$
- Fit quality: $\chi^2/ndf = 28.7/23$
- Major sources of uncertainty:
  - Calorimeter energy
  - Detector correction model
  - Scale uncertainty (dominant)

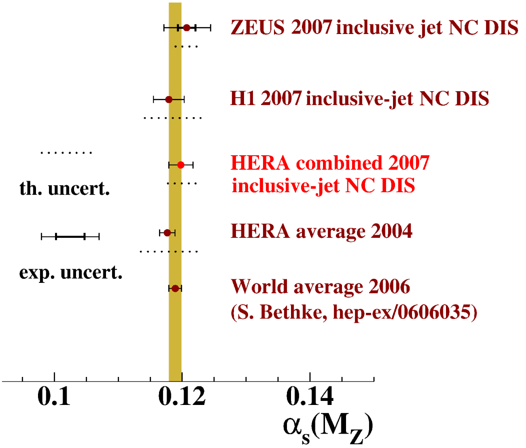


Observed running agrees with extracted value

2007 HERA $\alpha_s(M_Z)$ from Incl. Jets

- **Combined fit to 30 measurements of inclusive jet cross sections in NC DIS**
  - 24 H1 data points from $\frac{d^2\sigma_{JETS}}{dQ^2 dE_T}$
  - 6 ZEUS data points $\frac{d\sigma_{JETS}}{dQ^2}$
- **NLO** $(O(\alpha_s^2))$ **QCD calculations**
  - PDFs: MRST
  - $\mu_R = E_T^{jet,B}$
  - $\mu_F = Q$
- **Experimental uncertainties on combined** $\alpha_s(M_Z)$
  - Obtained from Hessian Method
- **Theoretical uncertainties on combined** $\alpha_s(M_Z)$
  - Terms beyond NLO: 0.0021
    (as per Jones et. al. JHEP 12 (2003) p007)
  - Factorization scale: 0.0010 $(\mu_F/2 \leftrightarrow 2\mu_f)$
  - pPDFs: 0.0010 (30 sets of MRST)
  - Hadronization: 0.0004 (different shower models)

2007 HERA jets: $\alpha_s(M_Z) = 0.1198 \pm 0.0019$ (exp.) ± 0.0026 (th.)



Compatible with world average

Improvement over 2004 HERA:

- **theoretical uncertainty cut in HALF**

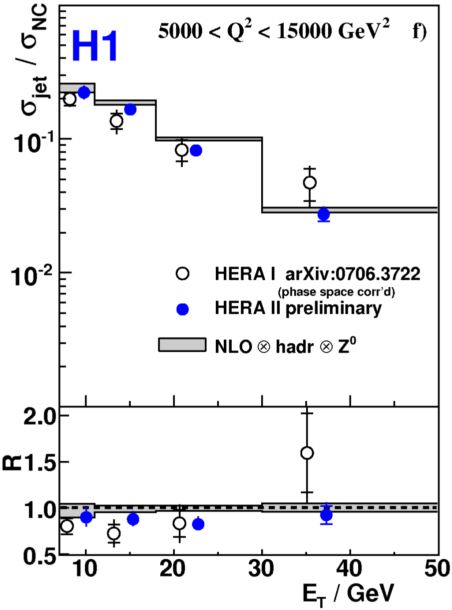
Comparable **uncertainties** to 2006 LEP result:

$\alpha_s(M_Z) = 0.1211 \pm .0010(exp.) \pm .0018(th.)$

Identical phase space to analysis used in 2007 combined α_s extraction

Improvements:

- 4.9$\times$ more luminosity
- Improved calorimeter calibration
  - Better description at high E_T, Q^2



Conclusions

Jet production at HERA provides a valuable tool to study QCD dynamics and the structure of the proton.

- **Excellent contribution to PDF determination**
  - New high Q^2 NC dijets study can improve gluon PDF
  - New CC jets study can improve d PDF
- **Study of non-perturbative effects**
  - Description of minijets at low Q^2 improved by MC+MI, but high Q^2 data not in agreement.
- **Extraction of α_s**
  - Combined α_s measurement utilizes individual strengths of H1 & ZEUS analyses to provide competitive measurement.

HERA has finished taking data, but many important jet measurements are just coming out now or yet to come.