# Inclusive Jet Cross-Sections in Neutral Current DIS Events Using the Breit Frame

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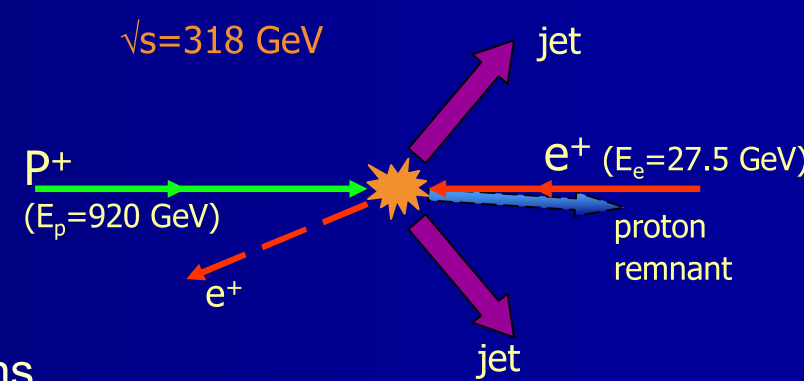
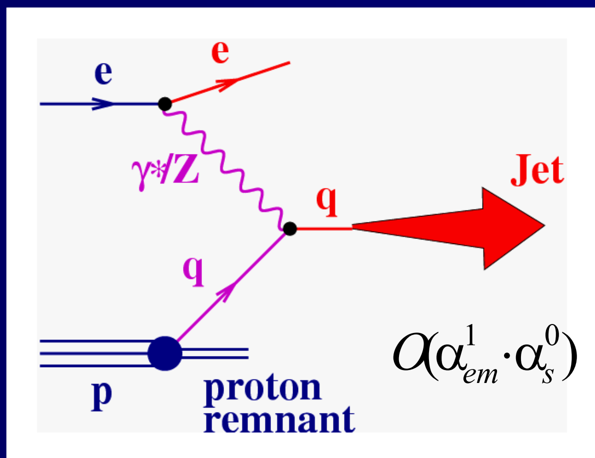
*… on behalf of the ZEUS Collaboration*

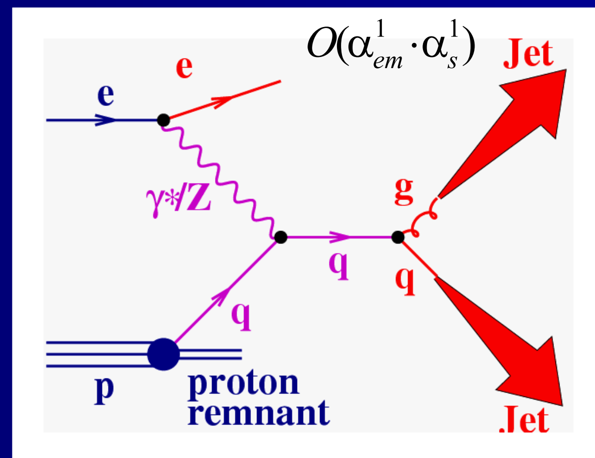
## OUTLINE

- Theoretical Motivations
- DIS Cross Sections and pQCD
- The Breit Frame
- Physics Event Reconstruction
- Jet Reconstruction
- Event Sample
- Next-to-Leading Order QCD Calculations
- Differential Cross Section Measurements (predicted, measured)
- Comparisons of Data with NLO Predictions
- Conclusions and Summary

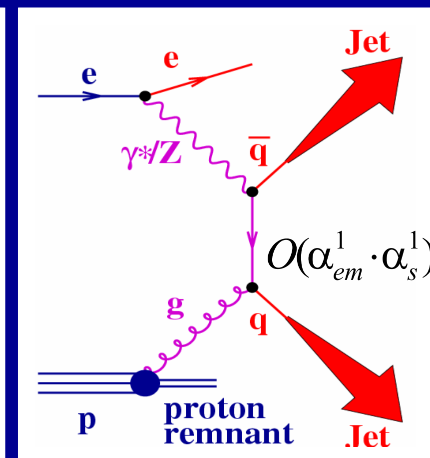


- Jet production in Neutral Current (NC) DIS provides a test of pQCD.
- These are the Feynman diagrams, up to first order in $\alpha_s$, that contribute to jet production cross sections in NC DIS.




QCD Compton



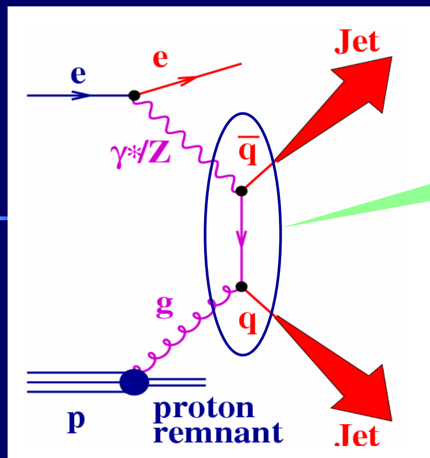

Boson Gluon Fusion (BGF)

- Jet cross section is given by:

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

$f_a$ represents the Parton Distribution Function (PDF).

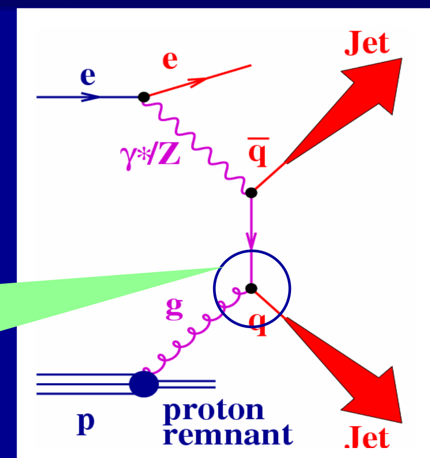
$d\hat{\sigma}_a$ represents the calculable QCD subprocess cross sections (see above).



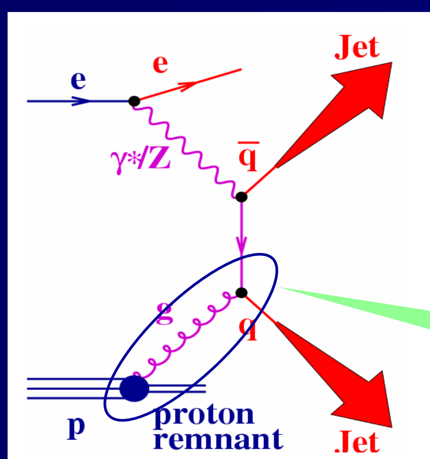

BGF

Test of QCD matrix elements and colour factors.

BGF




Determination of $\alpha_s$ and its dependence on scale.

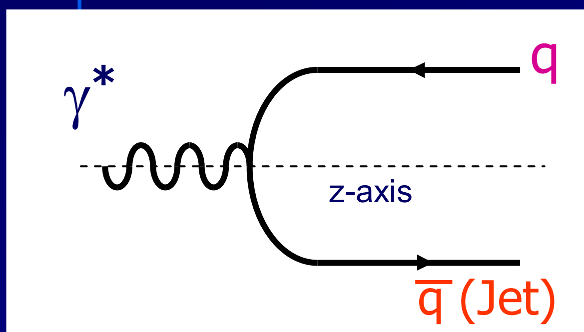



BGF

Inclusive cross-section for high-$E_T$ jets $\propto \alpha_s$.

Proton PDF determination.

# Why… The Breit Frame ?



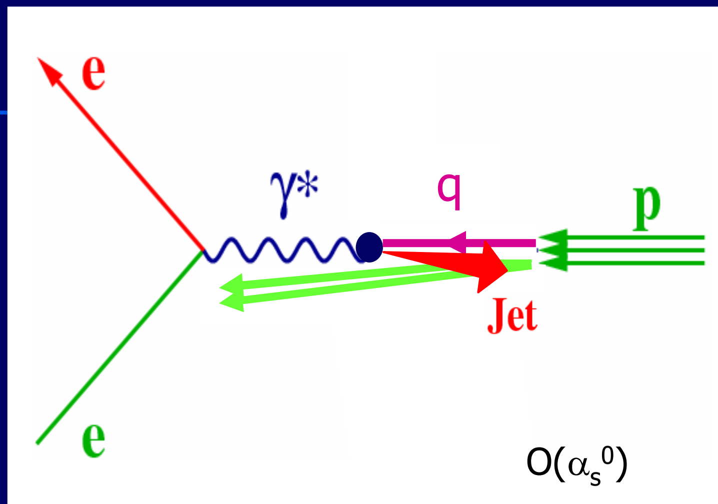

"Brick Wall"

Breit Frame (also known as the 'Brick Wall Frame') is that frame in which the struck quark and exchange photon collide head on such that:

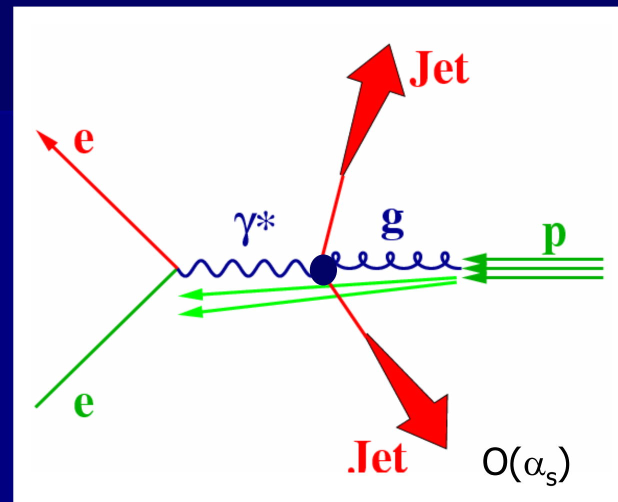
$$q + 2x_B P = 0$$

| | |
|---|---|
| P: | four-momentum of proton |
| $x_B$ : | proportion of P carried by struck quark (q) |
| $q$ : | four-momentum of exchange boson |

# Why… The Breit Frame ?




BREIT



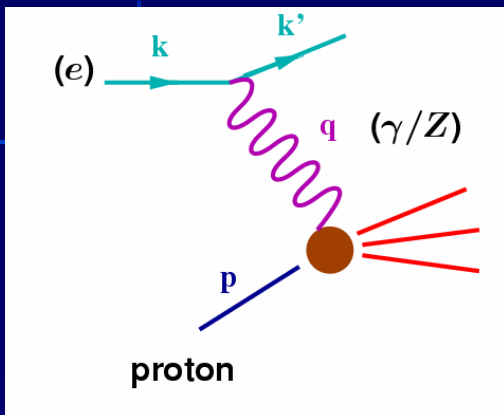

BREIT (BGF)

- ✓ One process, which has no $\alpha_s$ dependence, is completely suppressed by placing a cut on $E_T^B$, as the struck parton has close to zero $E_T^B$.
- ✓ The beam remnant also has close to zero $E_T^B$ and is likewise suppressed.

$E_T^B$: Energy transverse to $\gamma^*q$ axis in Breit Frame.

- ✓ Hence the lowest order non-trivial contributions to the jet cross sections are due to QCD Compton ($\gamma^*q \rightarrow gq$) and BGF ($\gamma^*g \rightarrow q\bar{q}$).
- ✓ These processes are directly sensitive to QCD hard processes, i.e. $\alpha_s$.

# Reconstruction of Events




A DIS event can be described by a number of event variables, the most common of which are defined thus:

$$Q^2 = -q^2 = -(k - k')^2$$

$$x = \frac{-Q^2}{2p\cdot q}$$

$$y = \frac{p\cdot q}{p\cdot k} = \frac{Q^2}{sx}$$

$Q^2$ is known as the virtuality of the exchange boson.

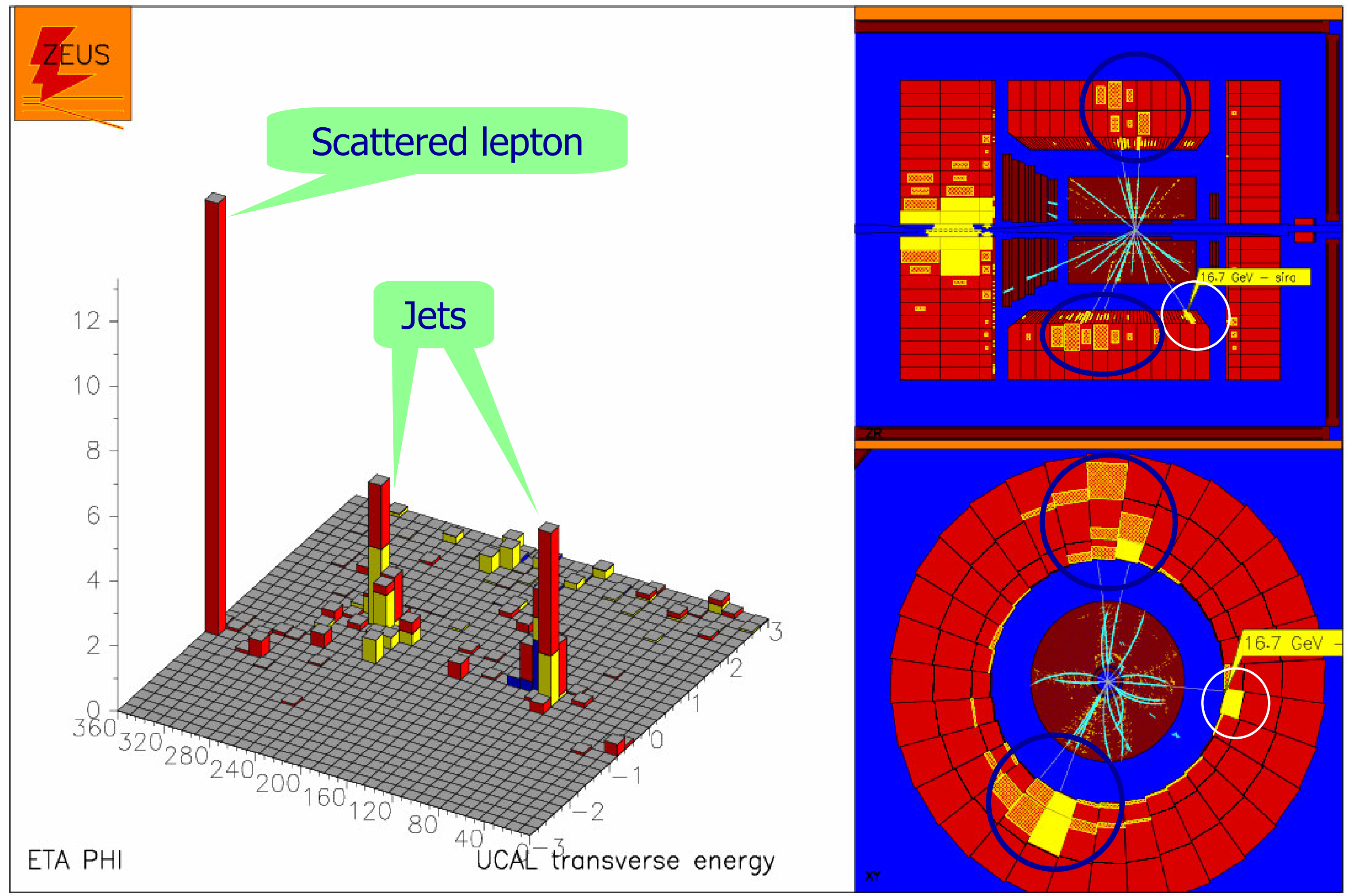
$x$ is the fraction of the proton momentum that is carried by the struck parton.

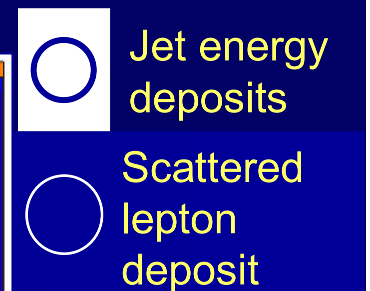
y is the inelasticity of the interaction.

$s$ is the (centre of mass energy)$^2$ of the event, $s$ = (318 GeV)$^2$.

Any DIS event is kinematically described if the value of any two event variables are known.

# Display of a 2-jet NC DIS Event




**Side View**

**End View**

# Jet Reconstruction

- Jets reconstructed from CAL cell energy deposits boosted into the Breit Frame.
- This is done by using the $k_T$ Cluster Algorithm.
- This is an iterative process:

  (i) For each pair of 'deposits', (i,j), a distance parameter, $d_{ij}$ is defined;
  (ii) For each 'deposit' a distance from the beam, $d_i$ is defined such that:

$$d_{ij} = \min(E_{T,i}, E_{T,j}) \cdot (\Delta\eta_{ij}^2 + \Delta\phi_{ij}^2) \qquad d_i = E_{T,i}^2$$

- The minimum value of all the $d_{ij}$ and $d_i$ is taken:

  - If this is a $d_{ij}$ (i.e. between two particles) then the two particles are combined to form a new 'particle' for the next iteration.
  The new particle parameters are found using the Snowmass convention:

$$E_{T,jet} = \sum_i E_{T,i} \qquad \eta_{jet} = \sum_i \frac{E_{T,i} \cdot \eta_i}{E_{T,jet}} \qquad \phi_{jet} = \sum_i \frac{E_{T,i} \cdot \phi_i}{E_{T,jet}}$$

  - If this is a $d_i$ then this particle is considered a 'jet' and removed from the sample.

- After each iteration, the number of particles is reduced by one.
- Process continues until all particles have been assigned to a 'jet'.

# Jet Reconstruction

$k_T$ Cluster algorithm has a number of advantages:

- ✓ It is infrared and collinear safe.
- ✓ It is not possible to get overlapping jets.
- ✓ Jet variables, $E_T$, $\eta$, $\phi$ are invariant under longitudinal boosts.

## Data Sample

- $e^+p$ data obtained by ZEUS Group during 99-00 running period.
- Luminosity: 65.1 $pb^{-1}$ $E_p = 920$ GeV $E_e = 27.5$ GeV
- Events selected in the kinematic range such that

**$Q^2 > 125\ GeV^2$**

**$-0.7 < \cos\gamma_h < 0.5$**

$\gamma_h$: angle of hadronic system wrt beam axis

- Jets selected such that

**$E_T^B > 8$ GeV**

**$-2.0 < \eta^B < 1.8$**

$\eta$: pseudorapidity

## Next-to-Leading Order (NLO) Calculations - *Theory*

- Theoretical predictions were obtained using DISENT to calculate same differential cross sections measured in data.
- PDF set: MRST99
- $\alpha_s(M_z) = 0.1175$
- Renormalization scale: $\mu_R = E_T^B(jet)$
- Factorization scale: $\mu_F = Q$

- Calculated cross sections are at the parton level, using $\gamma^*$ exchange.

  Corrections are required because
  (i) data results are presented at the hadron (QED Born) level,
  (ii) calculations do not take account of $Z^0$ exchange.

  Corrections are obtained using Monte Carlo simulations.

## NLO - *Theoretical Uncertainties*

The overall uncertainties in the NLO predictions were estimated in the following way:

(i) Uncertainties due to terms beyond $O(\alpha_s)$ (NLO) were estimated by varying the value $\mu_R$ by a factor of two higher and lower.

(ii) Uncertainties due to the PDFs were estimated by taking into account the experimental errors of the data sets used and the theoretical assumptions in the fits.

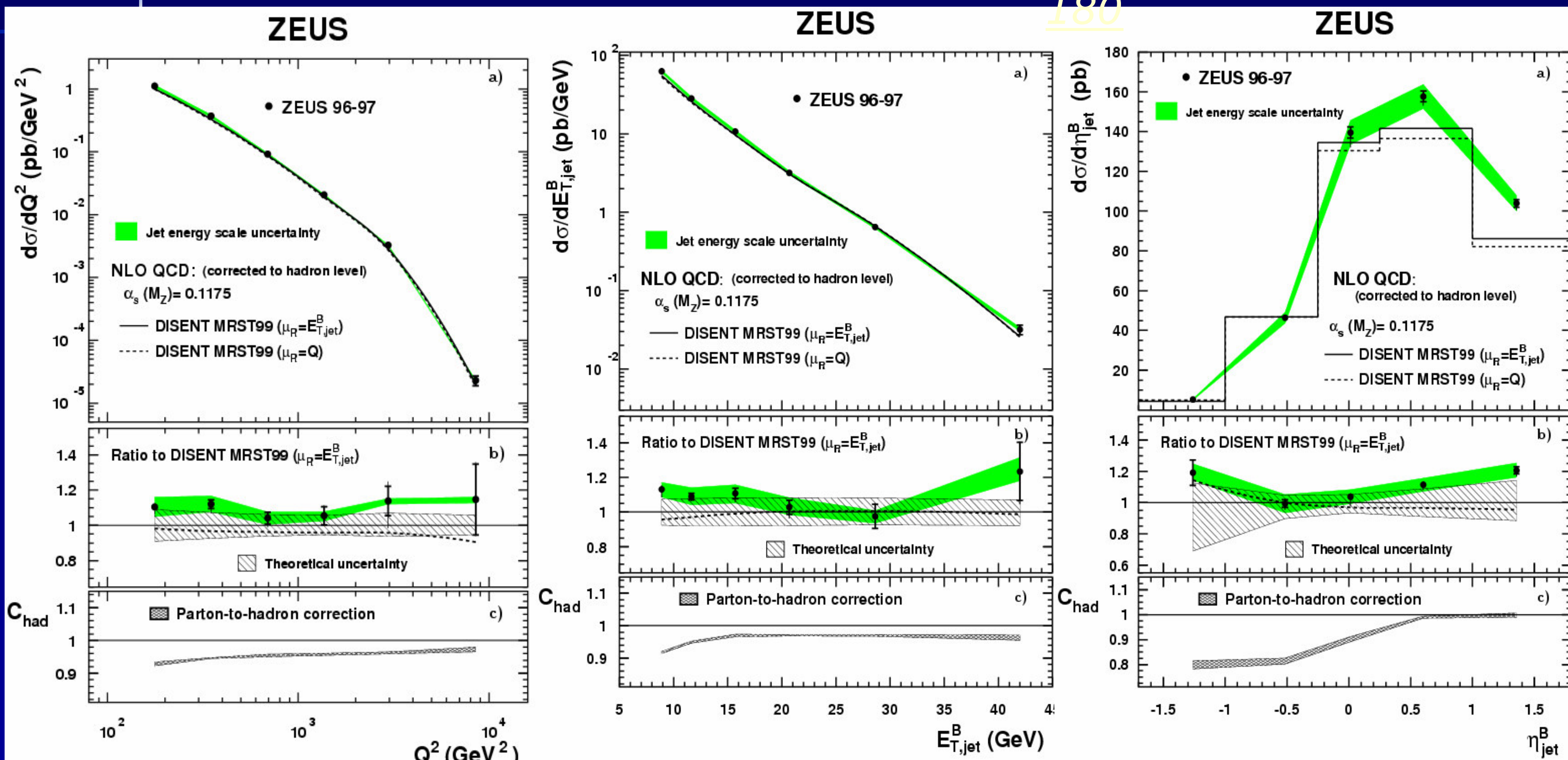
(iii) Uncertainties due to the value of $\alpha_s(M_z)$ were estimated by using the other two values for $\alpha_s(M_z)$ in the MRST99 PDFs.

# Previously Published Results

**Luminosity ≈ 38 $pb^{-1}$**

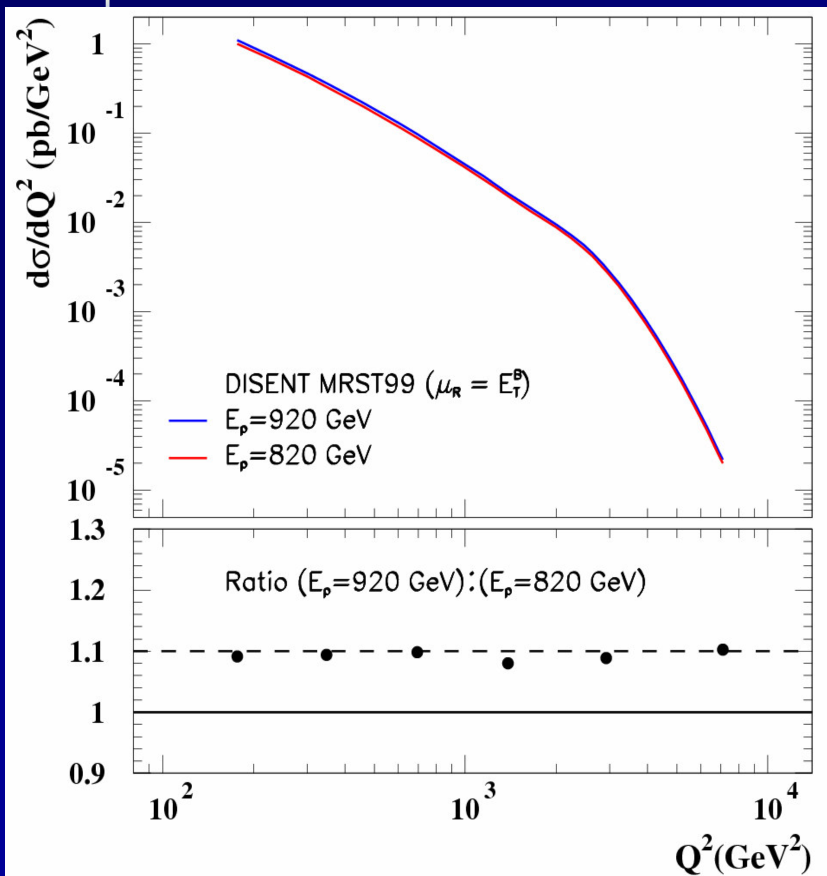
**$E_p$ = 820 GeV**

*Physics Letters B 547 (November 2002) 164-180*



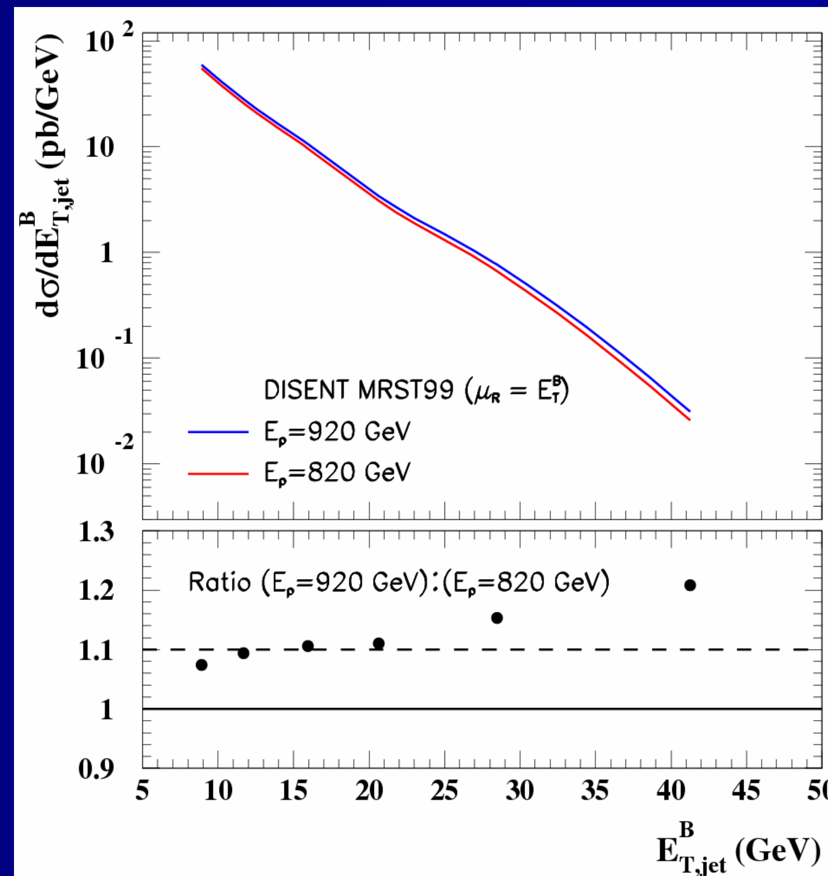
# Comparison of NLO Predictions for Different Proton Energies

Effect of beam energy:
~10% increase in differential cross section with the increased $E_p$.




$Q^2$

Effect of beam energy:
Steadily increasing effect on differential cross section with increased $E_p$.

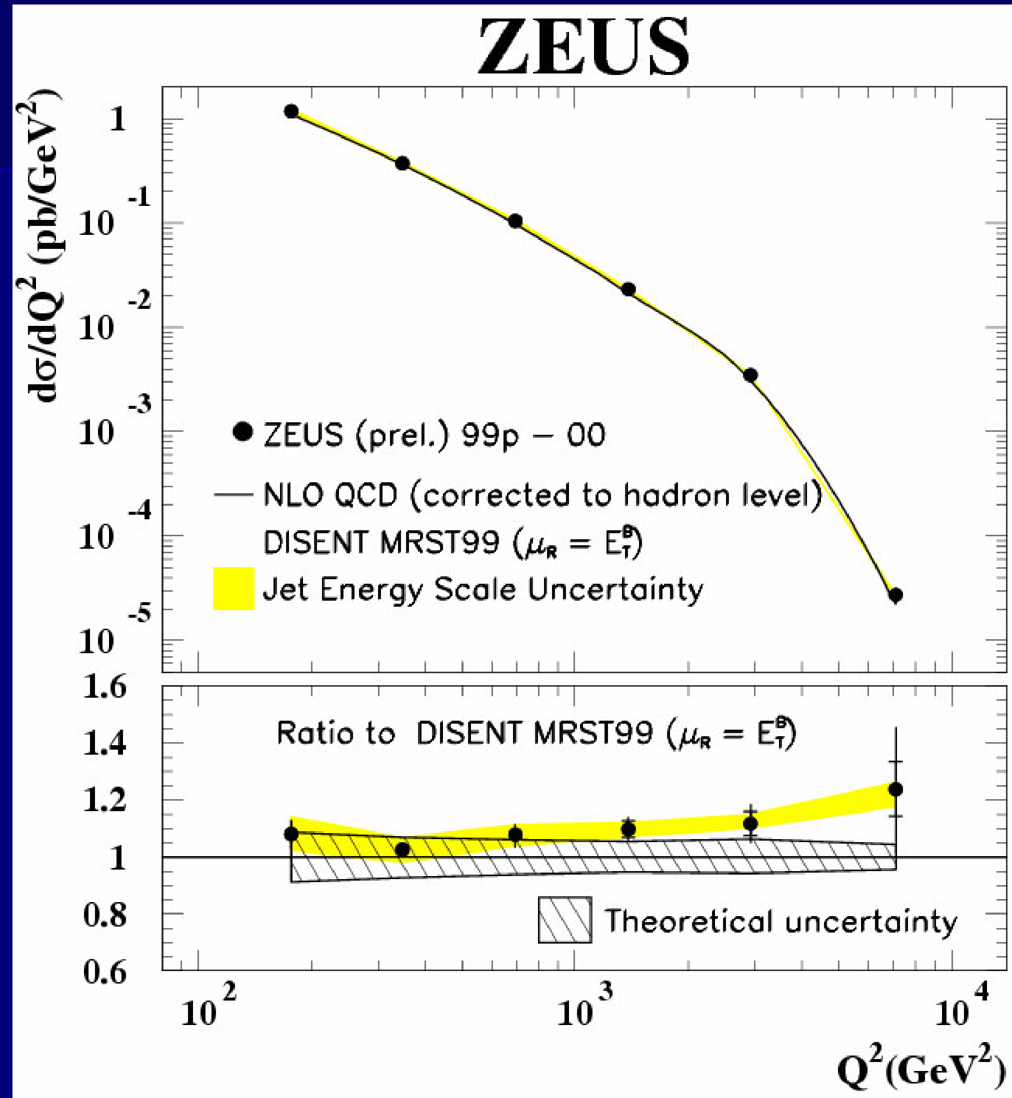



$E_T$(jet)

## Results: $Q^2$

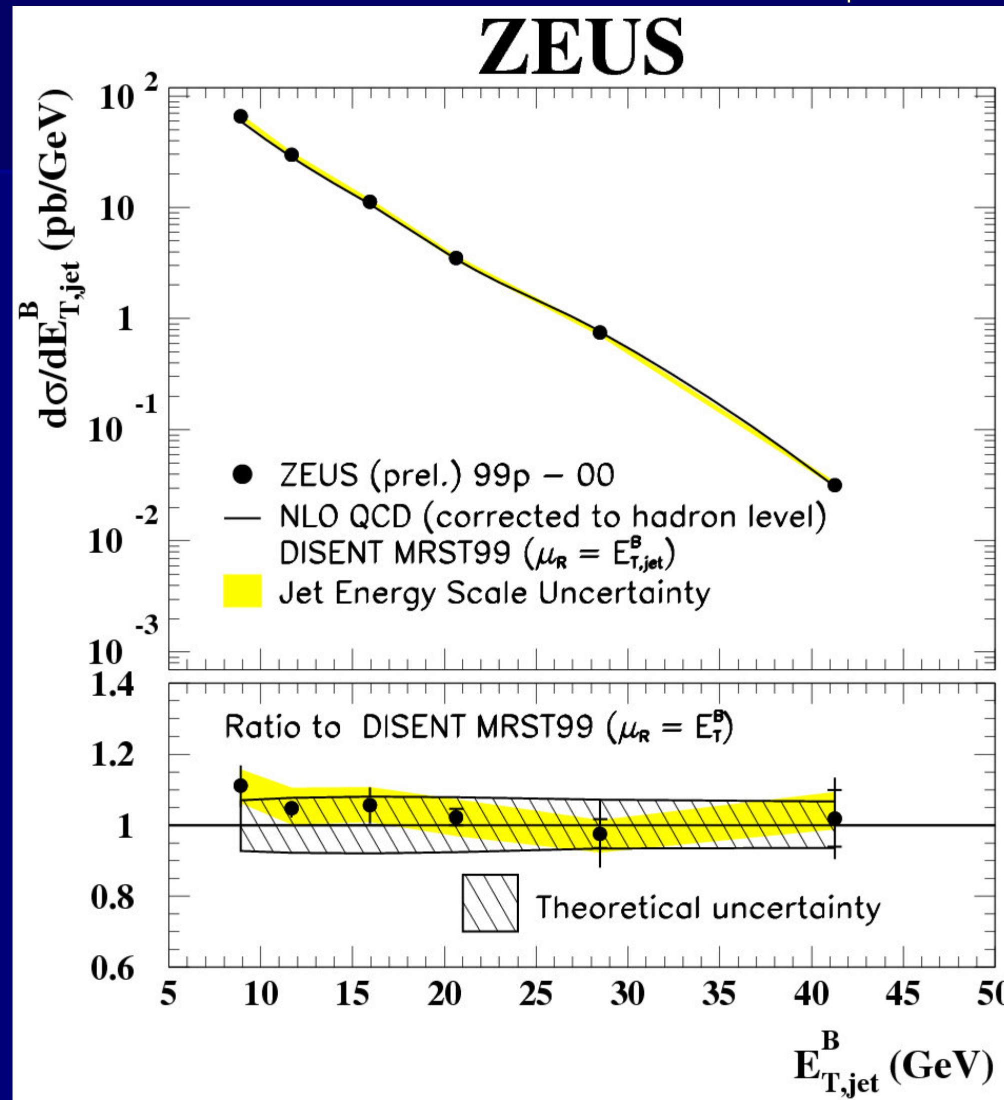
- Data points consistent with NLO prediction within the uncertainties.
- This measurement is directly sensitive to value of $\alpha_s(M_z)$ and the scale dependence of $\alpha_s$.

Differential cross section with respect to $Q^2$.



## Results: $E_T^B(jet)$

Differential cross section with respect to $E_T^B$(jet).

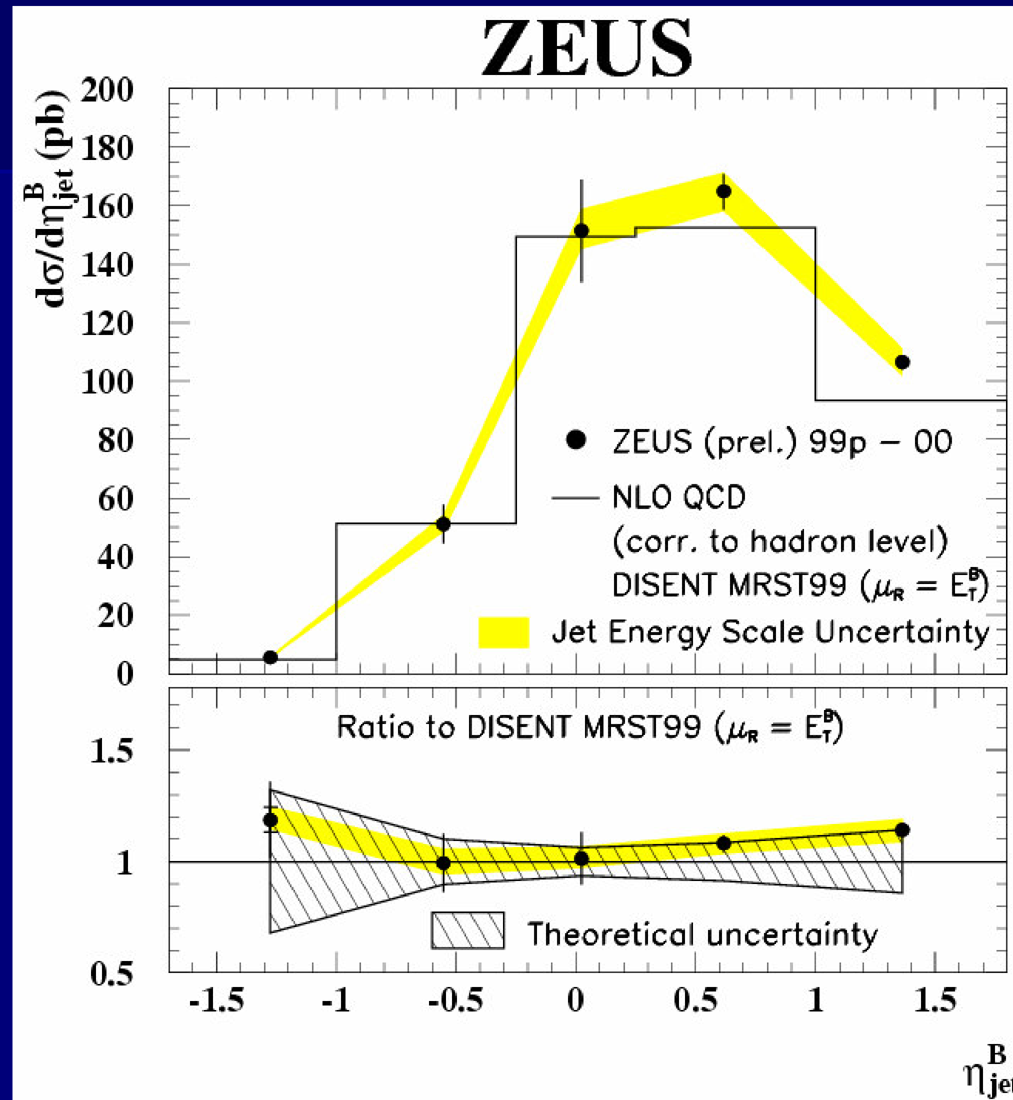



- Data points consistent with NLO prediction within the uncertainties.
- This measurement is directly sensitive to value of $\alpha_s(M_z)$ and the scale dependence of $\alpha_s$.

## Results: $\eta^B$*(jet)*

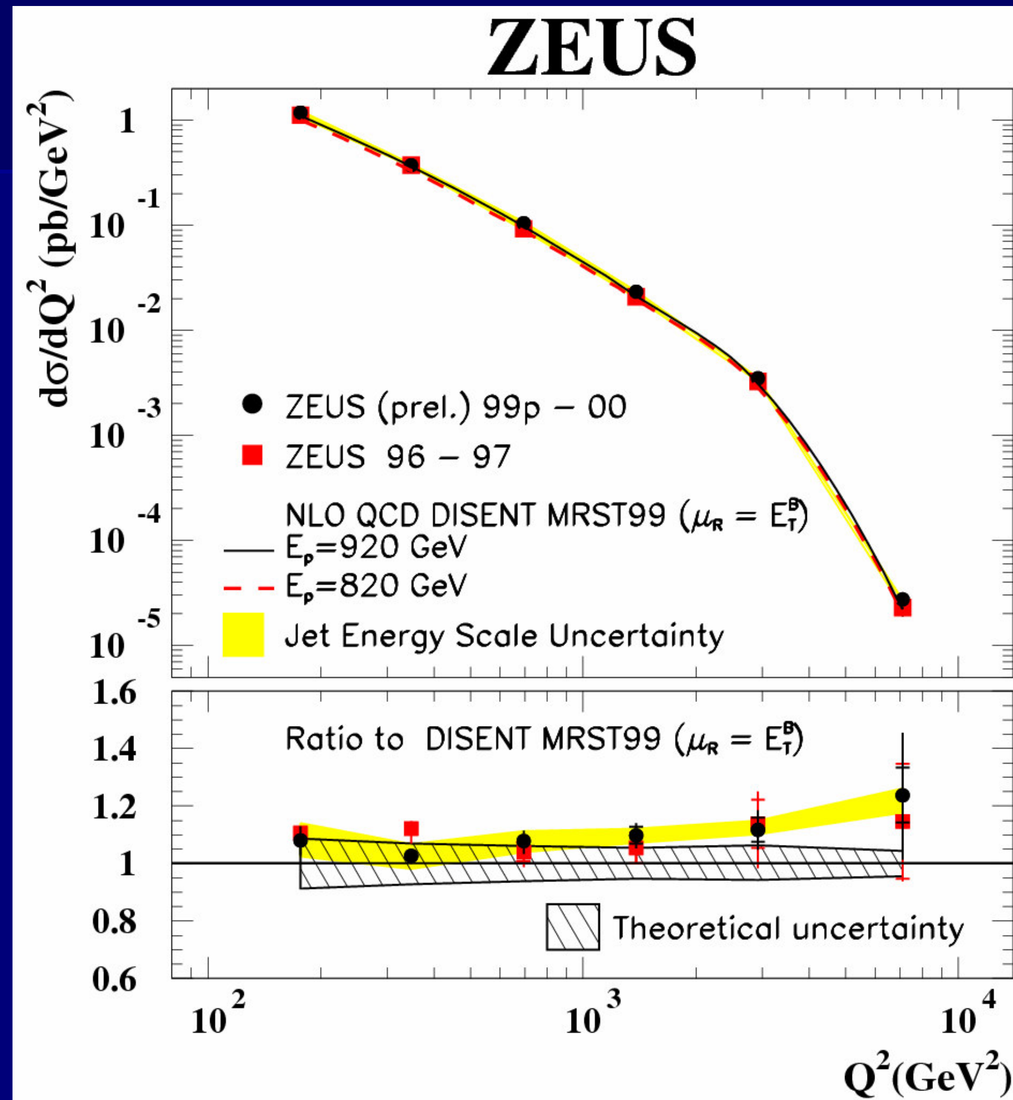
- Data points consistent with NLO prediction within the uncertainties.

Differential cross section with respect to $\eta^B$(jet).



# Results: *$Q^2$ Comparison*

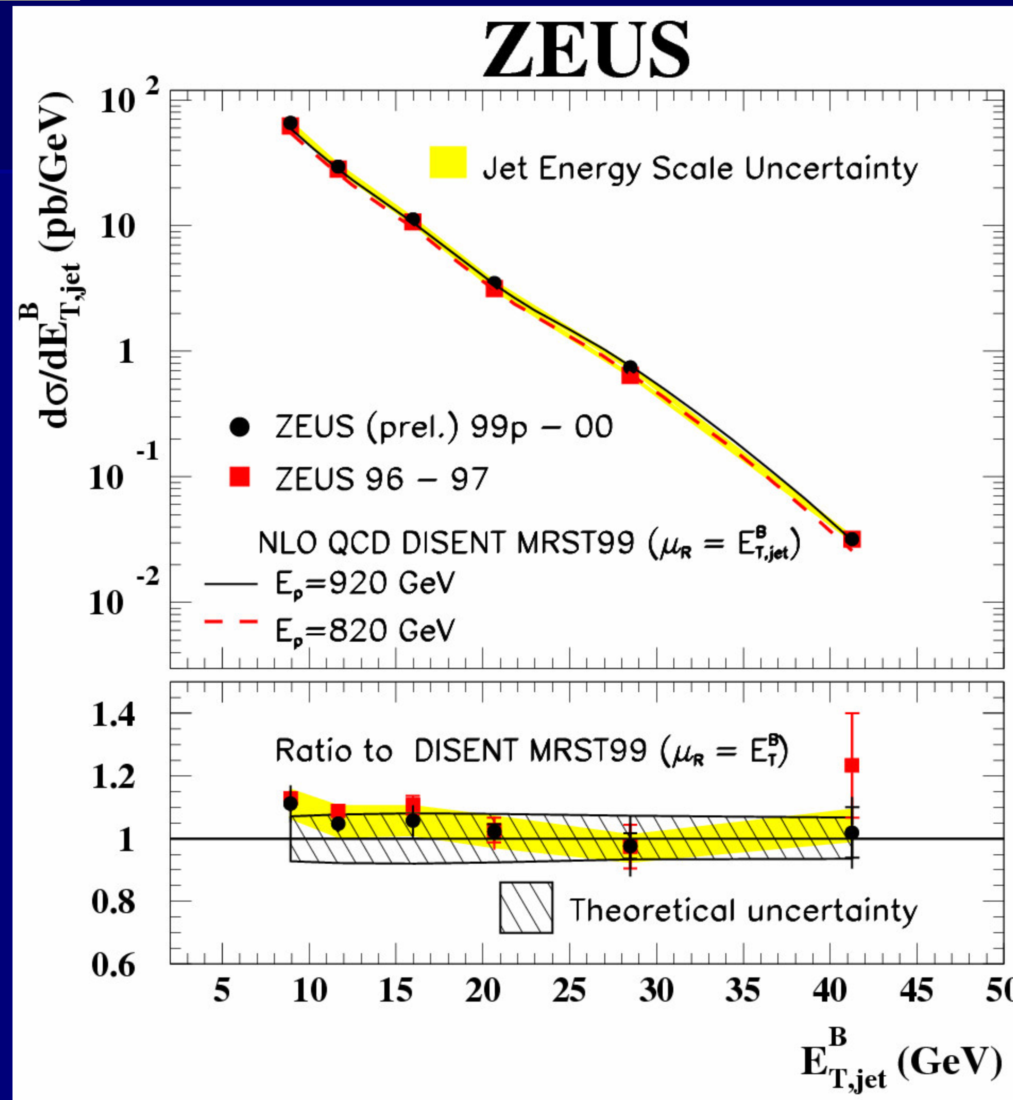
Differential cross section with respect to $Q^2$.




- 99-00 result agrees with 96-97 data points within the uncertainties.
- Results consistent with NLO prediction of ~10% increase in differential cross section.

## Results: $E_T^B$(jet) Comparison

Differential cross section with respect to $\eta^B$(jet).




- 99-00 result agrees with 96-97 data points within the uncertainties.
- Results consistent with NLO prediction of 10-20% increase in differential cross section.

## Summary

- Inclusive jet cross-sections have been measured for ZEUS 1999-2000 positron-proton data.
- The effect of increasing proton beam energy from 820 to 920 GeV is to increase differential cross section with respect to $Q^2$ by ~10%.
- The effect on the differential cross section with respect to $E_T^B$(jet) is to increase it by ~10% for $E_T^B$(jet) $\approx$ 10 GeV. This effect increases steadily with $E_T^B$(jet).
- Significantly reduced statistical errors with respect to the previously published analysis.
- Results agree well with previously published analysis.
- Differential cross-sections with respect to $Q^2$, $E_T^B$(jet) and $\eta^B$(jet) are well-described by NLO calculations, to within experimental and theoretical uncertainties.