

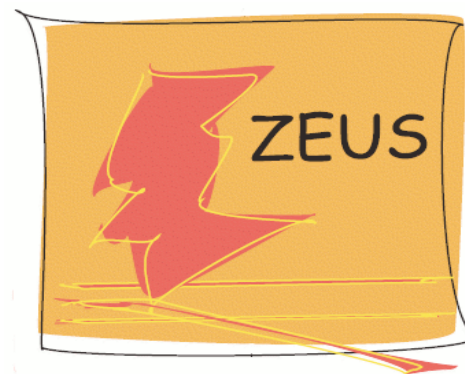
# High Et jets and $\alpha_s$ at HERA

**Arnd Specka**

Laboratoire Leprince-Ringuet

Ecole Polytechnique - CNRS/INP3, Palaiseau, France

**on behalf of the H1 and ZEUS Collaborations**



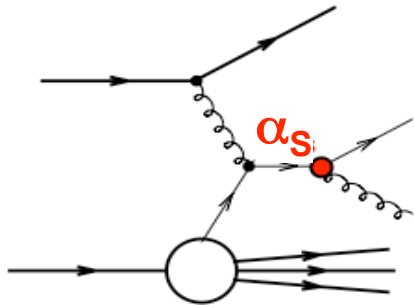
# Abstracts covered

- **121 Measurement of the jet-radius dependence of inclusive-jet cross sections**  
DESY-06-241, Physics Letters B 649 (2007) 12-24
- **132 Measurement of multi-jet cross sections in charged current ep scattering**  
DESY-08-24, to be published in Physical Review D
- **137 Measurement of angular correlations in three-jet production**  
ZEUS preliminary DESY-08-100
- **143 Measurement of dijet cross sections in deep inelastic ep scattering**  
ZEUS-prel-07-005
- **145 Measurement of jet substructure in neutral-current deep inelastic ep scattering at high  $Q^2$**   
ZEUS-prel-07-013
- **152 / 628 Precision measurements of alphas at HERA (H1 and ZEUS)**  
H1prelim-07-132 ZEUS-prel- 07-025
- **788 Measurement of Inclusive Jet Production in Deep-Inelastic Scattering at High  $Q^2$  and Determination of the Strong Coupling**  
DESY 07-073 , Phys.Lett.B653:134-144,2007
- **844 Inclusive and Multi-Jet Production at high  $Q^2$  and determination of  $\alpha_s$  using full HERA data**  
H1prelim-08-031
- **845 Measurement of jet production in deep-inelastic ep scattering at low  $Q^2$**   
H1prelim-08-031

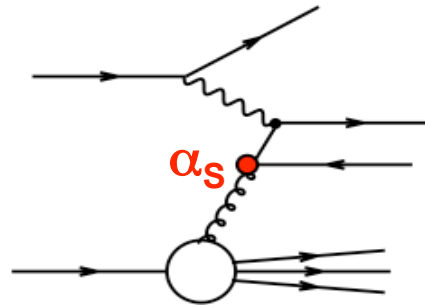
# Jet production in electron-proton scattering

multi-jet states ( $> 1+1$ ) = direct manifestation of QCD

Deep inelastic scattering (DIS)

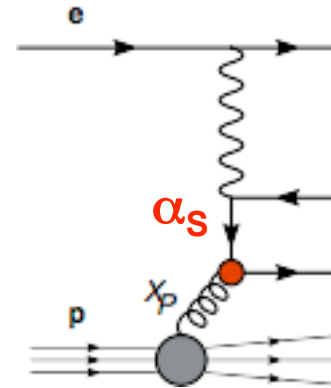


QCD Compton

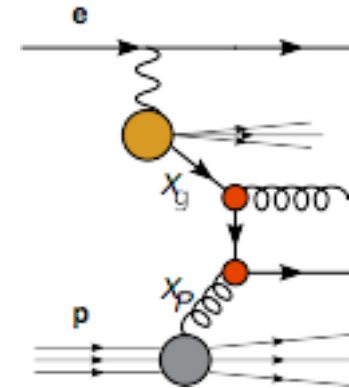


BGF

Photo-production ( $Q^2 \approx 0$ )



direct

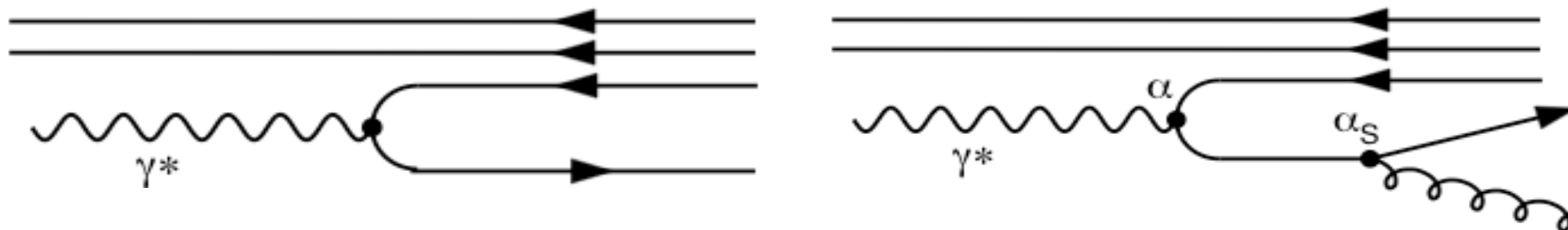


resolved

comparison with & fit to pQCD predictions  $\Rightarrow$  access to:

- parton distribution functions (gluon pdf)
- precision measurement of **strong coupling constant  $\alpha_s$**

# Jet Finding: $k_T$ Algorithm in the Breit Frame



- ◆ **Breit frame: proton and virtual photon collide head-on**, in the naïve quark parton model the quark bounces off from the photon like from a “brick wall”
- ◆ **transverse momentum in Breit frame stems mainly from QCD process**
- ◆ **longitudinally invariant  $k_T$  jet-algorithm in the Breit frame**
  - collinear and infrared safe
  - iterative clustering:  $d_{i,j}^2 = \min(E_{T,i}^2, E_{T,j}^2) \cdot [(\eta_i - \eta_j)^2 + (\varphi_i - \varphi_j)^2]$
  - result:  $n$  jets with  $d_{i,j} > R$  where  $R = 1$
- ◆ **observables:  $\sigma(\geq n \text{ jets})$  single and double differential**  
**as functions of:  $E_T$ ,  $Q^2$ ,  $x_B$ ,  $\eta$ , parton momentum fraction  $\xi$ , invariant mass  $m$**

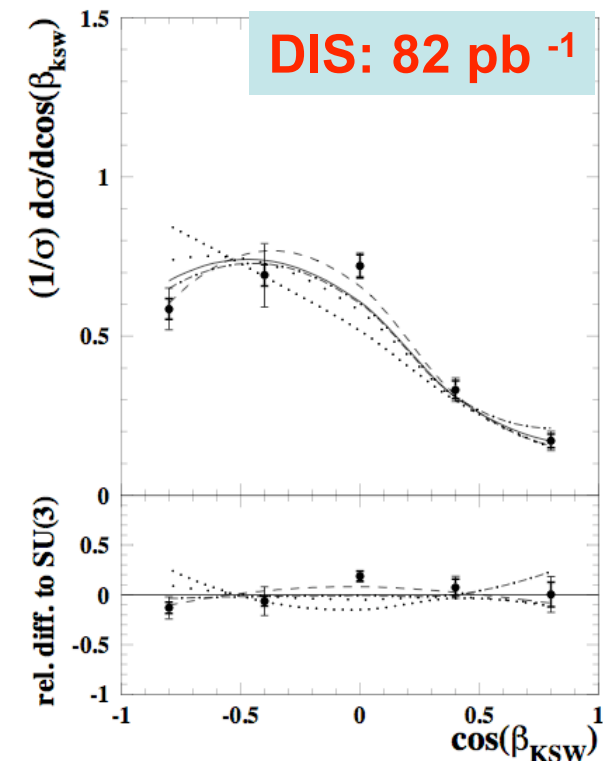
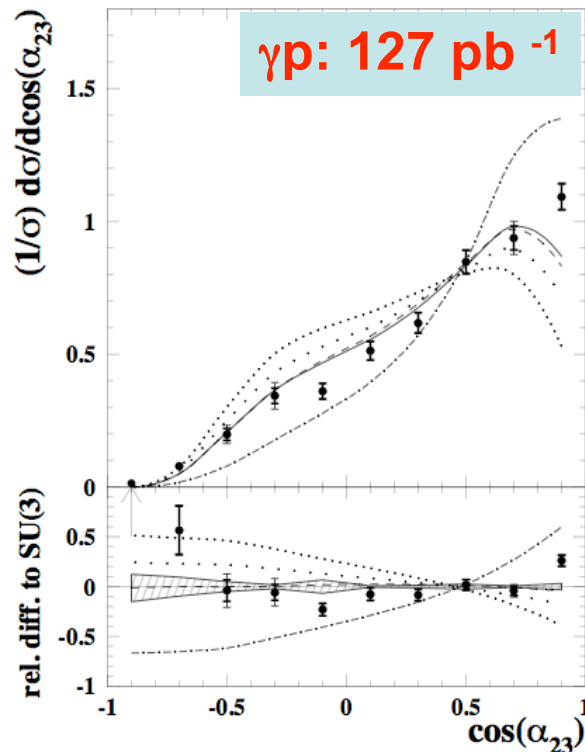
# Checking the Gauge: 3-Jet Angular Correlations



$$\sigma_{ep \rightarrow 3\text{jet}} = C_F^2 \left| \text{Diagram (A)} \right|^2 + C_F C_A \left| \text{Diagram (B)} \right|^2 + C_F T_F \left| \text{Diagram (C)} \right|^2 + T_F C_A \left| \text{Diagram (D)} \right|^2$$

angle between 2 lowest  $E_T$  jets

« Körner, Schierholz, Willrodt »



- ◆ 3-jet angular correlations in  $\gamma p$  and DIS compatible with SU(3)
- ◆ SU( $N_c = \infty$ ) and  $C_F = 0$  models are disfavored

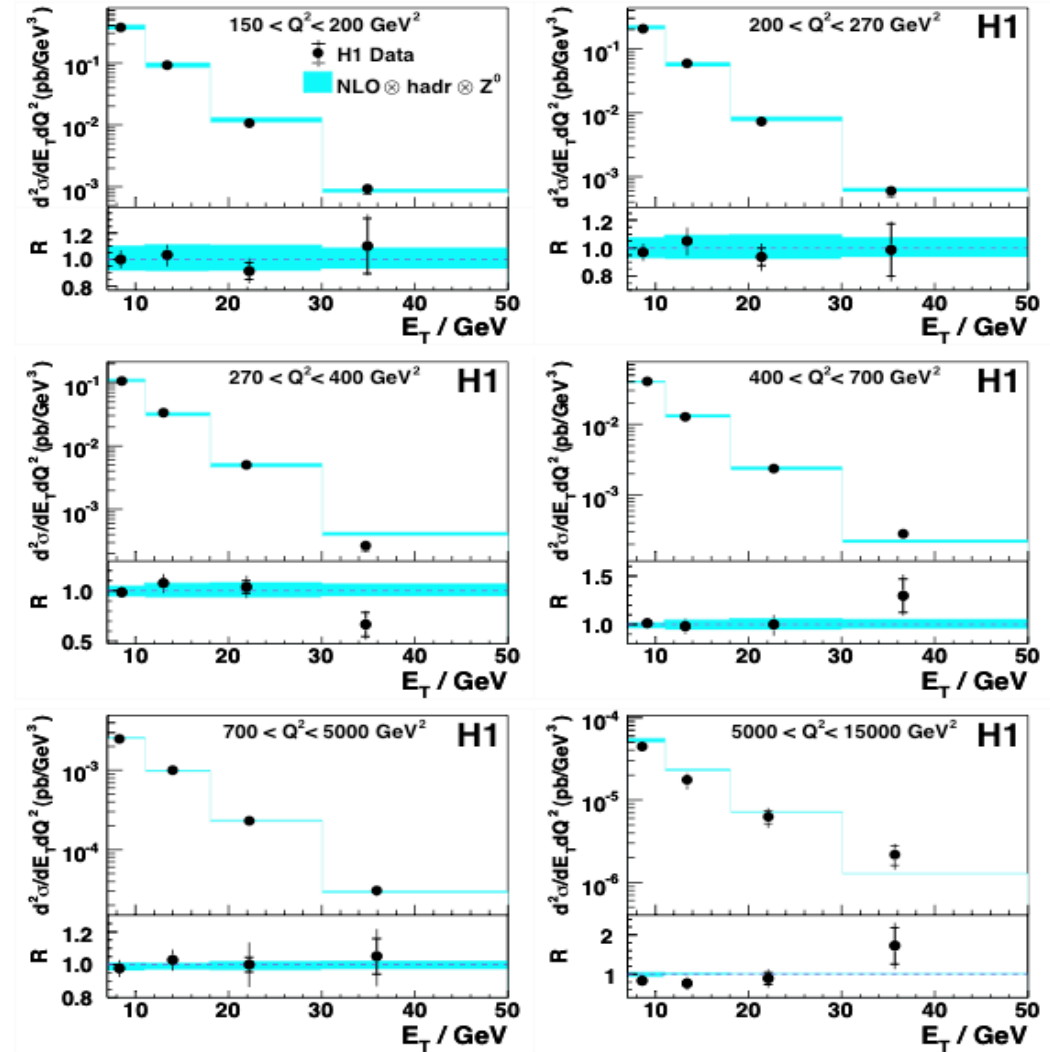
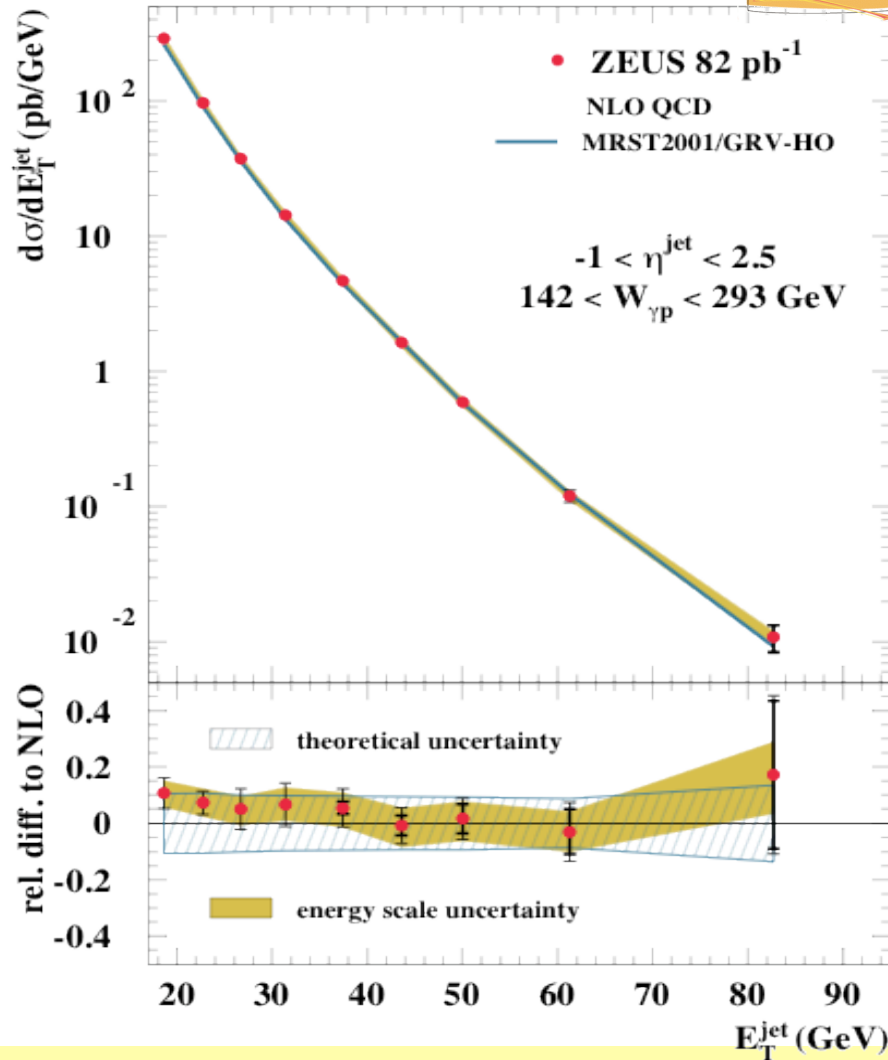
# Inclusive Jet Production



in photo-production (ZEUS)



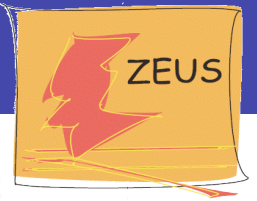
in deep-inelastic scattering (H1)



$$\alpha_s(m_Z) = 0.1223 \pm 0.0001(\text{stat}) \pm 0.022(\text{exp}) \pm 0.030(\text{th})$$

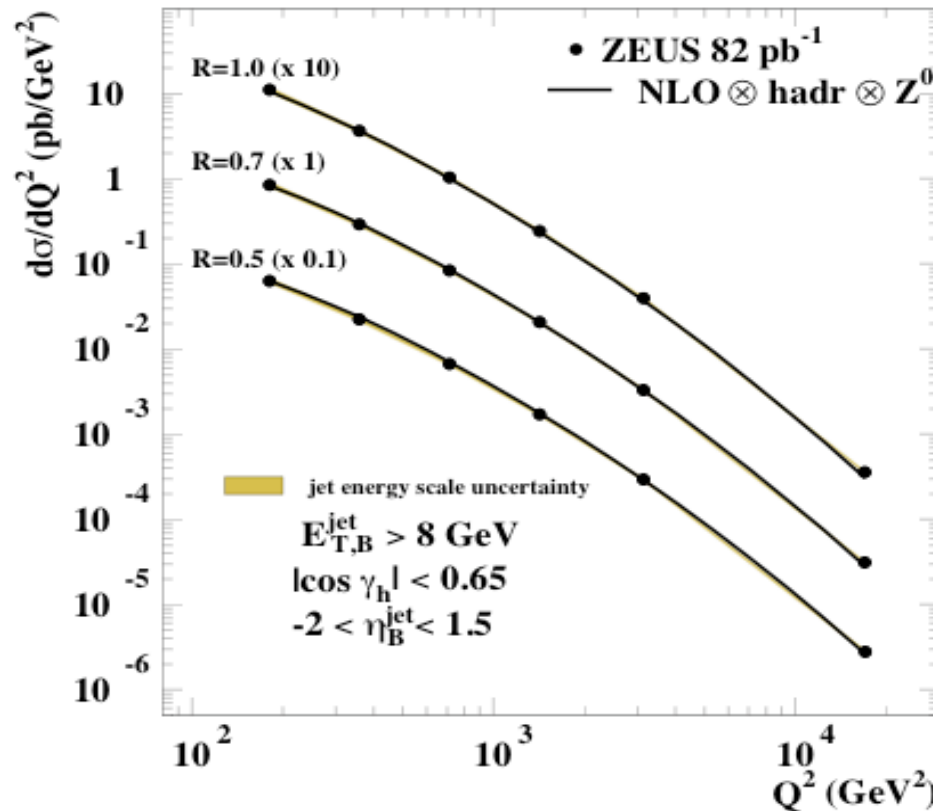
$$\alpha_s(m_Z) = 0.1179 \pm 0.0024(\text{exp})^{+0.0047}_{-0.0030}(\text{th}) \pm 0.016(\text{pdf})$$

# Influence of Radius on Jet Production

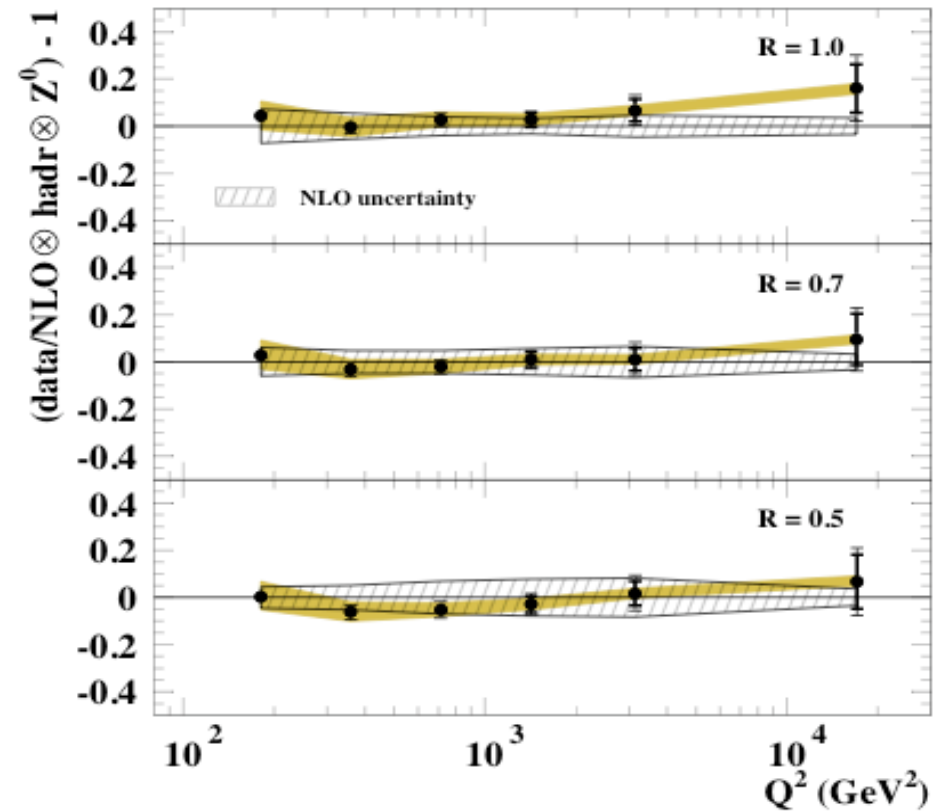


◆  **$k_T$  algorithm:**  $d_{i,j}^2 = \min(E_{T,i}^2, E_{T,j}^2) \cdot [(\eta_i - \eta_j)^2 + (\varphi_i - \varphi_j)^2] < R = 1$

**inclusive jet cross-section in DIS**



**exp. & theory uncertainties**



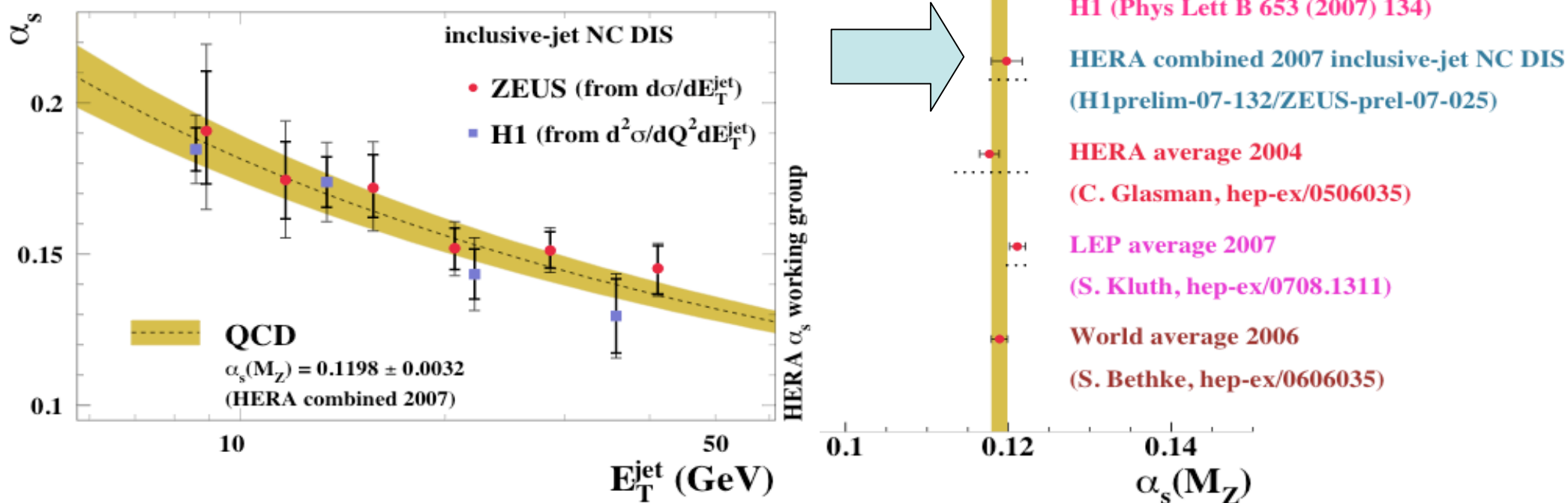
◆ NLO describes well jet productions for **radius parameter** down to 0.5

◆ **for R=1:**  $\alpha_s(m_Z) = 0.1207 \pm 0.0014 \text{ (stat.)} \pm 0.0034 \text{ (syst.)} \pm 0.022 \text{ (th.)}$

# HERA $\alpha_s$ determination: H1 and ZEUS



- ◆ **HERA I incl. jet cross-sections in DIS** .....
- ◆ **syst. exp. uncertainties partially uncorr'd between experiments**
- ◆ **simultaneous fit of  $\alpha_s(m_Z)$  to 24 + 6 data points**

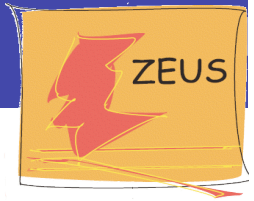


$$\alpha_s(m_Z) = 0.1198 \pm 0.0019 \text{ (exp.)} \pm 0.0026 \text{ (th.)}$$

**HERA I (2007) average competitive with LEP average**



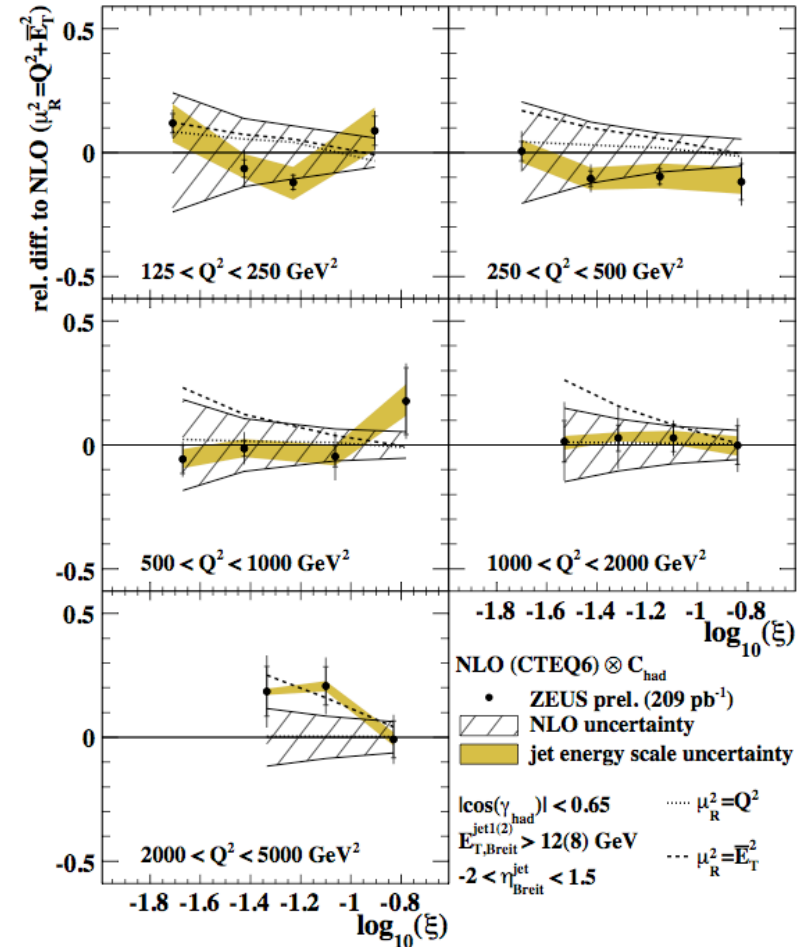
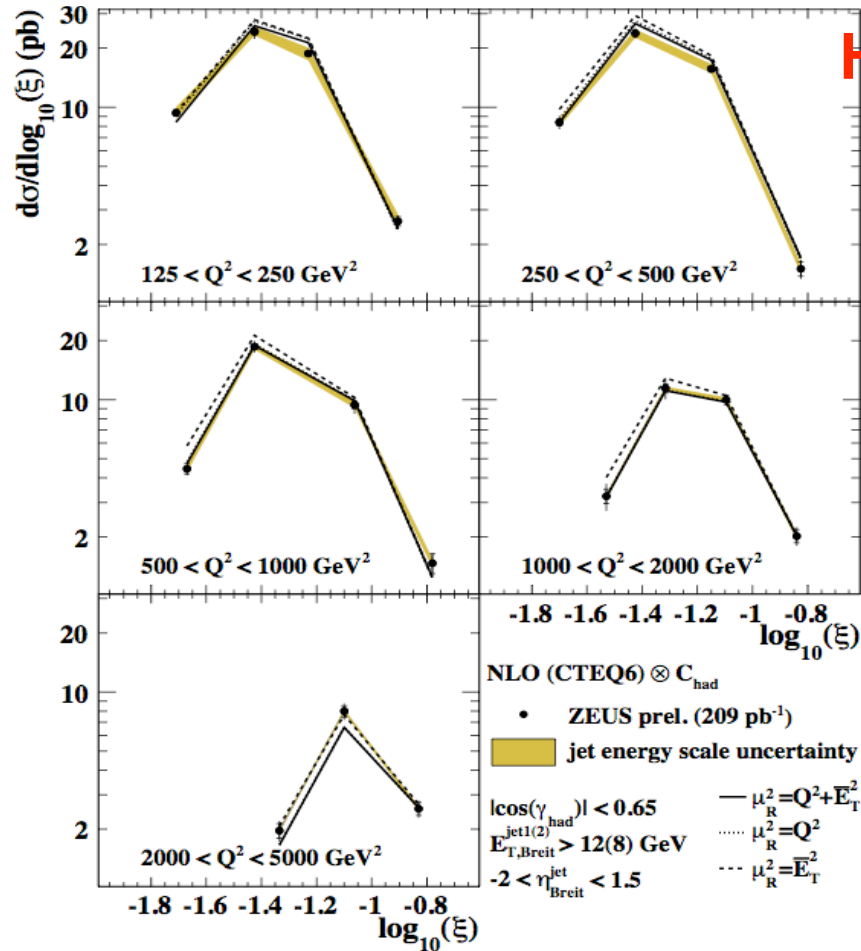
# Dijet Production in DIS



parton momentum fraction  $\xi = x_B \cdot (1 + M^2/Q^2)$

(data-NLO)/NLO

HERA II



differential 2-jet cross-sections ( $E_T$ ,  $Q^2$ ,  $x_B$ ,  $\eta^*$ ,  $\xi$ ,  $m_{12}$ ) well described by NLO pQCD, theory uncertainty dominates

# Normalized Jet Cross-Sections



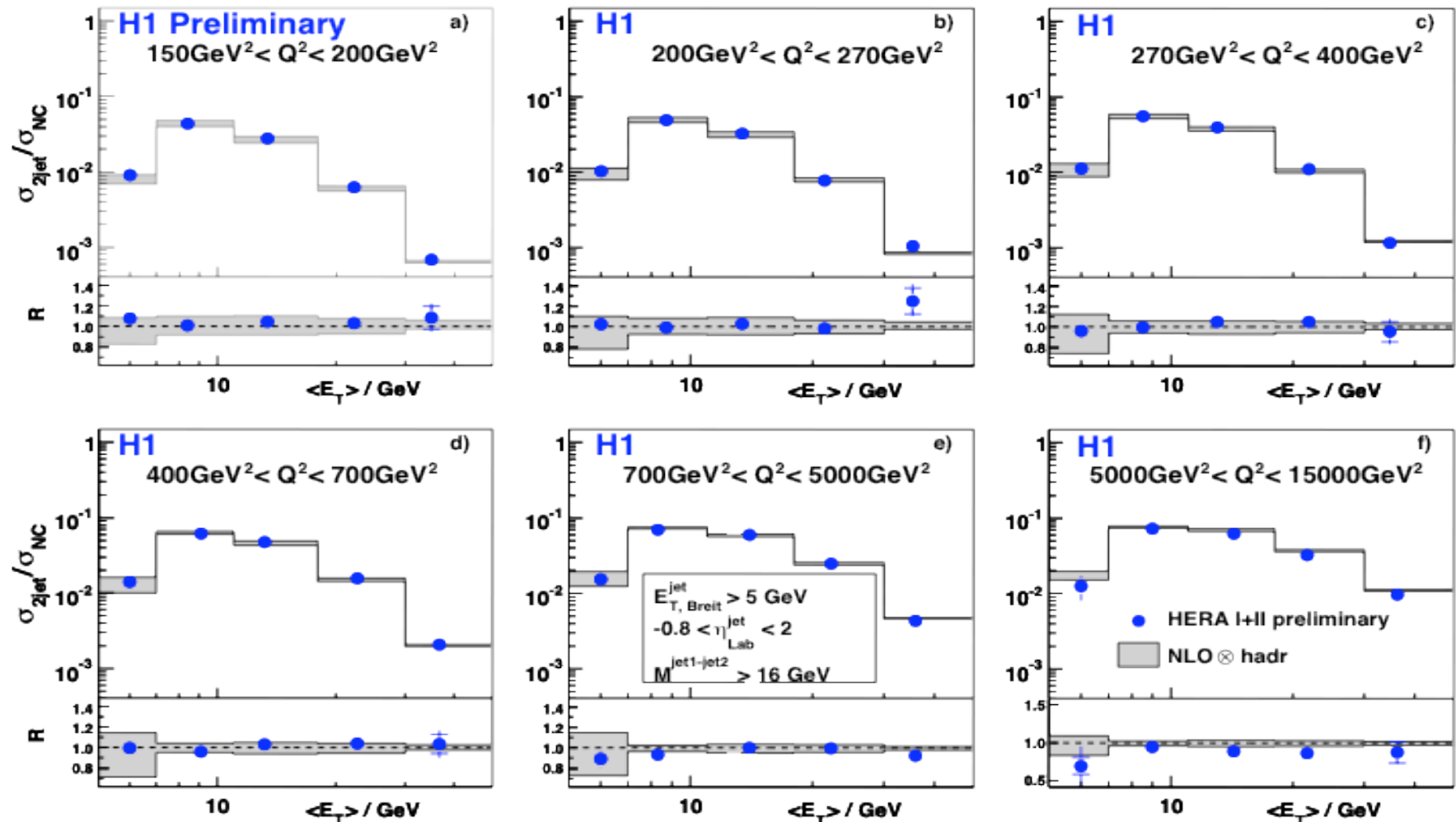
- ◆ partial cancellation of experimental and theoretical uncertainties
- ◆ Inclusive, dijet and 3-jet normalized cross-sections

HERA I+II

Normalised 2-Jet Cross Section

$$\frac{\sigma_{2\text{Jet}}}{\sigma_{\text{DIS}}}$$

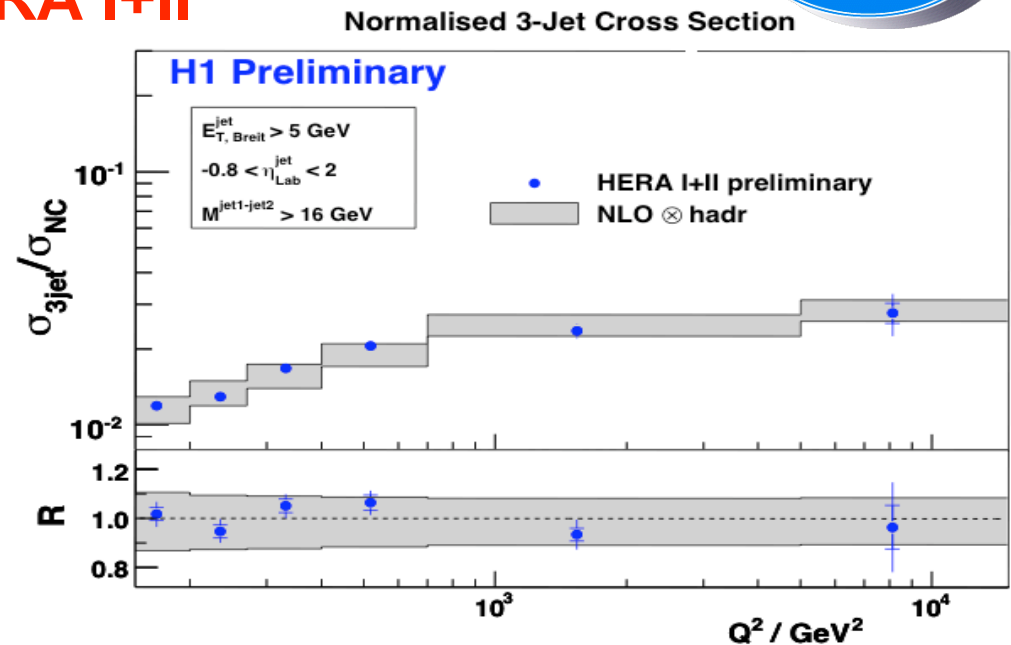
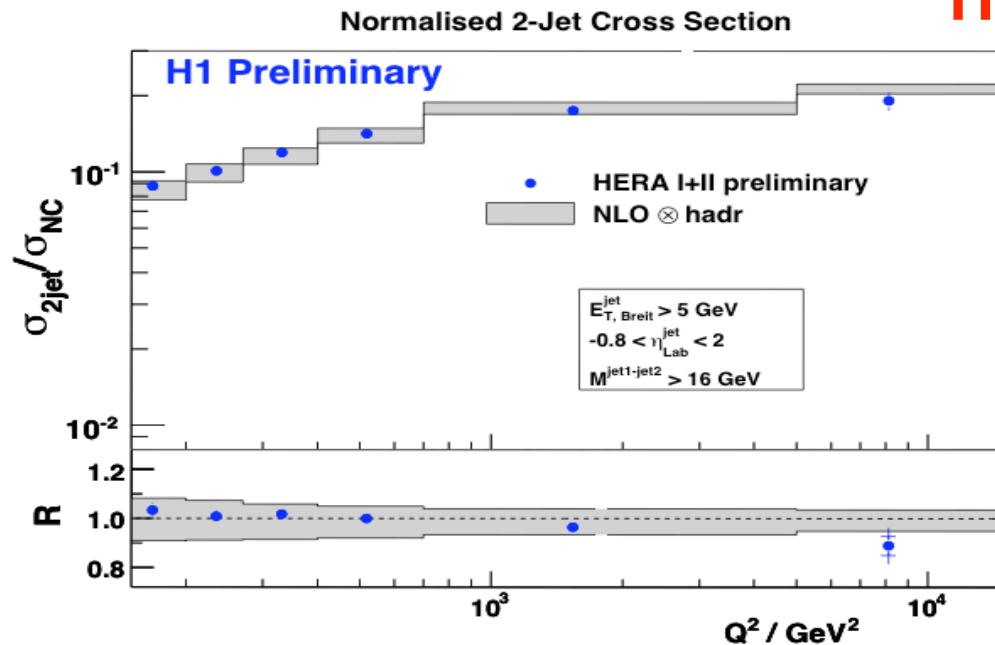
data/NLO



# Normalized multi-jet cross-sections in DIS



HERA I+II

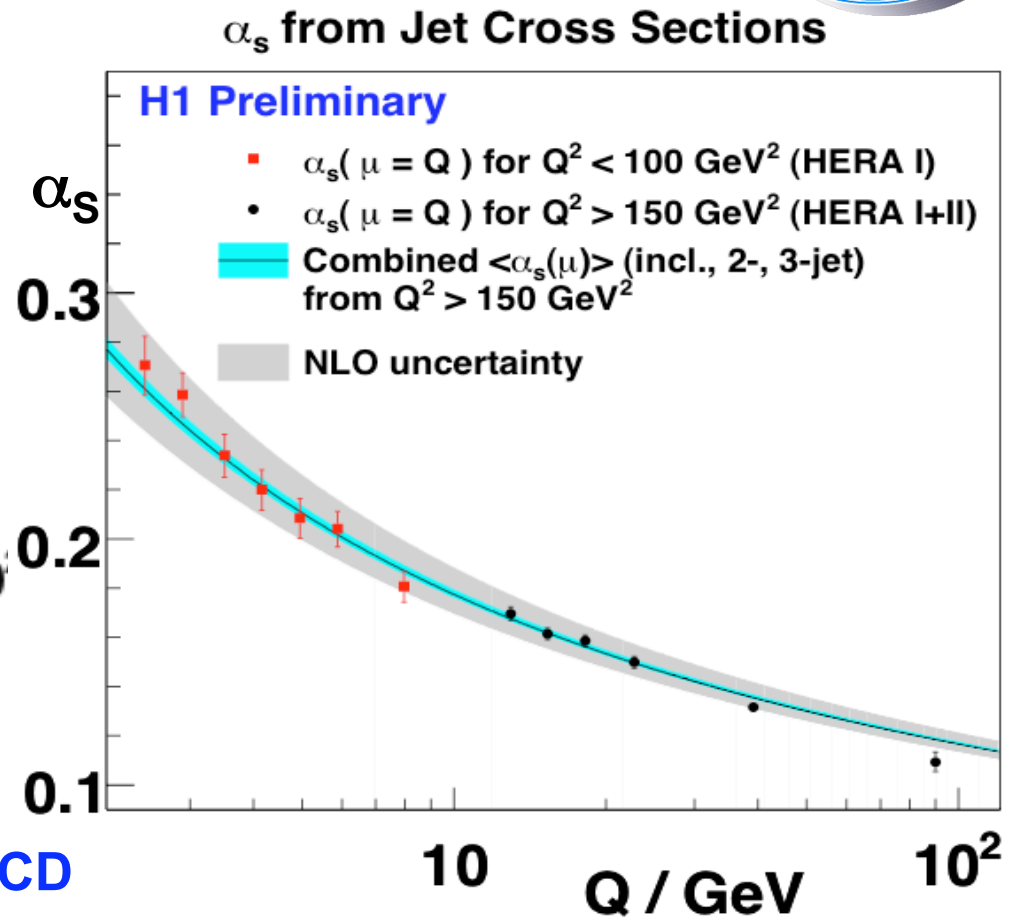
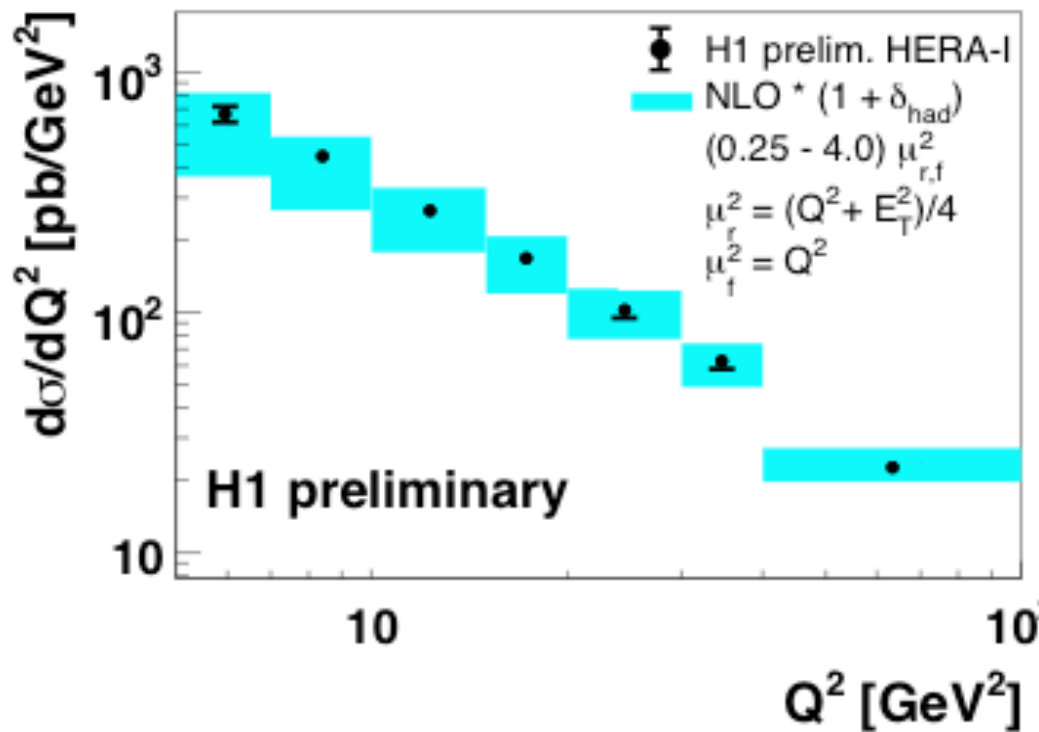


- ◆ good agreement with NLO predictions (NLOJET/DISENT)
- ◆  $\alpha_s$ -fit to inclusive, 2- and 3- jet normalized cross-sections are good
- ◆ combined fit to all observables:

$$\alpha_s(m_Z) = 0.1182 \pm 0.0008 \text{ (exp)} + {}^{+0.0041}_{-0.0031} \text{ (th)} \pm 0.0018 \text{ (PDF)}$$

⇒ 20-40% improvement of experimental and theory errors

# Inclusive Jet Production at Low $Q^2$



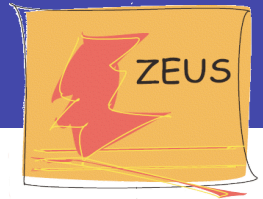
◆  $Q^2 = 5\text{-}100\text{GeV}^2$ ,  $E_T > 5\text{GeV}$

◆ cross-section data agree with NLO pQCD

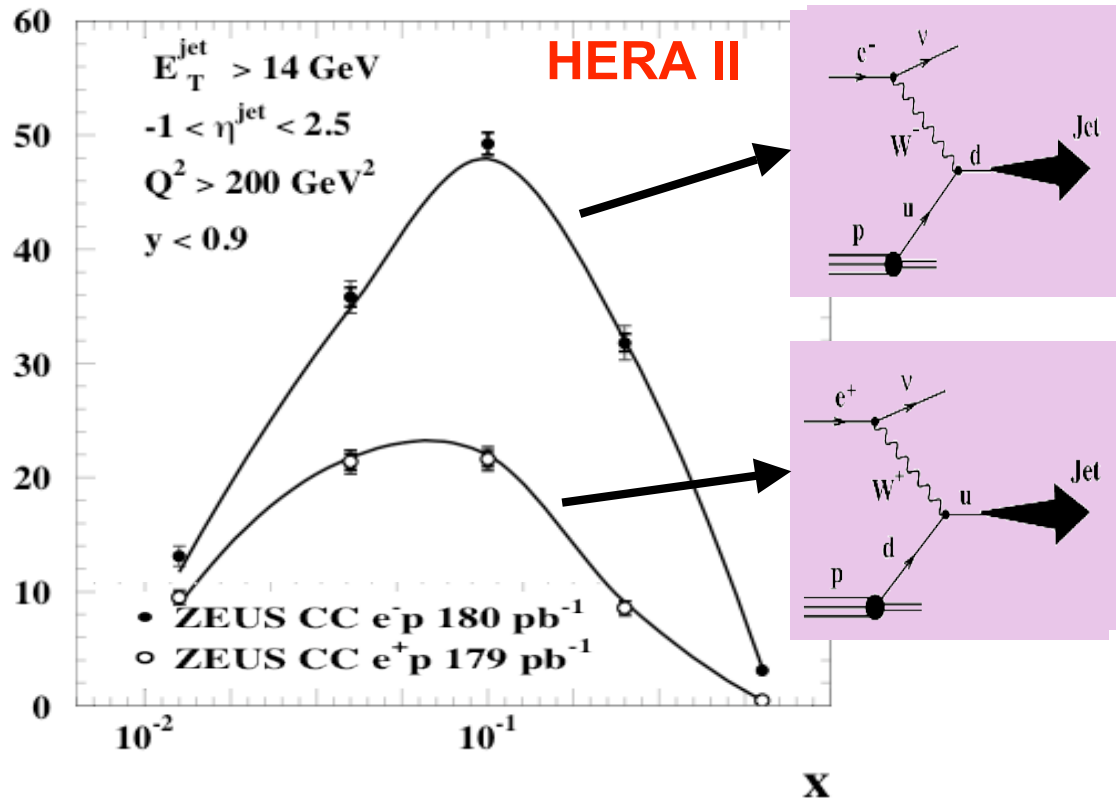
◆ agreement of fitted  $\alpha_s$  with running from high  $Q^2$  multi-jet cross-section fit

◆  $\alpha_s(m_Z) = 0.1186 \pm 0.0014 \text{ (exp)} + 0.0132 - 0.0101 \text{ (th)} \pm 0.0021 \text{ (pdf)}$

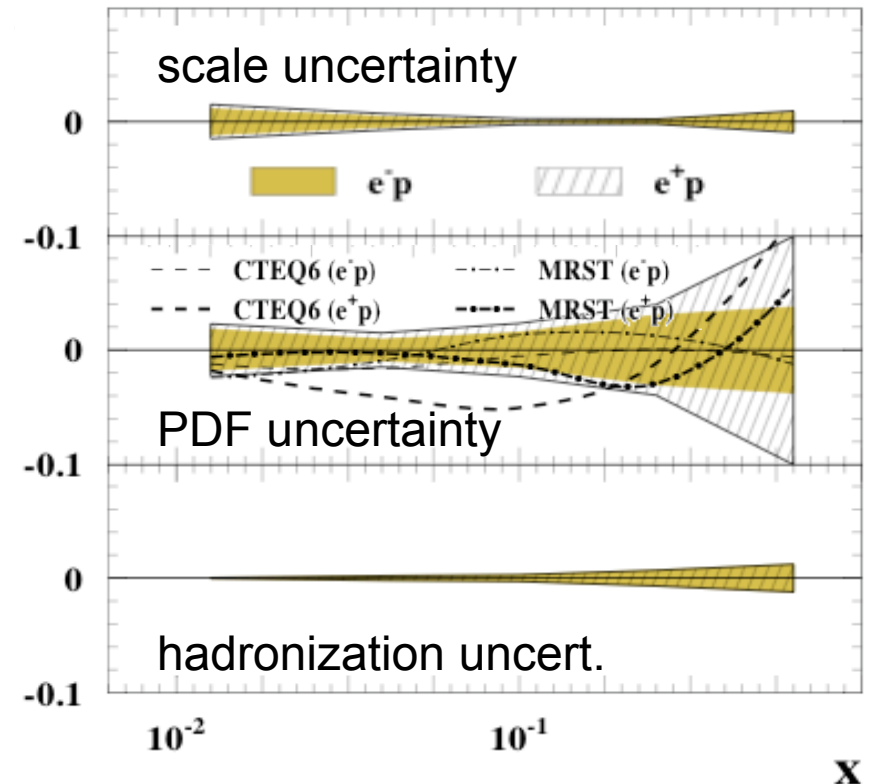
# Jet production in Charged Current DIS



## inclusive jet cross-section [pb]



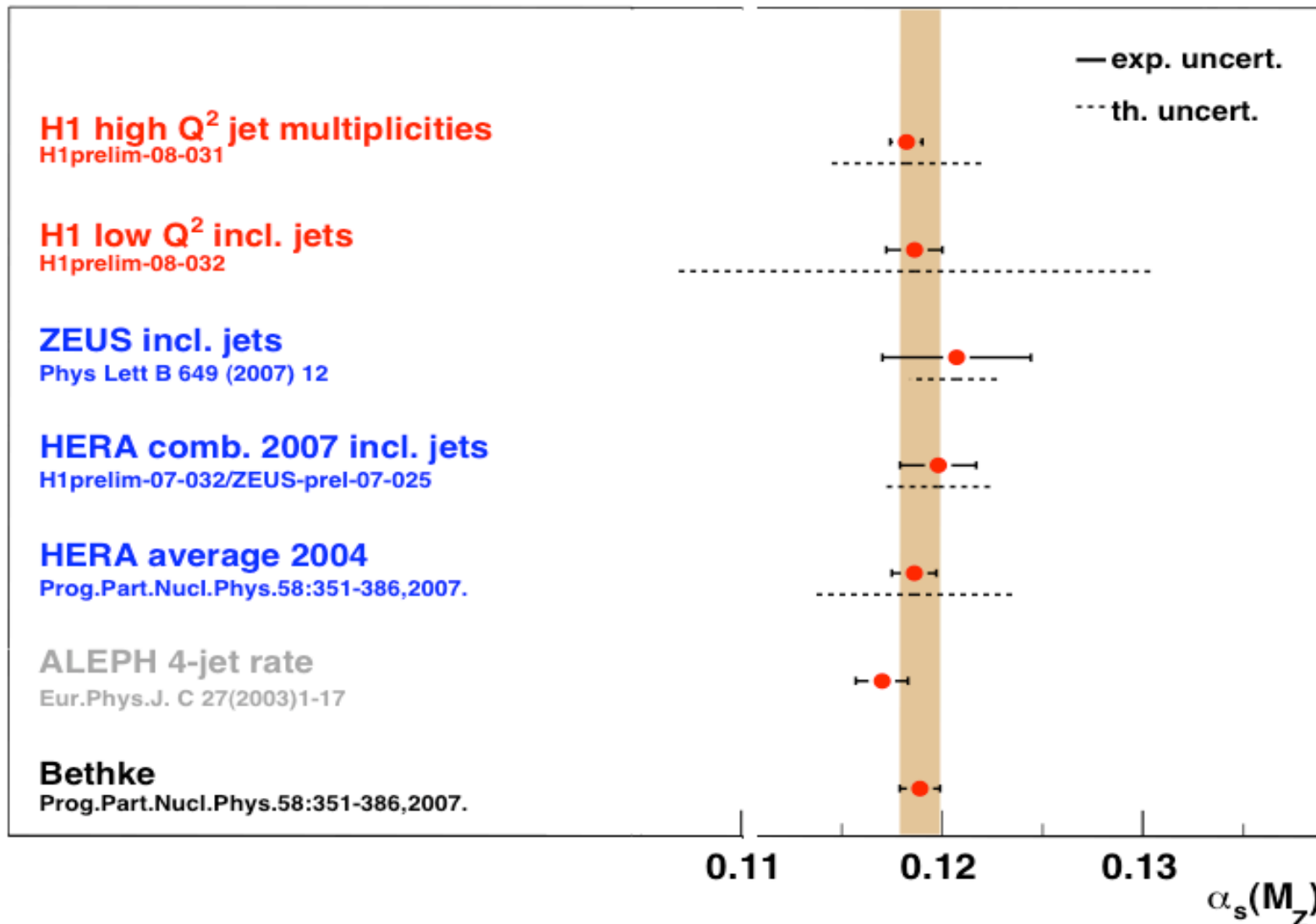
## theor. uncertainties



- ◆ inclusive and 2-jet cross-sections well described by NLO
- ◆ largest uncertainty from PDF for  $e^+$  at high  $x$ :  $d$ -quark density
- ◆ *CC DIS constrains flavour content of the proton at high  $x$*

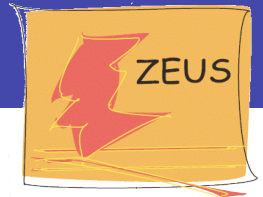
# Summary

jet observables at HERA (H1 and ZEUS) provide a wealth of high precision measurements of  $\alpha_s(m_Z)$



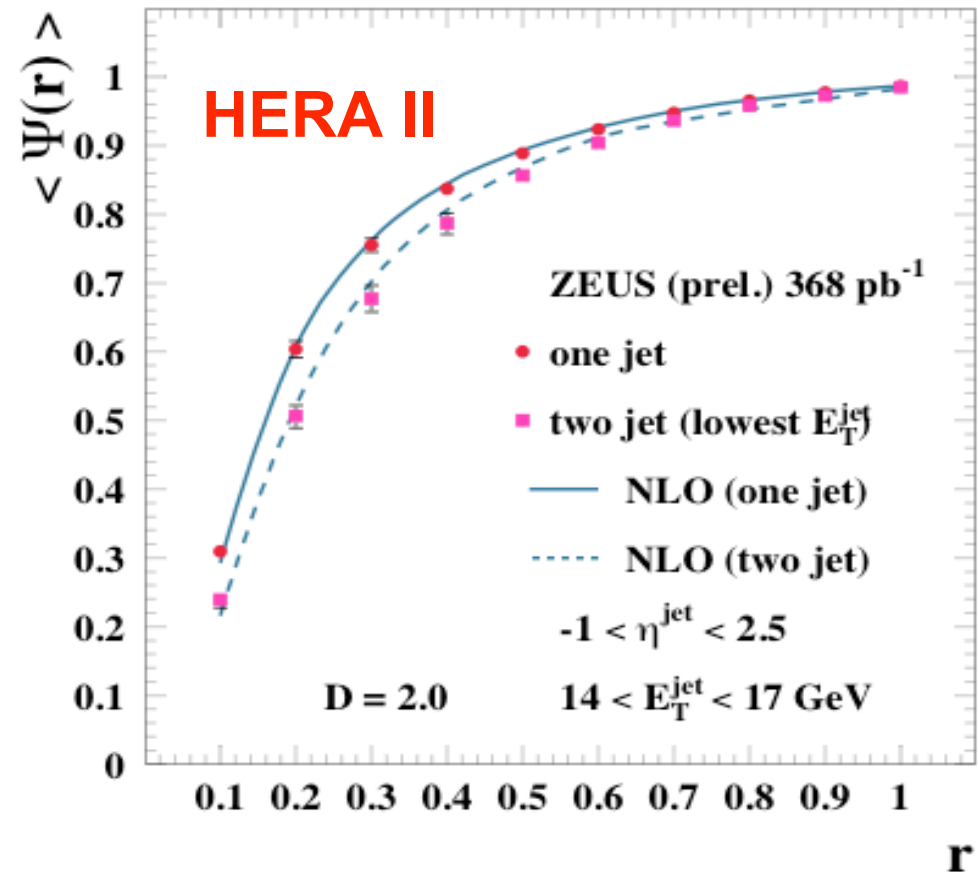
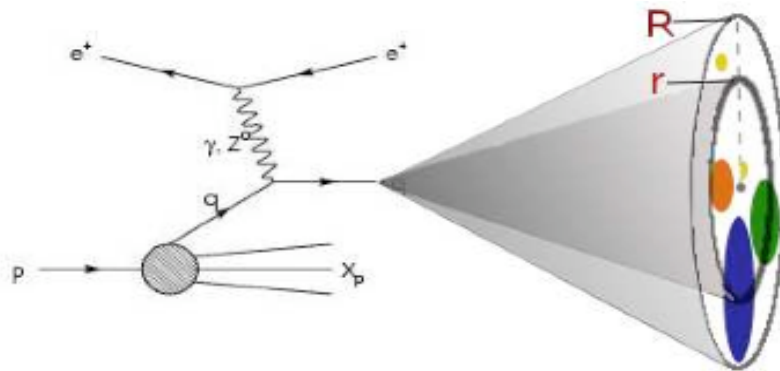
# BACKUP SLIDES

# Jet Substructure



Observable: **average jet shape**

$$\langle \psi(r) \rangle = \frac{1}{N_{jets}} \sum_{i=1}^{N_{jets}} \frac{E_T^i(r)}{E_T^i}$$



- ◆ broader jet shape for 2-jet-sample: gluon enriched
- ◆ shape for 1-jet and 2-jet sample well described by NLO