

Recent Jet Results and Precision α_s Measurements from HERA



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on behalf of the H1 and ZEUS collaborations



Lake Louise Winter Institute, Feb. 2008

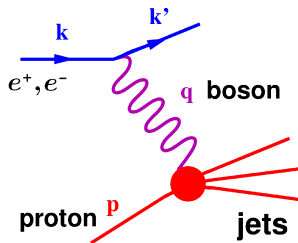
Deep Inelastic Scattering at HERA

Kinematic variables:

- $\sqrt{s} = 318\text{GeV}$: ep center of mass energy.
- $Q^2 = -(k - k')^2$: Virtuality of boson
- $x = \frac{Q^2}{p\bar{q}}$: 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

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

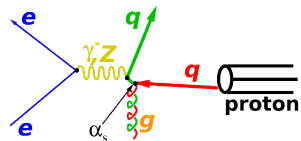
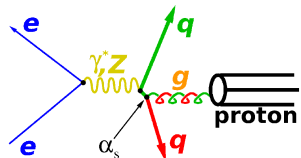
Born level has $E_T = 0$ in

boson-quark collinear frame:

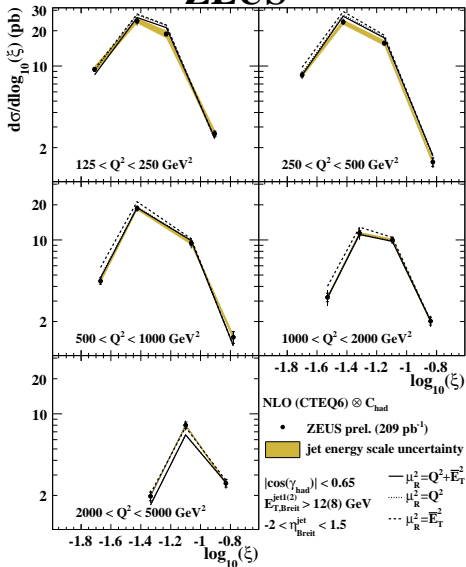
- Hadronic center of mass frame (HCM)
 - Center of mass of γ/Z^0 - q system
- Breit frame
 - Exchanged boson spacelike
 - Struck quark in Born level has $\vec{p}_i = -\vec{p}_f$

In these frames lowest order contribution proportional to α_S .

Allows **direct** QCD measurements.



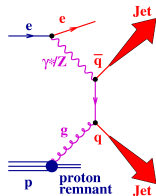
ZEUS



$4.4 \times$ **Statistical increase** over previous ZEUS study

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

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



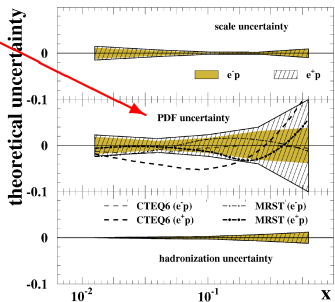
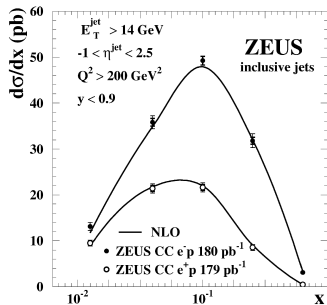
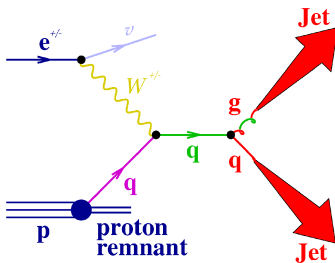
Charged Current Multijets at ZEUS



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

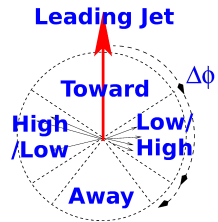
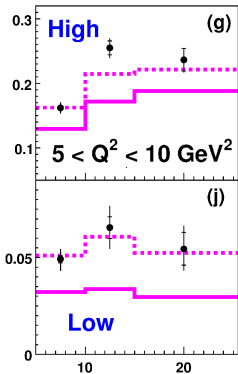
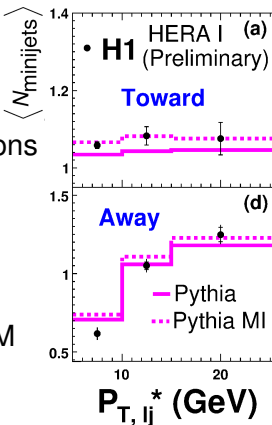
Conclusions:

- 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
- $5\text{GeV}^2 < Q^2 < 100\text{GeV}^2$
- Leading jet: $p_T^{jet} > 5\text{GeV}$ HCM
- **Minijet**: $p_T^{jet} > 3\text{GeV}$ HCM
- PYTHIA vs PYTHIA+MI & others

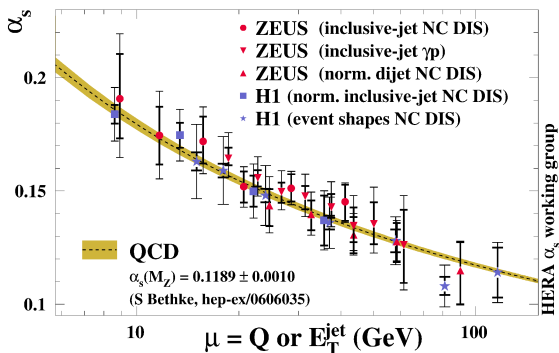


Conclusions:

- 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

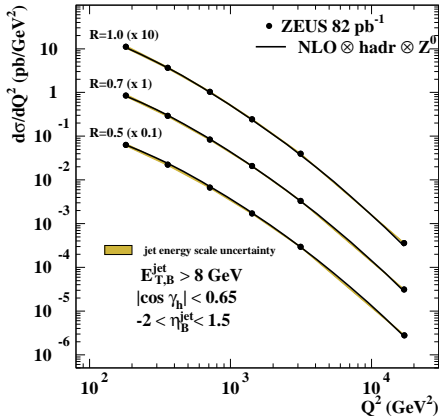
Result: Minimized **combined** uncertainty

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

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

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

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



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

For extraction of α_s :

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

$$\alpha_s(M_Z) = 0.1207 \pm 0.0014 \text{ (stat.)}$$

$$\begin{array}{l} +0.0035 \\ -0.0033 \end{array} \text{ (exp.)}$$

$$\begin{array}{l} +0.0022 \\ -0.0023 \end{array} \text{ (th.)}$$

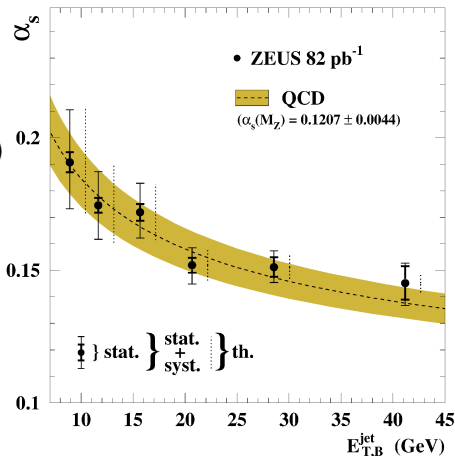
Major uncertainty sources:

- Jet energy: 2%
- Hadronization: 0.8%
- Terms beyond NLO: 1.5%

(as per Jones et. al. JHEP 12 (2003) p007)

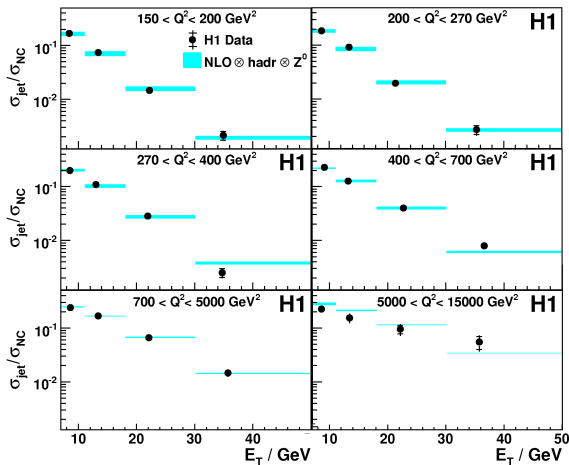
- PDFs: 1%

Observed running agrees with extracted value



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

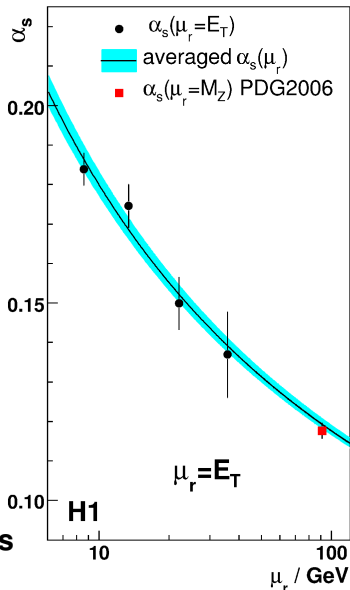
- $150 \text{ GeV}^2 < Q^2 < 15,000 \text{ GeV}^2$
- NC Selection
- Jets found in Breit frame
- $7 \text{ GeV} < E_T^{\text{Lab}} < 50 \text{ GeV}$
- Extracted $\alpha_s(M_Z)$ from fit to **24 data points** of $\frac{d^2\sigma_{\text{JETS}}}{dQ^2 dE_T} / \frac{d^2\sigma_{\text{NC}}}{dQ^2 dE_T}$.
- **Ratio**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



Extraction of α_s

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

**Observed running agrees
with extracted value**



- **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.)

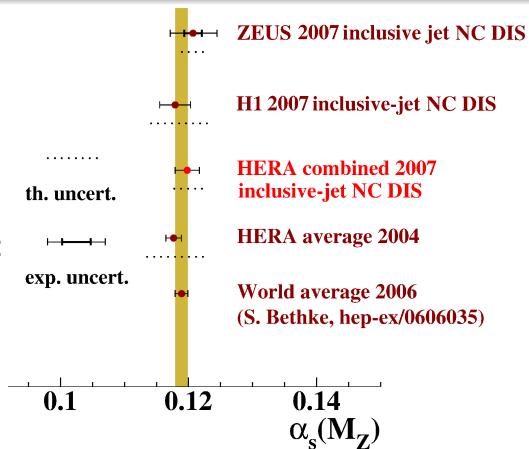
Compatible with world average

Improvement over 2004 HERA:

- **theoretical uncertainty cut in HALF**

Comparable **uncertainties** to 2006 LEP result:

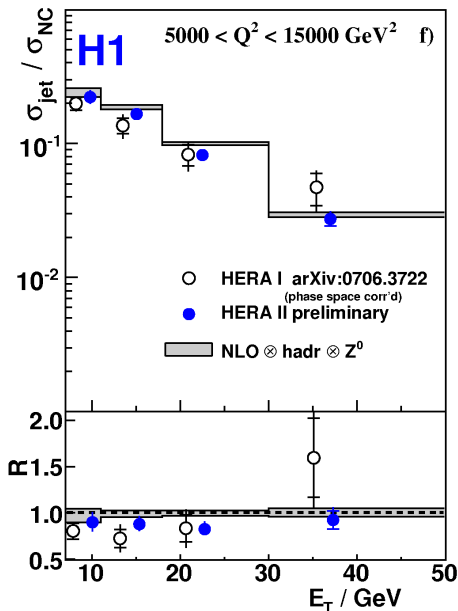
$$\alpha_s(M_Z) = 0.1211 \pm .0010(\text{exp.}) \pm .0018(\text{th.})$$



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



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.