# Test of QCD Using Multijets in Neutral Current DIS at HERA

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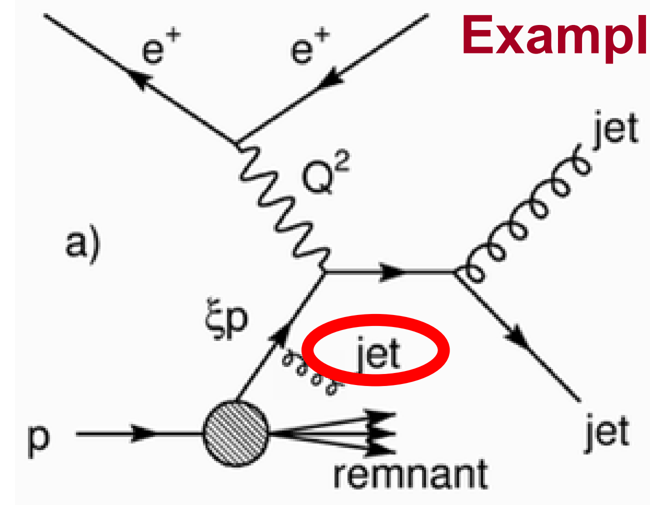
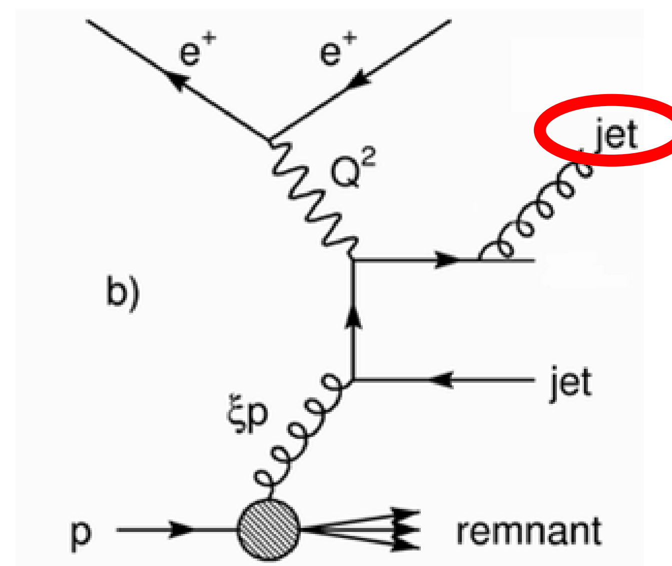
# Motivation for Multijets Study

- Add a gluon radiation to dijet or split a gluon to $q\bar{q}$
  $\rightarrow$ direct test of QCD at $O(\alpha_s^2)$
- An ideal laboratory for studying gluon radiation.
- In the ratio $\sigma_{trijet}/\sigma_{dijet} = O(\alpha_s)$, cancellation of many correlated experimental and theoretical uncertainties.
- Multijet NLO Calculations available

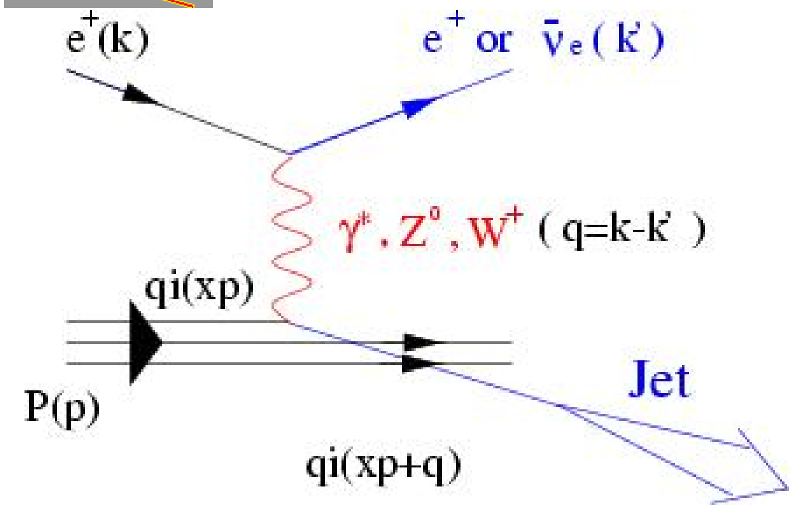
(Ref: Phys.Rev.Lett.87:082001,2001)

Example



# Deep Inelastic Kinematics and Data Selection




**Neutral Current:** $e^+p \rightarrow e^+ X \ (\gamma, Z)$

**$Q^2 \equiv -q^2$ : momentum transfer**

**$x \equiv Q^2 / 2pq$: momentum fraction carried by struck quark (QPM)**

**$y \equiv p \bullet q / p \bullet k$: fraction of electron energy transferred (in proton rest frame)**

**$s = (p+k)^2$ : center of mass energy**

## ZEUS 1998-2000 data

- $82.2\ pb^{-1}$
- $\sqrt{s} = 318$ GeV
- $E_p$=920 GeV, $E_e$=27.5 GeV

## Kinematic Range

- $10\ GeV^2 < Q^2 < 5000\ GeV^2$
- $Y_{EL} < 0.6$, $Y_{JB} > 0.04$
- $\cos\gamma_{had} < 0.7$

## Jet Reconstruction

- Invariant KT algorithm in Breit frame (inclusive)
- $E_{T,jet}^{BRT} > 5$ GeV
- $-1 < \eta_{jet}^{LAB} < 2.5$
- Invariant mass $M_{2,3jet}$ >25 GeV

# LO and NLO Calculation

## LO MC

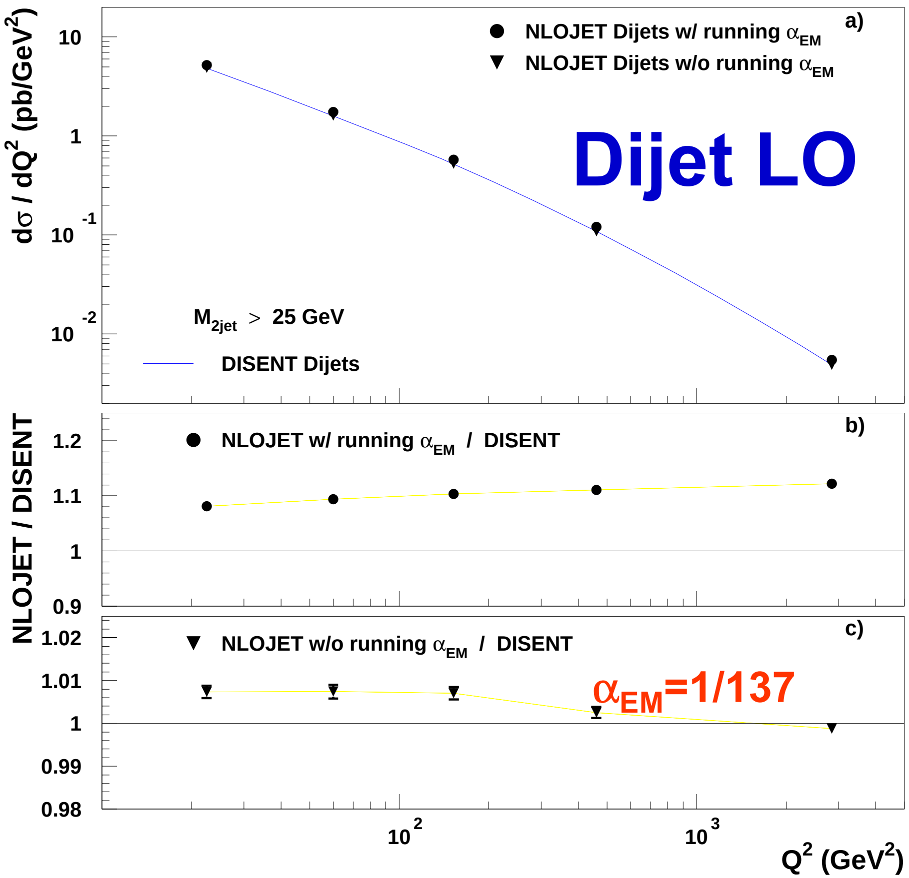
- LEPTO (6.5.1) used for acceptance corrections and hadronization corrections
- ARIADNE (4.0.8) used for systematic checks
- GEANT (3.13) used for detector simulation

## NLO Program

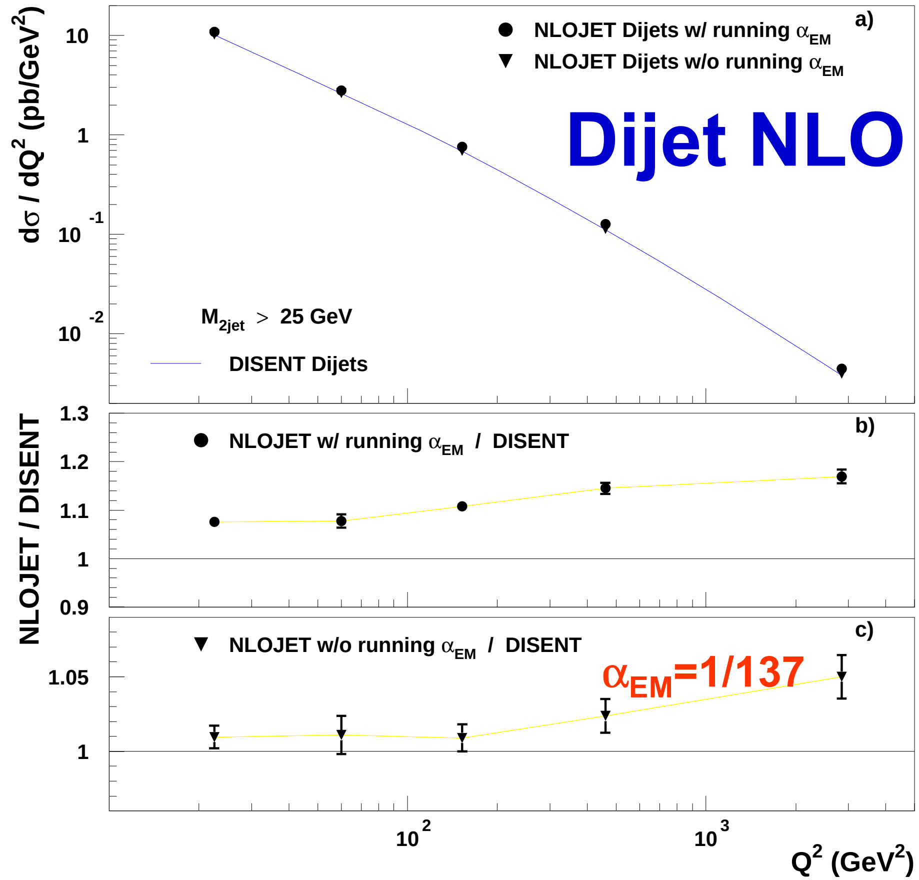
- NLOJET by Nagy Trocsanyi (Phys.Rev.Lett.87:082001,2001)
- Renormalization and factorization scales tested for $\overline{E}_T^2$ and $(\overline{E}_T^2 + Q^2)/4$
- Dijet: $\overline{E}_T = (E_{T,1} + E_{T,2})/2$ , trijet: $\overline{E}_T = (E_{T,1} + E_{T,2} + E_{T,3})/3$
- PDF: CTEQ6, MRST2001, CTEQ4
- Data and NLO compared at hadron level
- First NLO program for trijets, cross checked for dijets

# Comparison of NLOJET and DISENT Dijet

## LO MC Comparison




## NLO MC Comparison

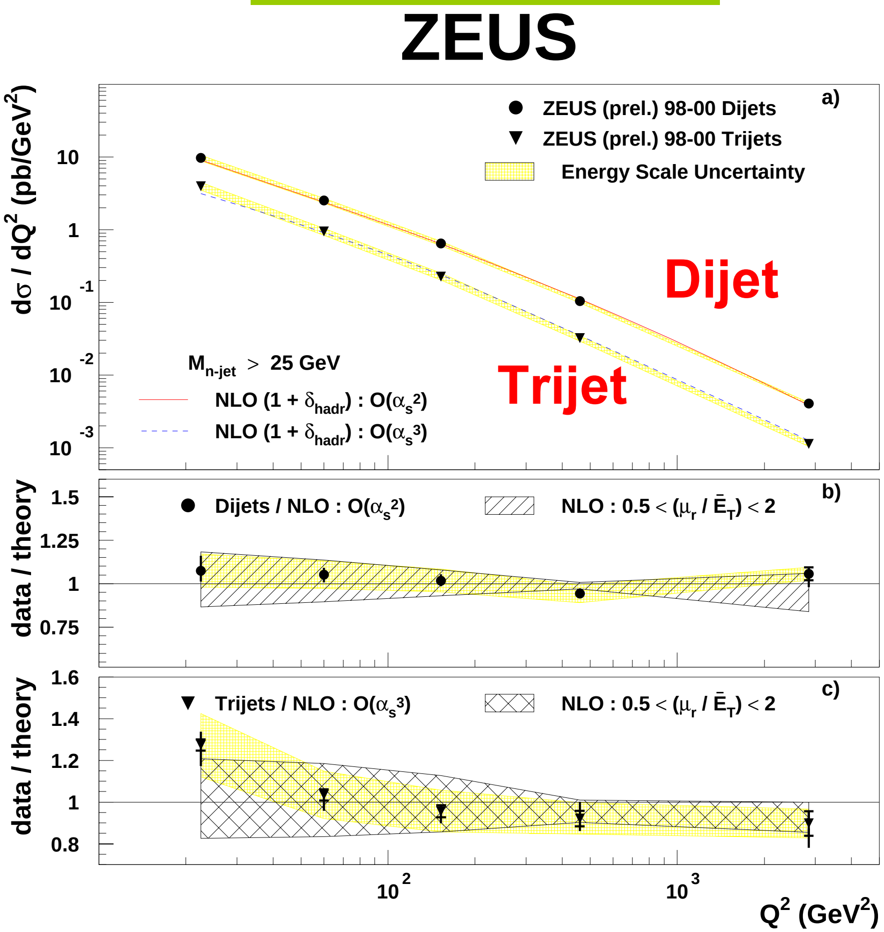



**By default, NLOJET: Running $\alpha_{EM}$, DISENT: fixed $\alpha_{EM}=1/137$**

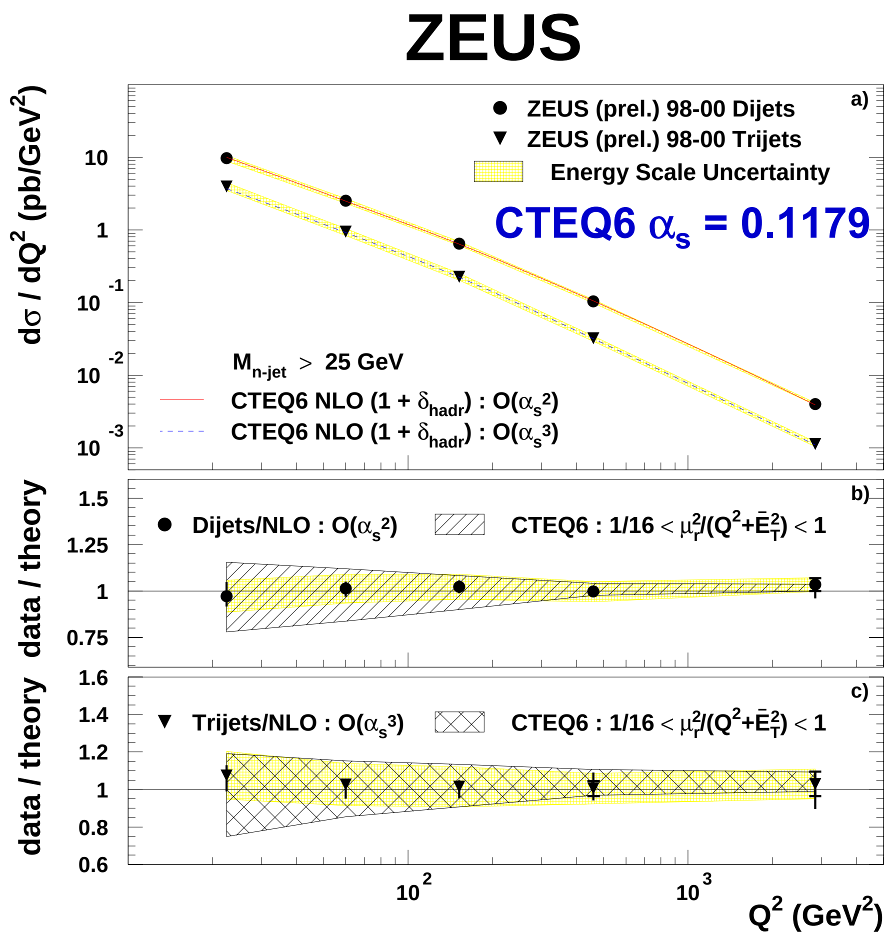
**Good agreement within 1~2% with fixed $\alpha_{EM}=1/137$**

# Compare Data vs. NLOJET : Choice
# Choice of Scale

**Scale $\mu_r = \mu_f = \bar{E}_T^2$**

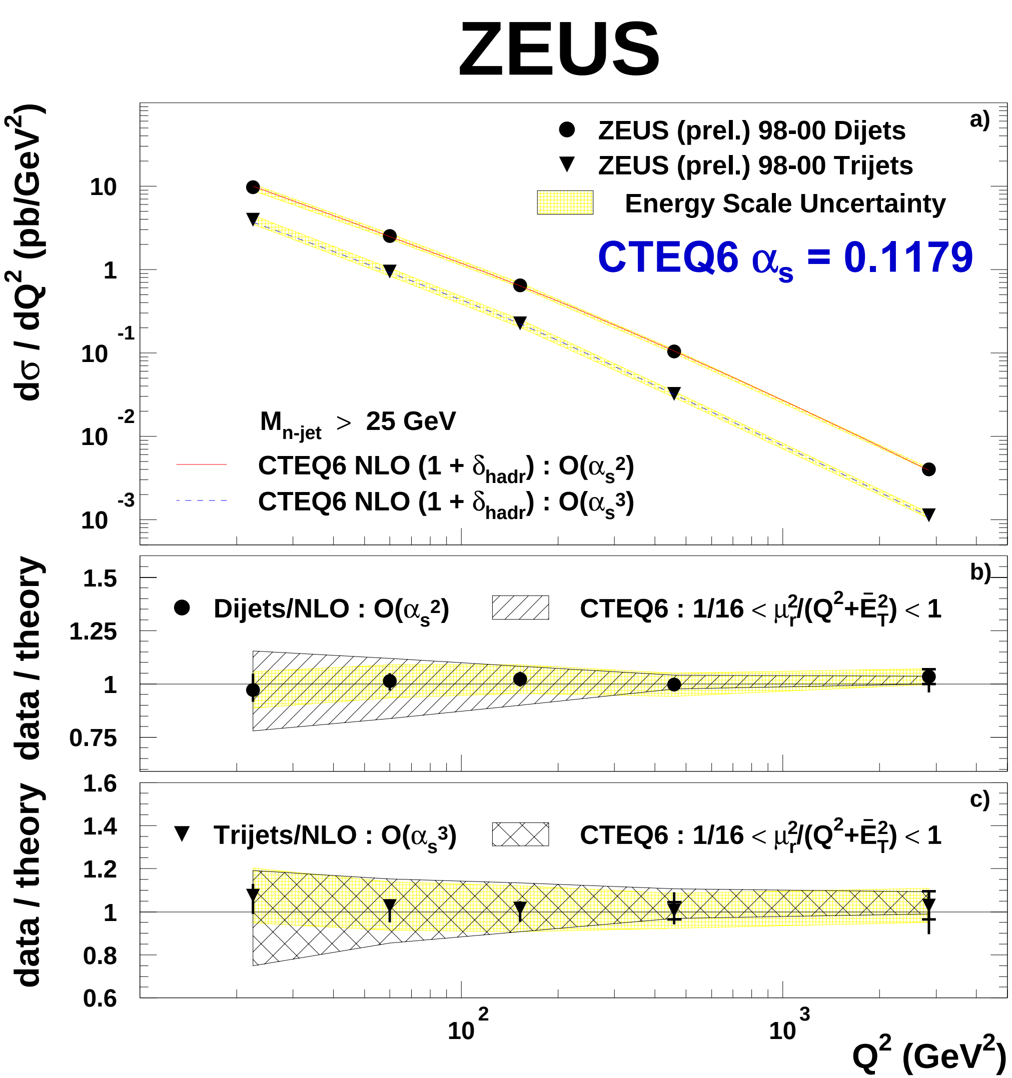



**Scale $\mu_r = \mu_f = (\bar{E}_T^2 + Q^2)/4$**




**Choose renormalization and factorization scale = $(\bar{E}_T^2 + Q^2)/4$**

# Compare Data vs. NLOJET : CTEQ6 CTEQ6 PDF

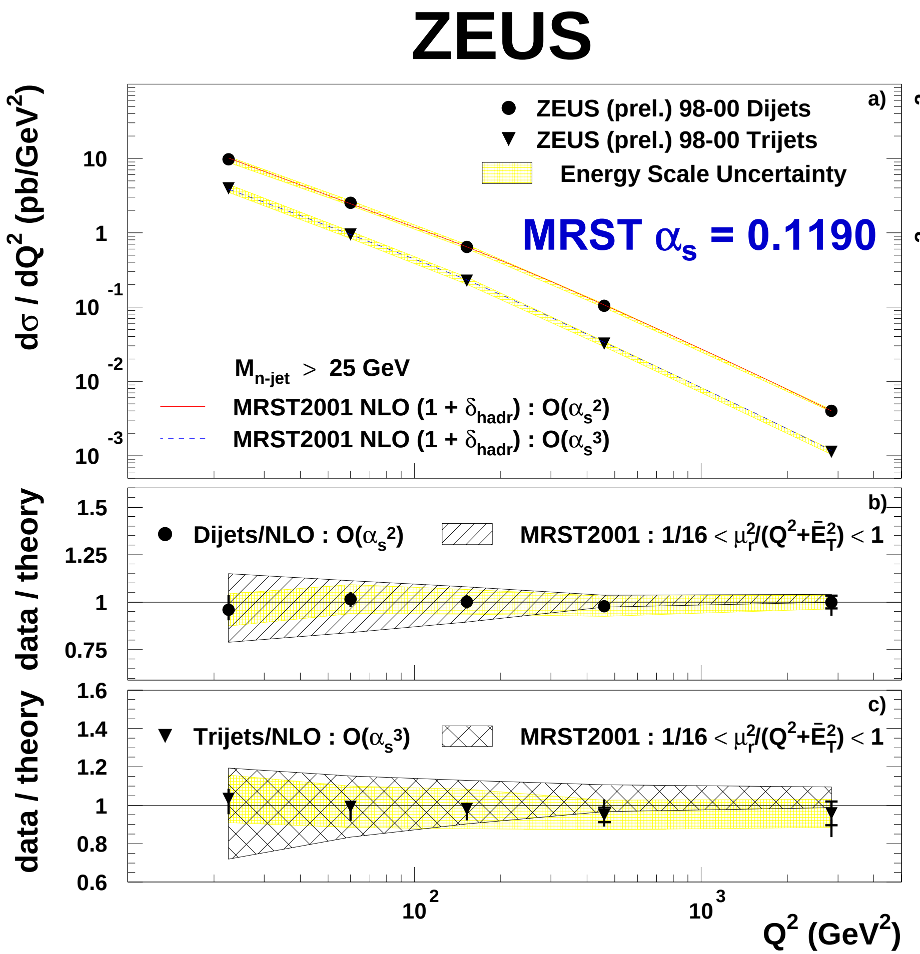


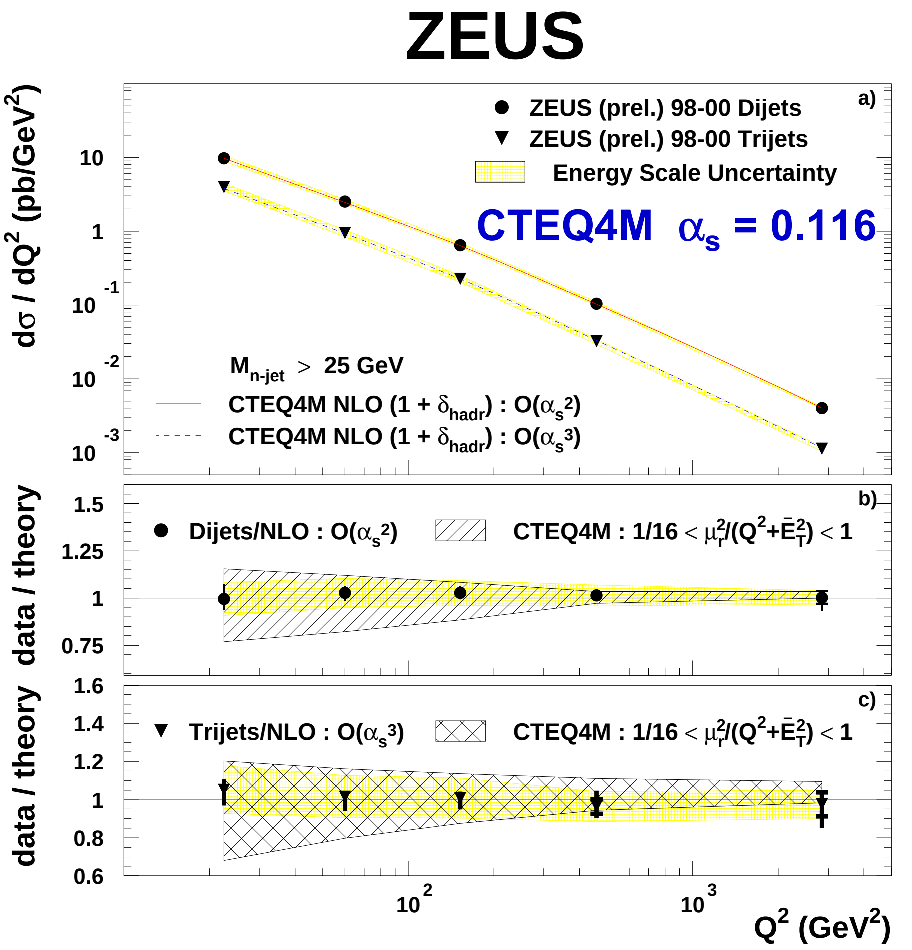

Scale $\mu_r = \mu_f = (\bar{E}_T^2 + Q^2)/4$

Dijet NLO: O($\alpha_s$)
Trijet NLO: O($\alpha_s^2$)

- Measurement down to low $Q^2$
- Test of scale dependence
- High renormalization scale dependence in low $Q^2$
- Good description of both dijets and trijets over 3 orders of magnitude in $Q^2$

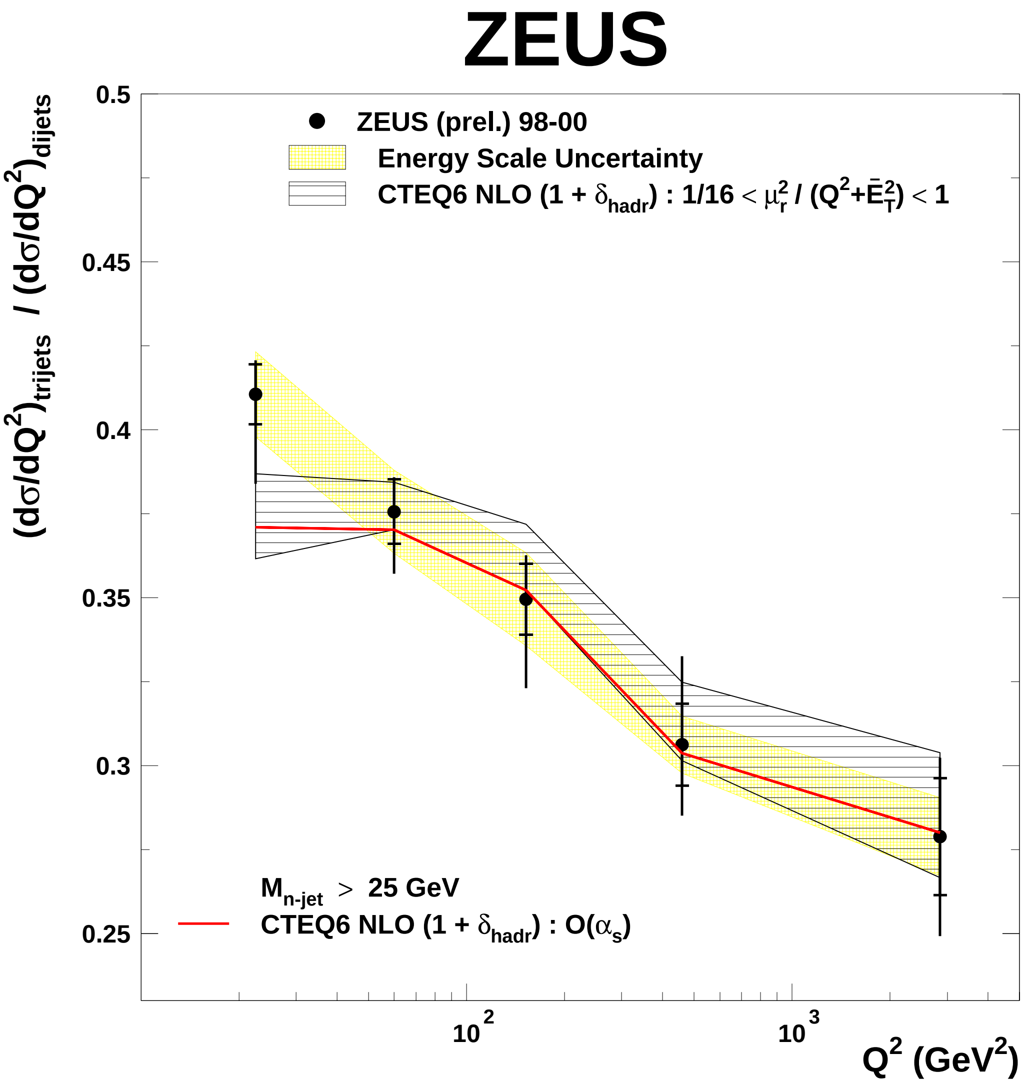
# Compare Data vs. NLOJET : MRST2001 and CTEQ4




**Good description of both dijets and trijets over 3 orders of magnitude in $Q^2$ for both PDFs**

# Cross Section Ratio: CTEQ6




$R_{3/2}=\sigma_{trijet}/\sigma_{dijet}$

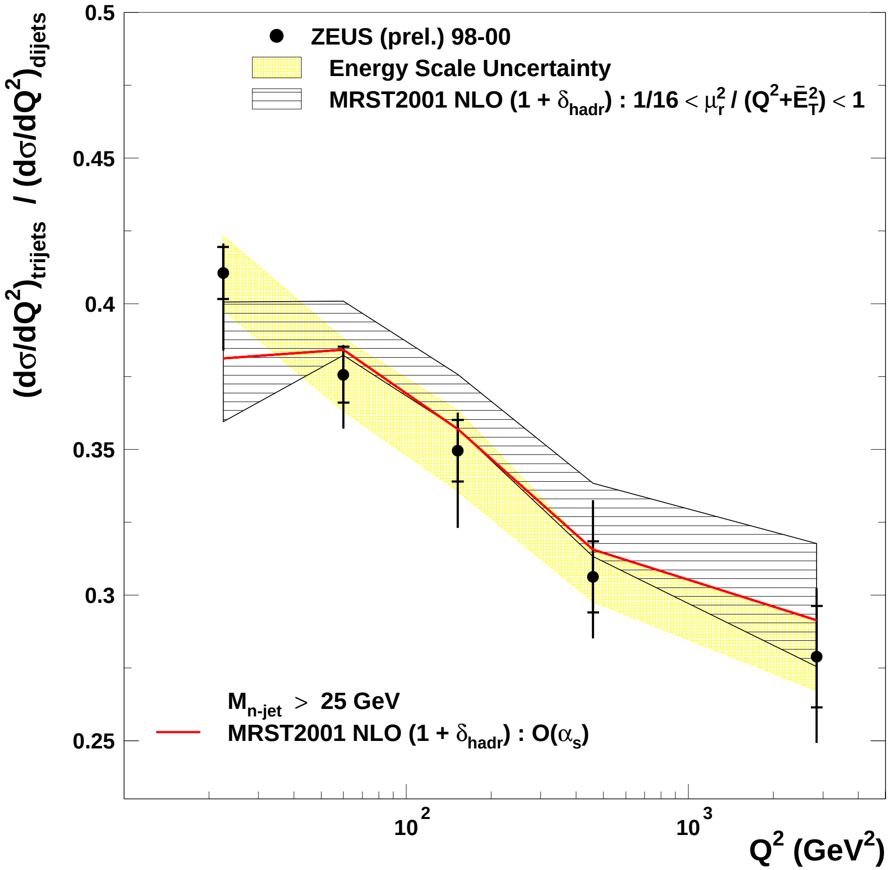
CTEQ6 $\alpha_s$ = 0.1179

- Systematic uncertainties substantially reduced
- Scale dependence reduced
- Very sensitive test of QCD calculation
- Good description of data over large range of scales

# Cross Section Ratio: MRST2001 and CTEQ4

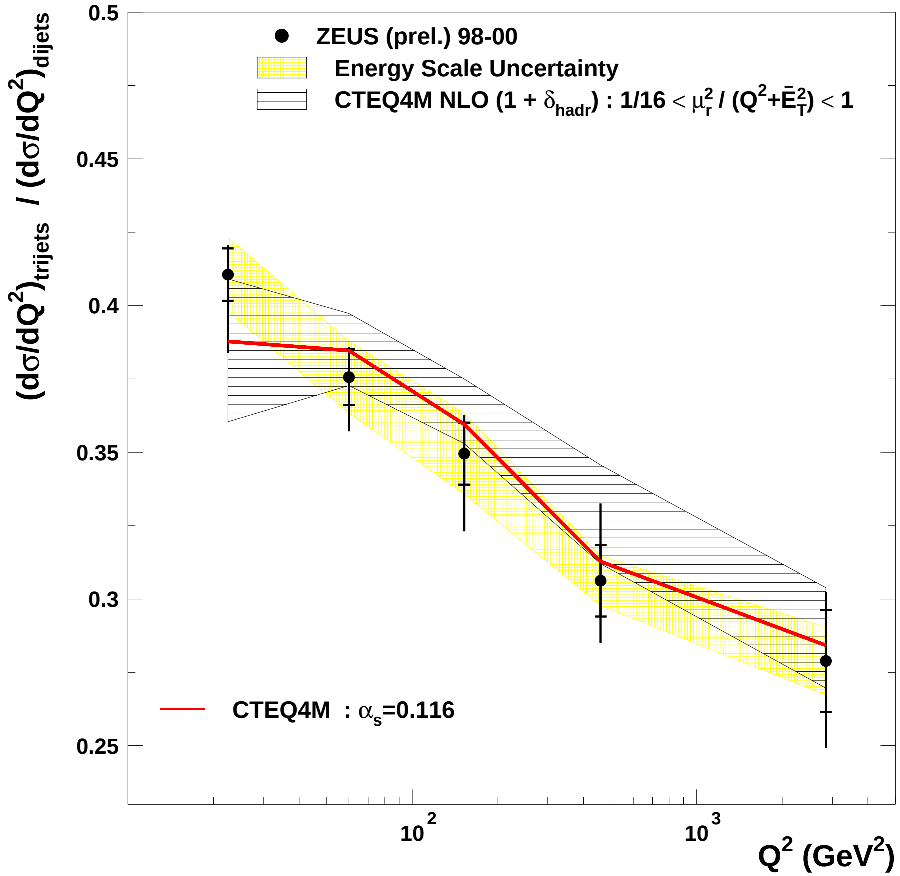
## MRST2001 $\alpha_s$ = 0.1190

**ZEUS**



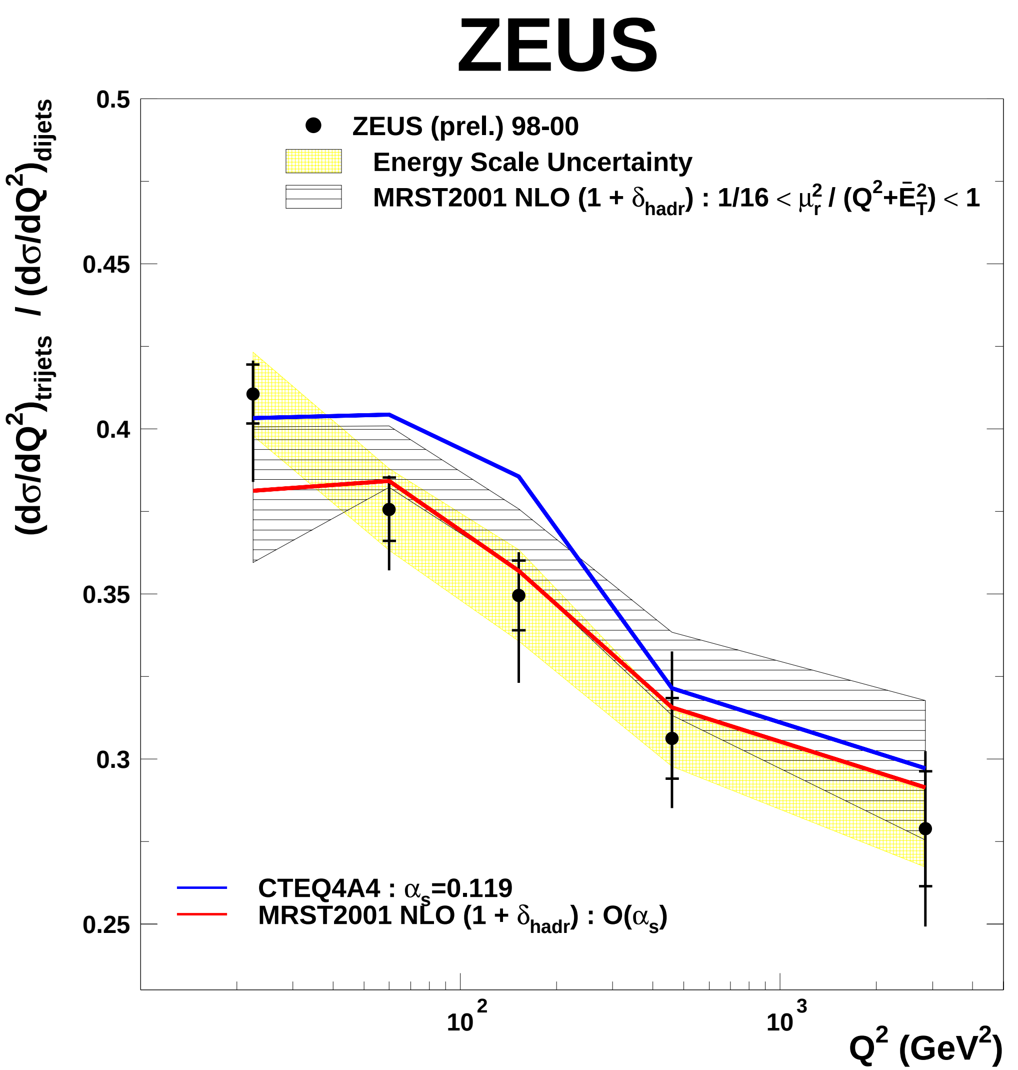

## CTEQ4M $\alpha_s$ = 0.1160

**ZEUS**



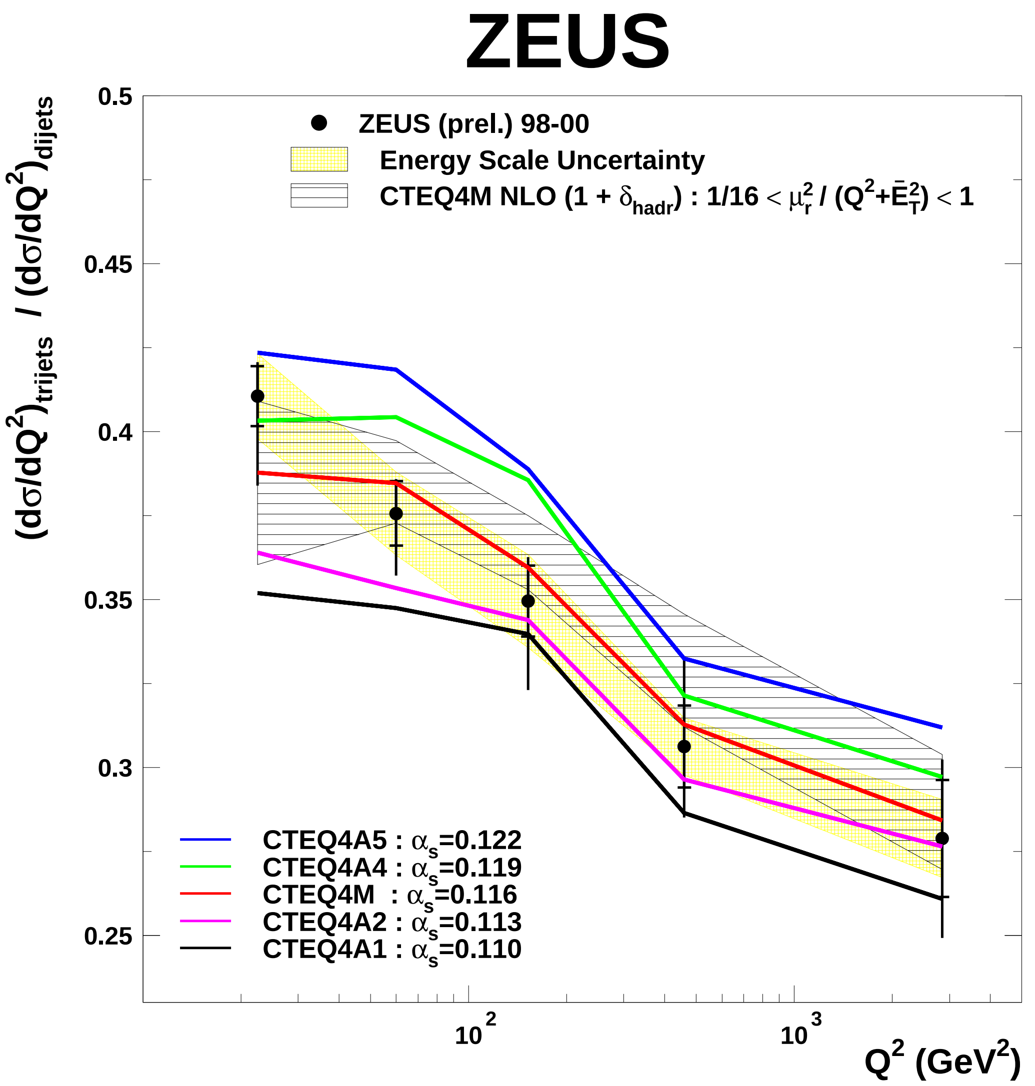

**NLO using MRST2001 and CTEQ4 PDF also describes data well over large kinematic range**

# Cross Section Ratio : CTEQ4 and MRST2001




- **Some sensitivity to PDF is observed**

# Cross Section Ratio : CTEQ4 with Different $\alpha_s$




- As expected, predictions within one PDF are sensitive to $\alpha_s$

# Summary and Outlook

- NLO with fixed $\alpha_{EM}$ describes data well using 3 different PDFs: CTEQ4, CTEQ6 and MRST2001
- $R_{3/2}$ cross section ratio is sensitive to $\alpha_s$ but some sensitivity to PDF is also observed and under study
- MRST2001 and CTEQ6 with different $\alpha_s$ sets are needed