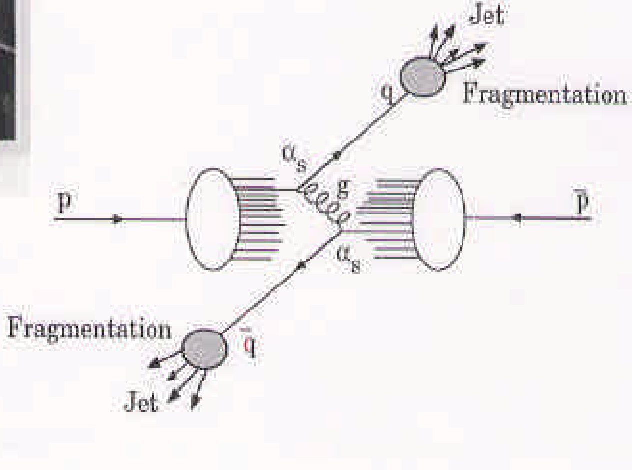
Jet Production at D0

Nikos Varelas

University of Illinois at Chicago

- rapidity dependence of inclusive jet cross section
- Inclusive jet cross section ratio: $\sigma(630)/\sigma(1800)$ vs X_T



Jets at Tevatron

Motivation:

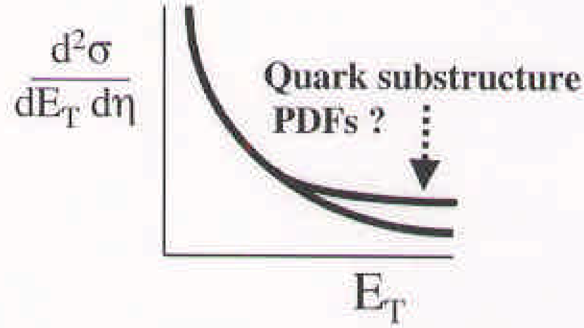
- Search for breakdown of the Standard Model at shortest distances
  - At Tevatron energies:

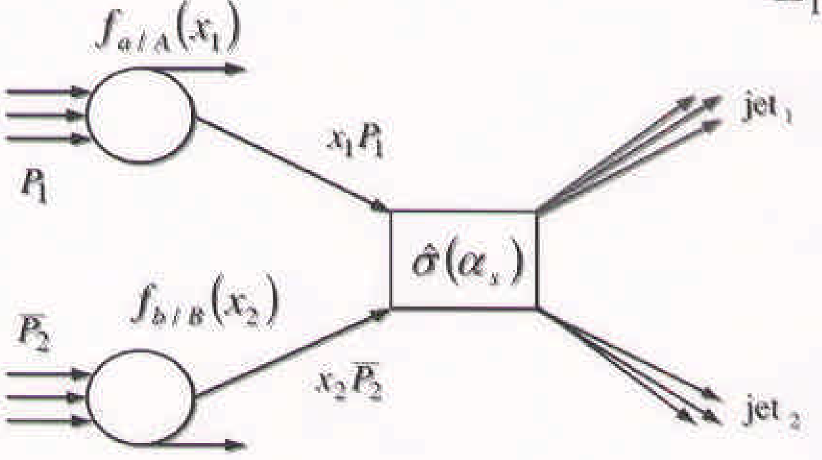
$$\boxed{\begin{array}{l} p_T^{\max} \sim 500\,GeV \\ \Rightarrow \text{distance} \sim \dfrac{\hbar c}{p_T} \sim \dfrac{200\,\text{MeV}\cdot\text{fm}}{500\,\text{GeV}} \sim 10^{-19}\,m \end{array}}$$

- Search for new particles decaying into jet final states
- Precision tests of QCD
  - inclusive jet production
    - cross sections vs rapidity, cross sections at different CM energies, jet shapes (quark vs gluon jets)...
  - dijet production
    - mass and triple differential cross sections, angular distribution, BFKL searches, diffraction...
  - multi-jets
    - cross sections, event topology, color coherence...
  - jets+vector bosons (γ, W, Z)
    - cross sections, angular distributions, color coherence...

Inclusive Jet Cross Section

- How well do we know proton structure (PDF)?
- Is NLO (α_s^3) QCD "sufficient"?
- Are quarks composite?



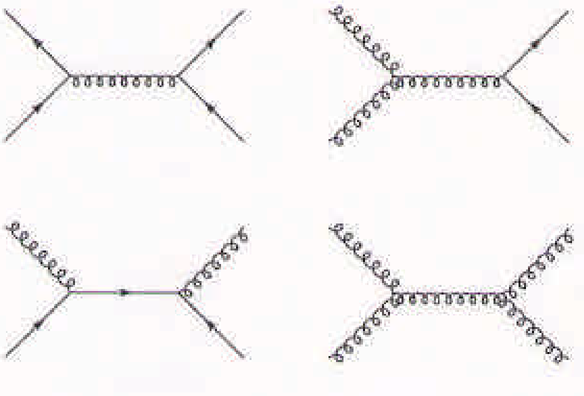


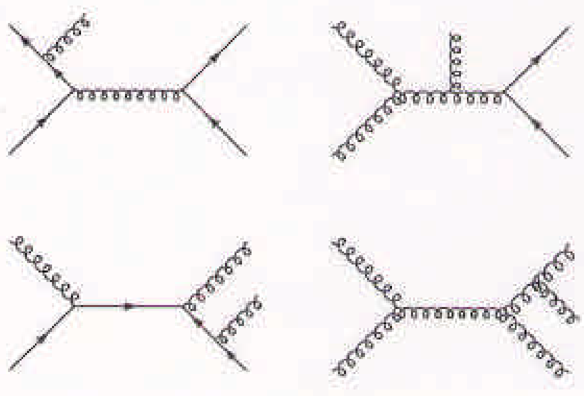
$$\frac{d\sigma}{dP_T} \approx \sum_{a,b} \int dx_a f_{a/A}(x_a,\mu) \int dx_b f_{b/B}(x_b,\mu) \frac{d\hat{\sigma}}{dP_T}$$

$$\frac{d\hat{\sigma}}{dP_T}(ab \to cd) \approx \sum_N \left(\frac{\alpha_s(\mu^2)}{\pi}\right)^N M_N$$

$\mathrm{LO} = O(\alpha_s^2)$

$\mathrm{NLO} = O(\alpha_s^2) + O(\alpha_s^3)$





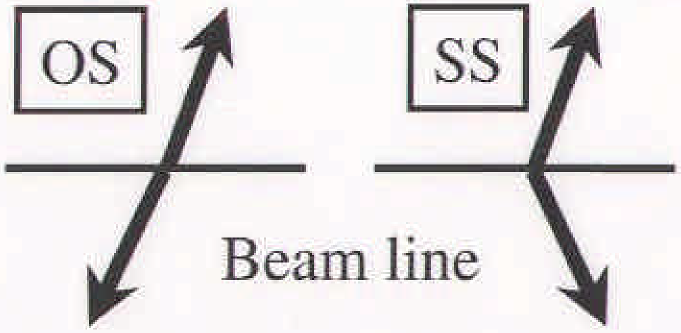
DØ Jet Cross Section Measurements

- **Inclusive Jet Cross Section** $|\eta|<0.5$, $|\eta|<0.7$ PRL 82, 2451 (1999)
- Dijet Mass Cross Section PRL 82, 2457 (1999)
- Dijet Angular Distribution PRL 80, 666 (1998)
- Ratio of Central Jet Cross Sections 630 (GeV)/1800(GeV) (preliminary)
- **Rapidity Dependent Analysis** (preliminary)

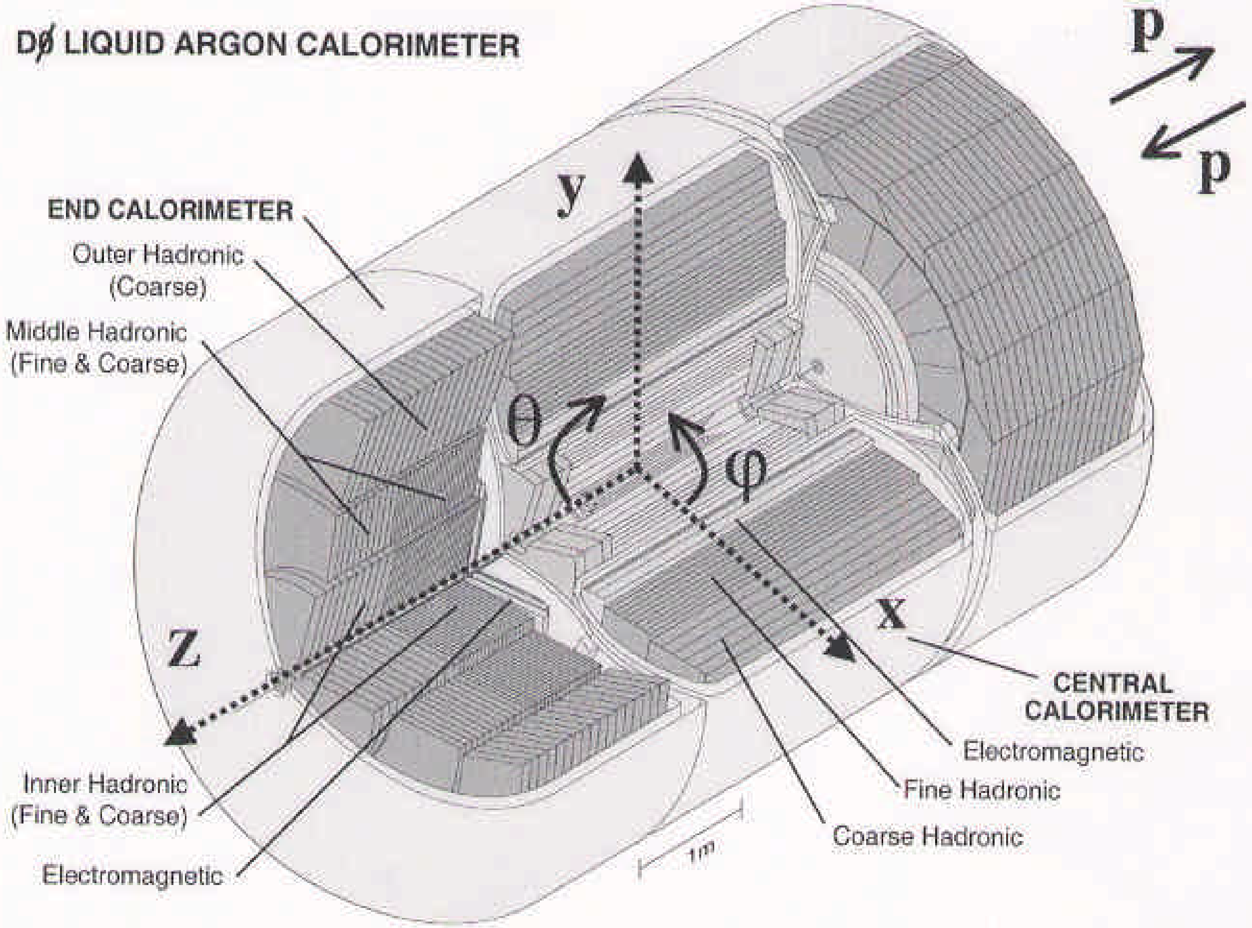
5 $|\eta|$ regions →

$0.0 \le |\eta| < 0.5$
$0.5 \le |\eta| < 1.0$
$1.0 \le |\eta| < 1.5$
$1.5 \le |\eta| < 2.0$
$2.0 \le |\eta| < 3.0$

- **Triple Differential Jet Cross Section** (preliminary)

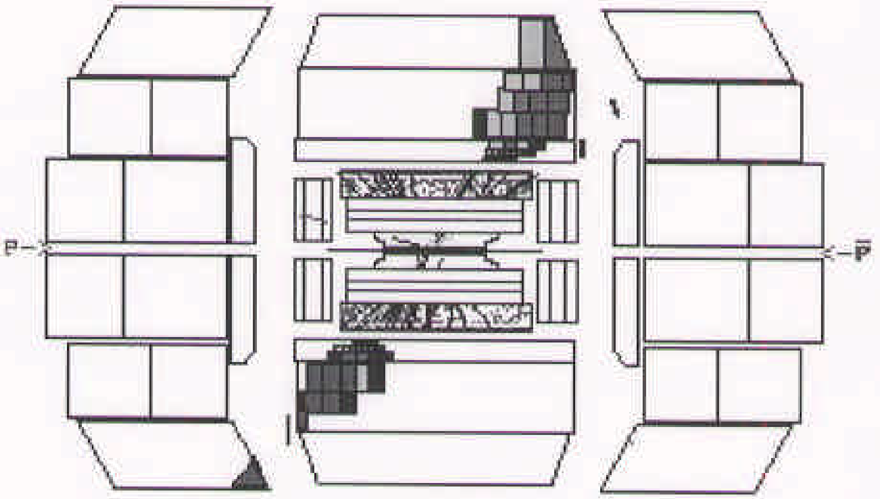


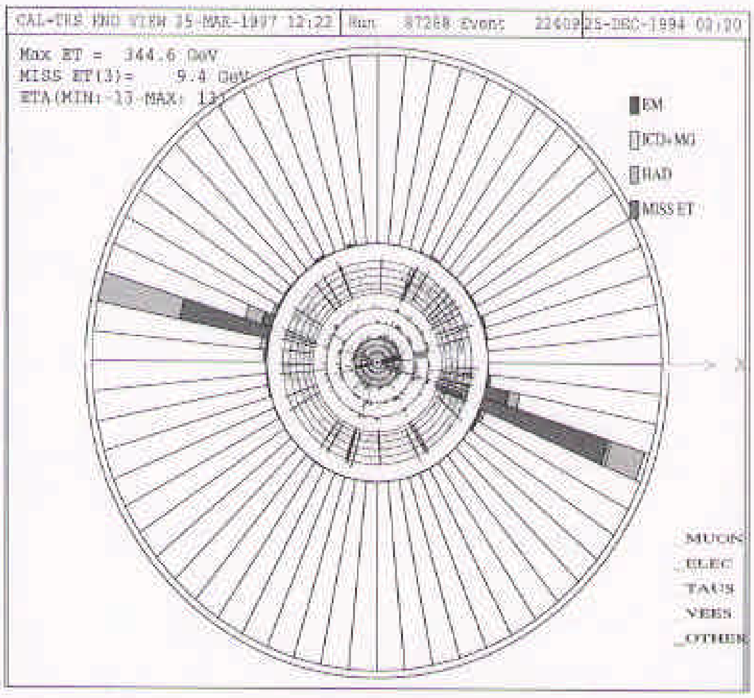
The DØ Calorimeter



- Hermetic with full coverage
  - $|\eta| < 4.2$ $\lambda_{int} > 7.2$ **(total)** $\eta = -\ln\tan\frac{\theta}{2}$
- Fine segmentation
  - **Towers of $\Delta\eta \times \Delta\varphi = 0.1 \times 0.1$**

High-E_T DØ Event





$E_{T,1} = 475$ GeV,
$\eta_1 = -0.69$, $x_1=0.66$
$E_{T,2} = 472$ GeV,
$\eta_2 = 0.69$, $x_2=0.66$

$M_{JJ} = 1.18$ TeV
$Q^2 = 2.2\text{x}10^5$ GeV^2

Data Samples

This Talk

Collider Run	D0 Luminosity
1992-93 @ 1800 GeV	13 pb^{-1}
1994-95 @ 1800 GeV	95 [redacted] pb^{-1}
Dec 1995 @ 630 GeV	0.5 pb^{-1}

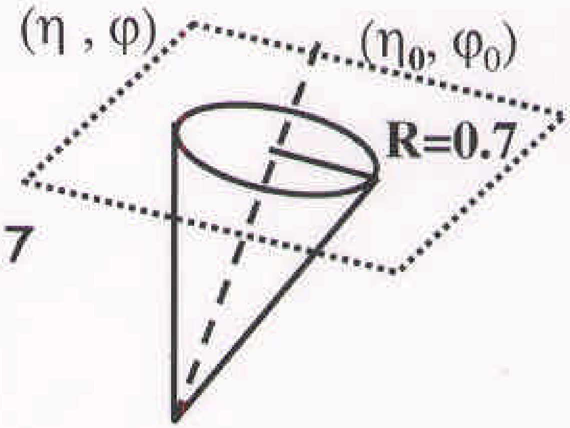
Calorimeter Trigger

Localized energy deposition: $E_T > E_T^{threshold}$
with variable thresholds

Event & Jet Selection

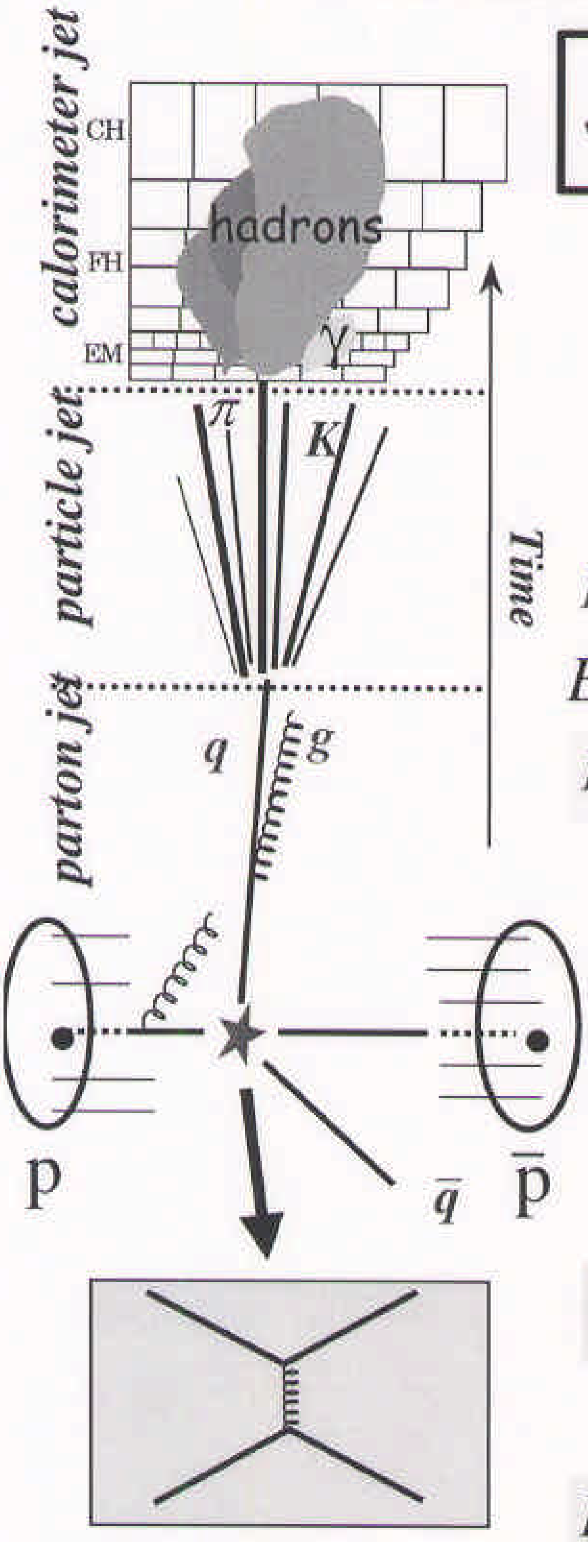
- Eliminate events with large $\not{E}_T$
- Apply jet quality cuts
- Vertex cut $|z| < 50$ cm
- Fixed Jet Cone Algorithm
  - Iterative algorithm R = 0.7
  - **Add up calorimeter towers**

$$E_T^{jet} = \sum_{R_i \leq 0.7} E_T^{tower}$$



Jet Energy Scale

NIM A424 352-392 (1999) (hep-ex/9805009)



Jet energy scale correction: "calorimeter" → "particle" jet

$$E^{ptcl} = \frac{E^{meas} - E_O}{R_{jet} \; R_{OOC}}$$

E^{ptcl} **"True" Jet Energy**

E^{meas} **Measured Jet Energy**

E_O **Offset** (Ur noise, Mult. Int., pile-up, UE)

- **At 1800 GeV**
  UE corresponds to E_T~0.9GeV under a R=0.7 jet cone
- **At 630 GeV**
  UE corresponds to E_T~0.6GeV under a R=0.7 jet cone

R_{jet} **Calorimeter Jet Response**
Measured in situ using γ − Jet P_T balance

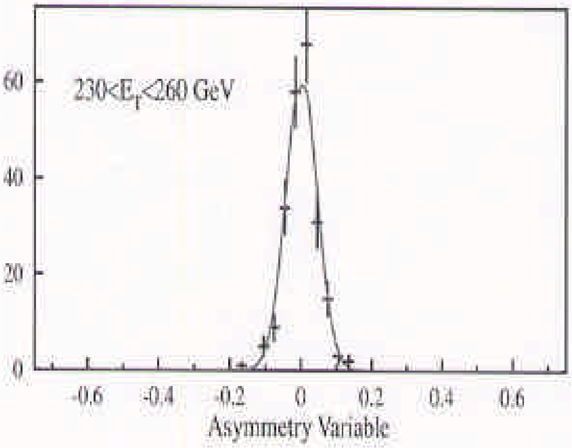
R_{OOC} **Out of Cone Calorimeter Showering**

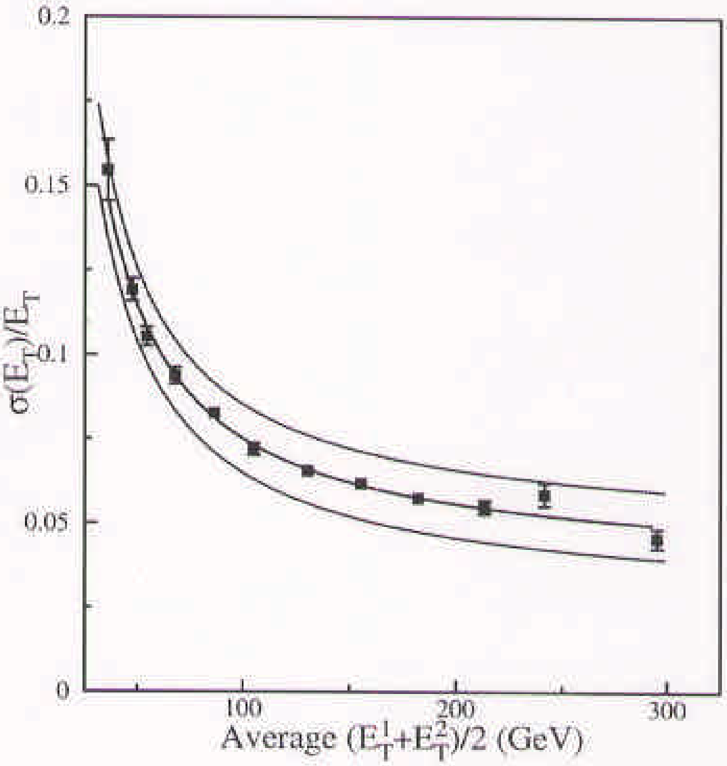
Jet Energy Resolution

- **Measured from dijet collider data using E_T balance:**

$$\boxed{A = \frac{E_{T1} - E_{T2}}{E_{T1} + E_{T2}}} \Longrightarrow \boxed{\frac{\sigma_{ET}}{E_T} = \sqrt{2}\sigma_A}$$

In the limit of no soft radiation





- **Unsmearing procedure:**
  - **convolute "true cross section" $f(E_T)$ with a Gaussian smearing**

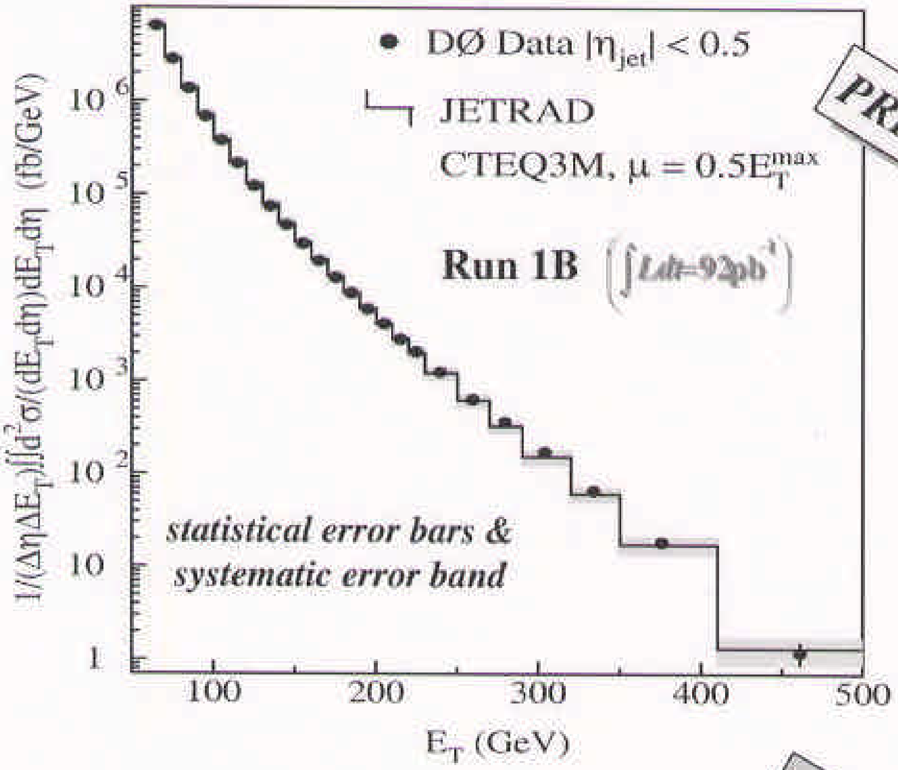
$$\boxed{F(E_T) = \int \frac{1}{\sqrt{2\pi}\sigma} e^{\frac{-(E'_T - E_T)^2}{2\sigma^2}} \cdot f(E'_T)\, dE'_T} \quad \boxed{f(E'_T) = A E'^{\,-B}_T \left(1 - \frac{2E'_T}{\sqrt{s}}\right)^C}$$

  - **Fit $F(E_T)$ to the data cross section**

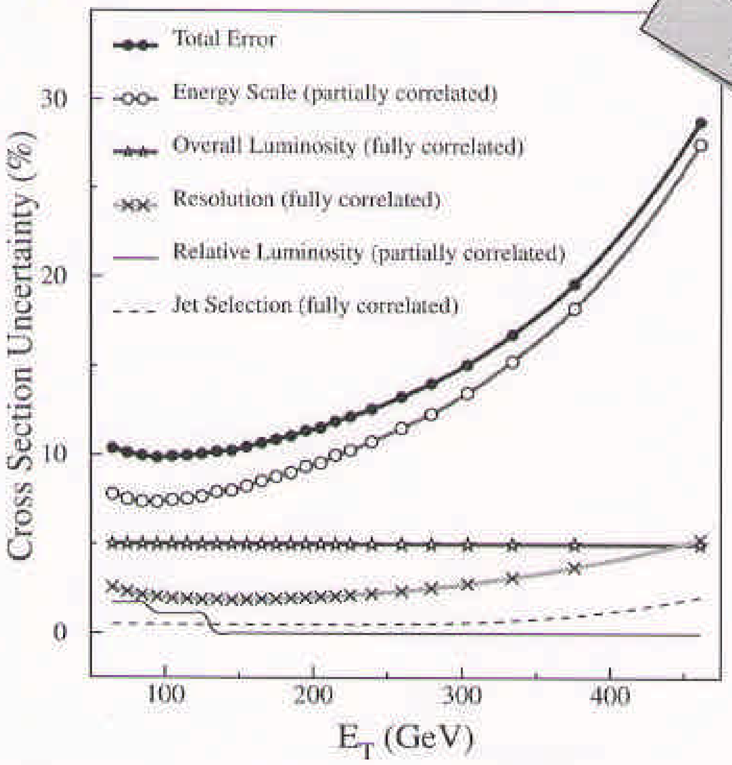
Central Inclusive Jet Cross Section

$(\sqrt{s} = 1800\ \text{GeV})$

PRL 82, 2451 (1999)



Uncertainties



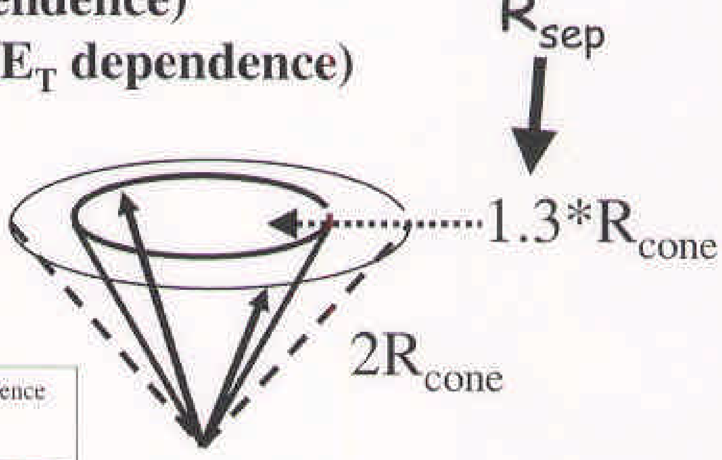
Nikos Varelas ICHEP OSAKA 2000

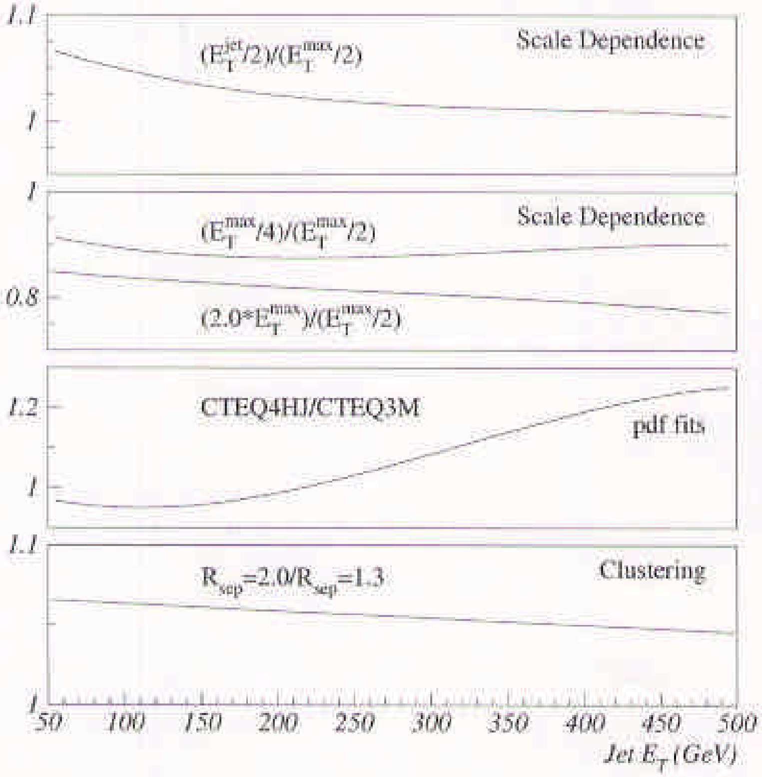
Theoretical Predictions

- **NLO QCD predictions (α_s^3) :**
  Ellis, Kunszt, Soper, Phys. Rev. D, 64, (1990) EKS
  Aversa, et al., Phys. Rev. Lett., 65, (1990)
  Giele, Glover, Kosower, Phys. Rev. Lett., 73, (1994) JETRAD

- **Choices (hep-ph/9801285, Eur. Phys. J. C. 5, 687 1998):**
  Renormalization Scale (10%)
  PDFs (~20% with E_T dependence)
  Clustering Alg. (5% with E_T dependence)

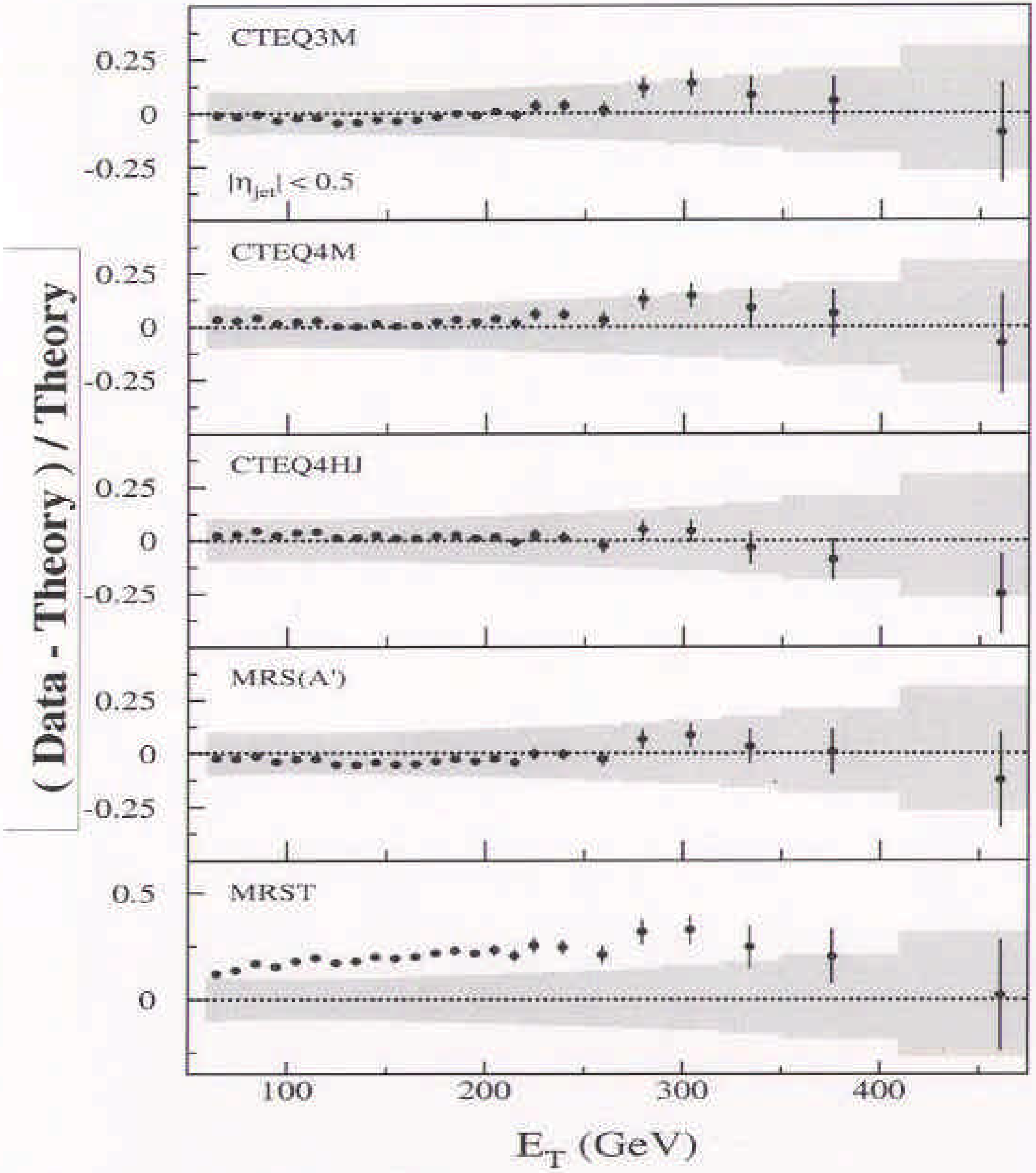
Jet Clustering Algorithm at NLO →





DØ uses: JETRAD
$\mu = 0.5E_T^{Max}$, $R_{sep}=1.3$

Comparisons to Theory



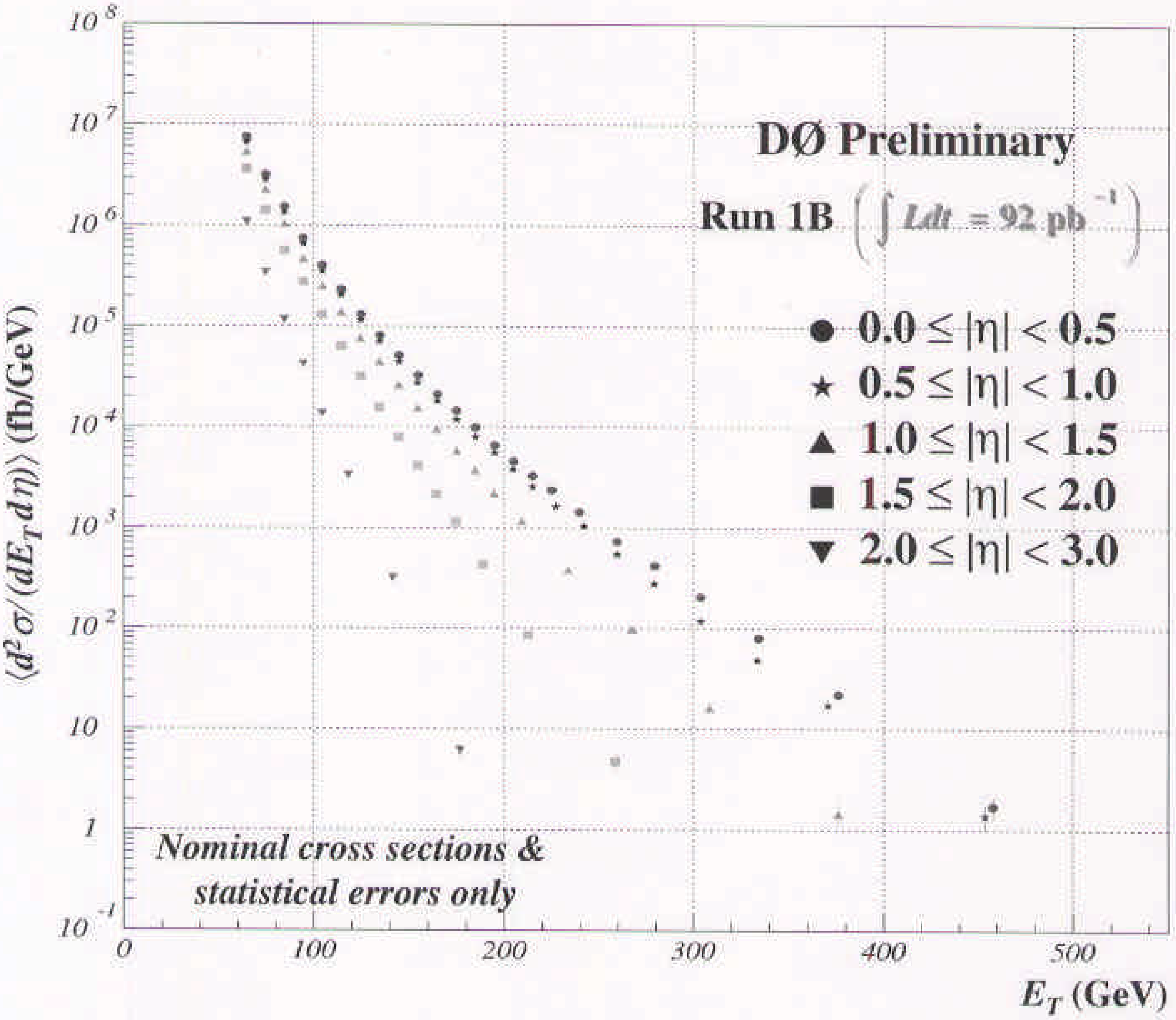
$$\chi^2 = \sum_{i,j} (D_i - T_i) \times \left[\mathrm{Cov}_{i,j}^{\mathrm{Full}}\right]^{-1} \times (D_j - T_j)$$

$$\mathrm{Cov}_{i,j}^{\mathrm{Full}} = \sum_{\beta}^{\mathrm{errors}} \rho_{i,j}^{\beta} \times \sigma_i^{\beta} \times \sigma_j^{\beta}$$

PDF	$0.0 \le \|\eta\| \le 0.5$	$0.1 \le \|\eta\| \le 0.7$
CTEQ3M	26.1 (35%)	33.2 (10%)
CTEQ4M	20.5 (67%)	27.2 (30%)
CTEQ4HJ	16.6 (86%)	22.3 (56%)
MRSA'	20.8 (65%)	28.8 (23%)
MRST	25.2 (40%)	29.5 (20%)
MRSTg↑	21.5 (61%)	30.1 (18%)
MRSTg↓	47.3 (0.003%)	47.5 (0.003%)

Rapidity Dependence of Inclusive Jet Cross Section

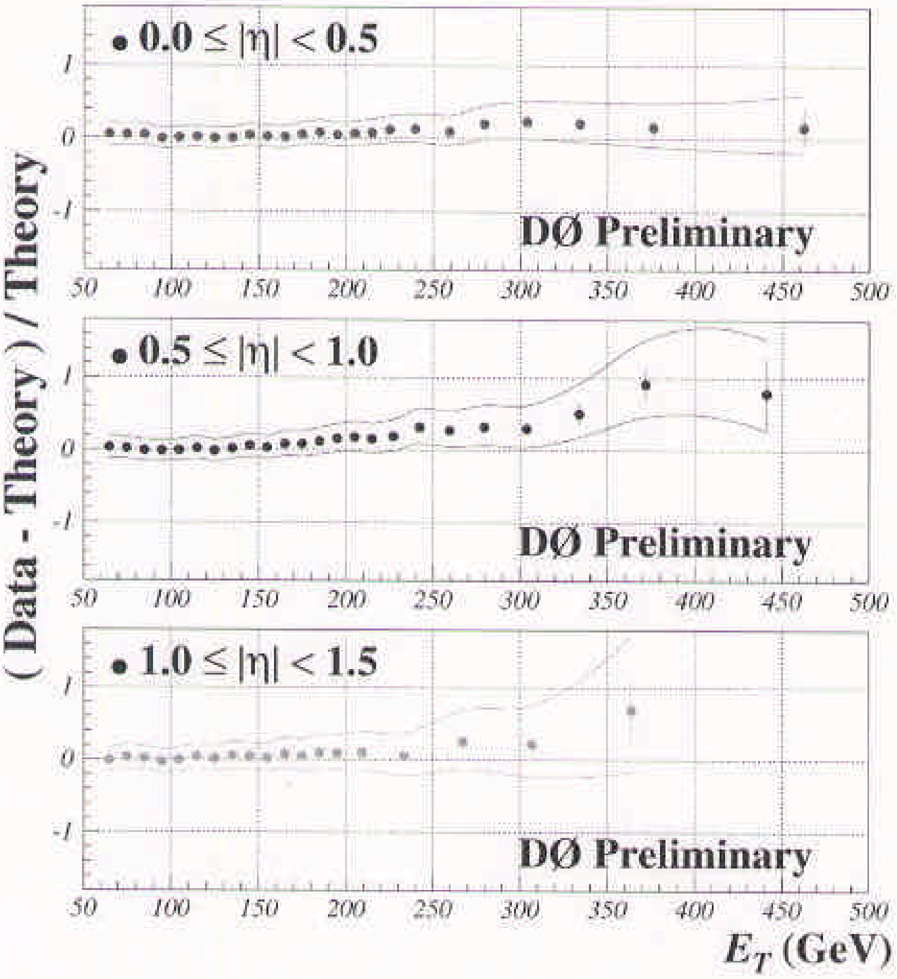
$\left(\sqrt{s} = 1800\,\text{GeV}\right)$



DØ inclusive cross sections up to $|\eta| = 3.0$

Comparisons to Theory

$\left(\sqrt{s} = 1800\ \text{GeV}\right)$

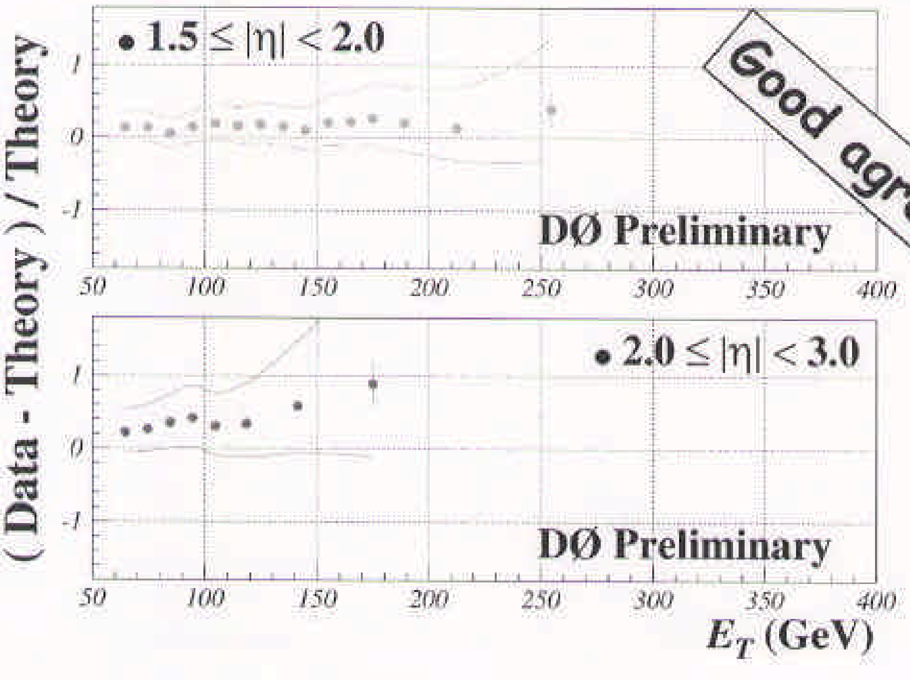


Comparisons to JETRAD with:

PDF: CTEQ4M

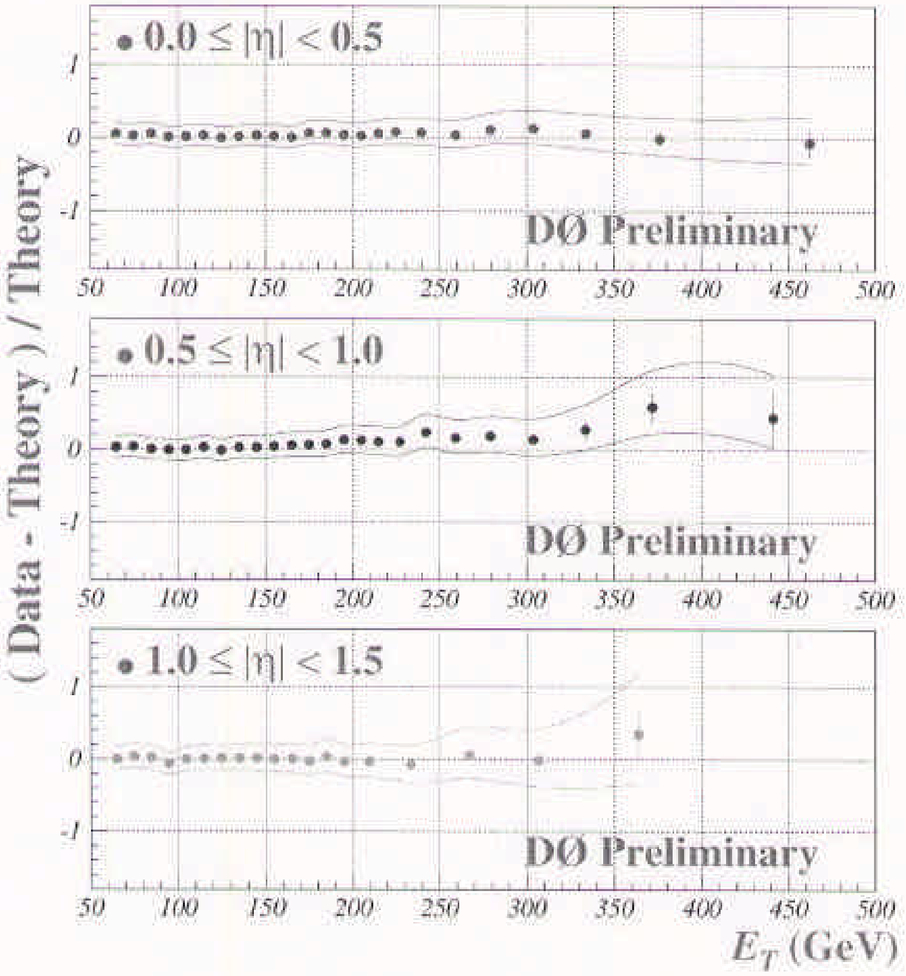
$$\mu = E_T^{\max}/2$$

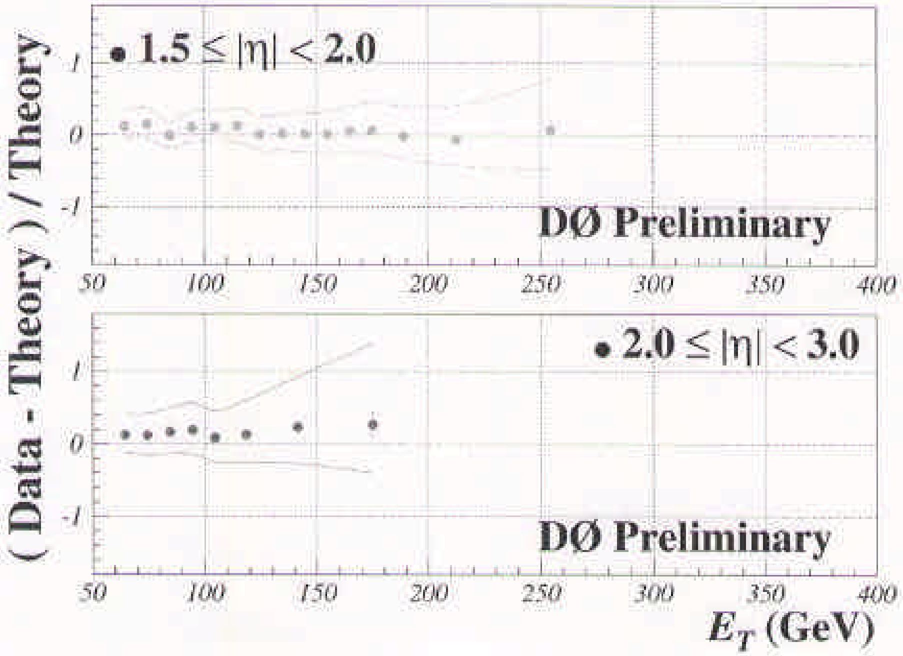
$R_{sep} = 1.3$



Good agreement with NLO QCD

Comparisons to Theory





$\left(\sqrt{s} = 1800\,\mathrm{GeV}\right)$

Comparisons to JETRAD with:

PDF: CTEQ4HJ

$$\mu = E_T^{\max}/2$$

$R_{sep} = 1.3$

CTEQ4HJ appears to produce better agreement with the data.

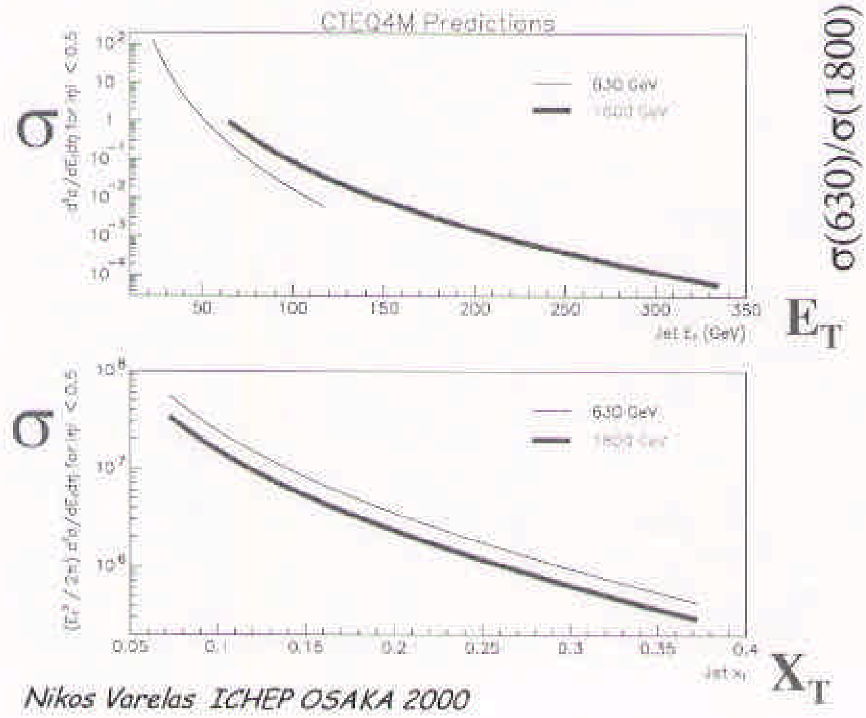
Work is underway to obtain a quantitative measure of agreement.

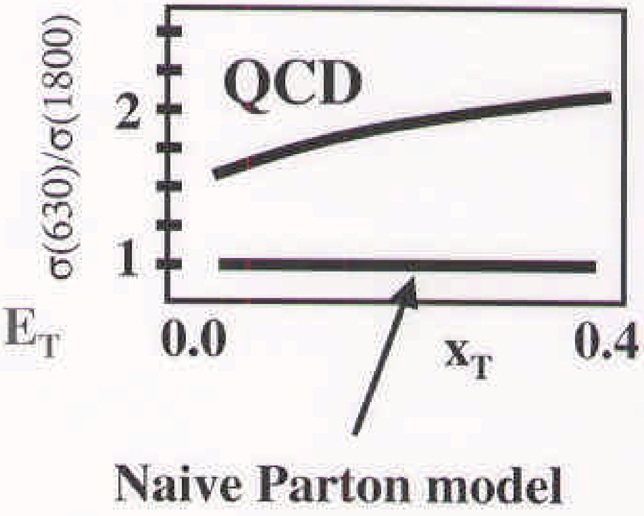
Inclusive Jet Cross Section Ratio: σ(630)/σ(1800) vs X_T

- Cross Section Scaling
  - At Born level ($\mathcal{O}(\alpha_s^2)$) :
- Scaling violations
  - PDFs, $\alpha_s(Q^2)$
- Ratio of the scale invariant cross sections at different CM energies
  - Ratio allows subrtantial reduction in uncertainties (in theory and experiment)

$$\boxed{E\frac{d^3\sigma}{dp^3} = \frac{1}{p_T^4} f(x_T) \qquad \text{where } x_T = \frac{2p_T}{\sqrt{s}}}$$

$$R(x_T) \equiv \frac{p_T^4 \cdot E\dfrac{d^3\sigma}{dp^3}(\sqrt{s} = 630\,\text{GeV})}{p_T^4 \cdot E\dfrac{d^3\sigma}{dp^3}(\sqrt{s} = 1800\,\text{GeV})} \sim 1 + \text{scaling violating terms}$$

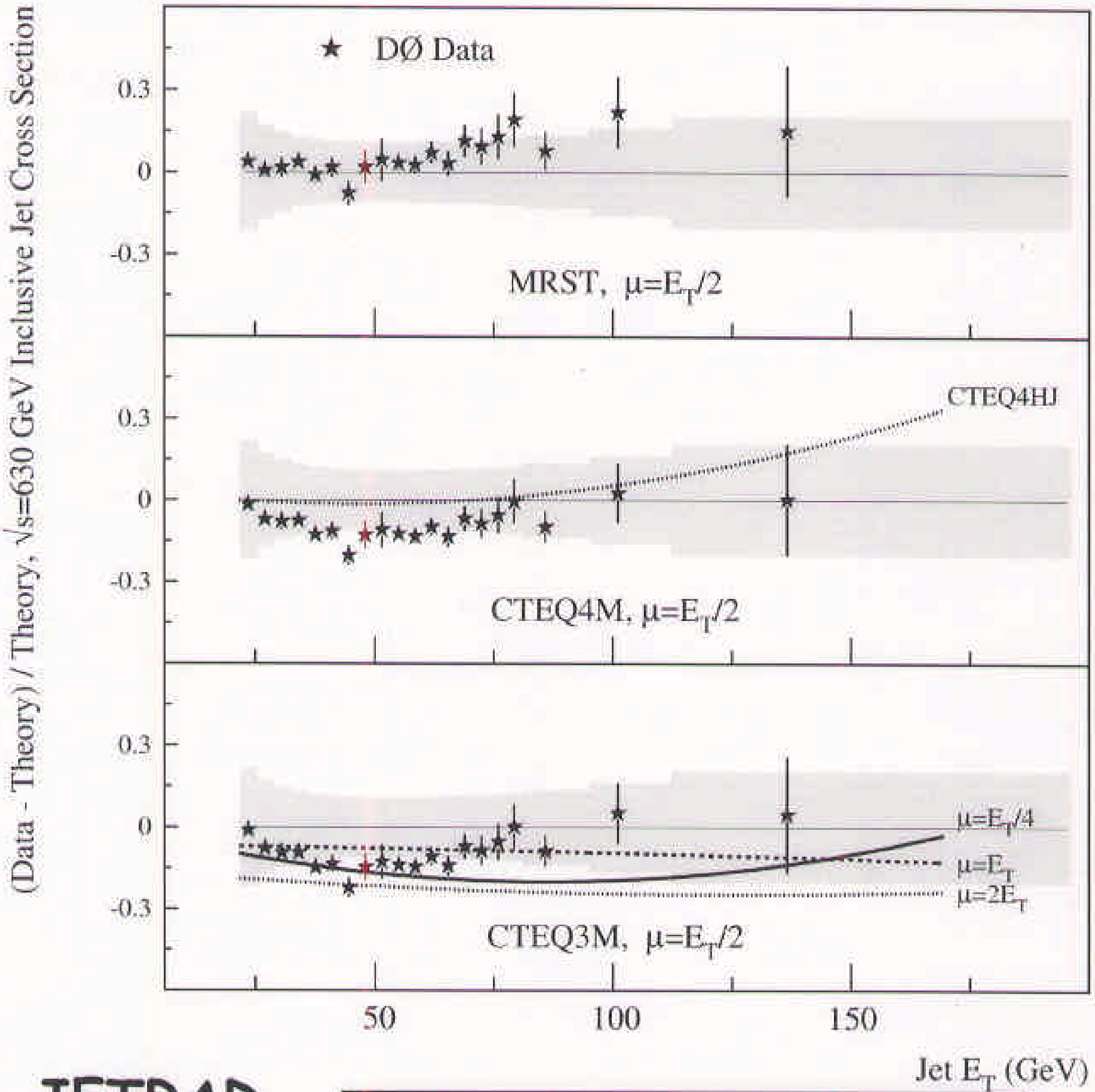




Comparisons to Theory

$\left(\sqrt{s} = 630\,\mathrm{GeV}\right)$

$|\eta| < 0.5$



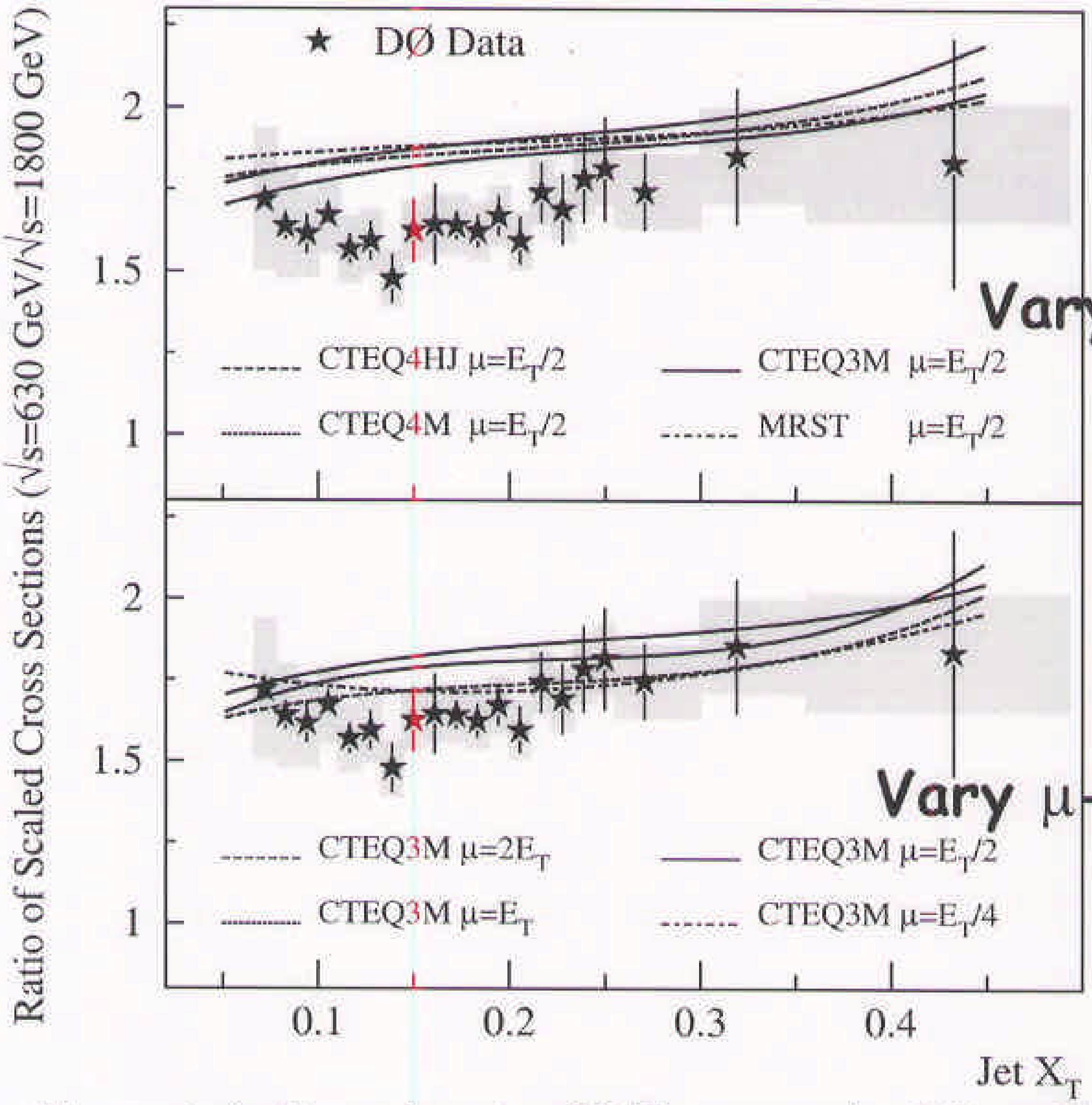
JETRAD

$$\mu = E_T^{\max}/2$$

$R_{sep} = 1.3$

PDF	χ^2 (20 dof)	Prob(%)
CTEQ3M	30.4	6.37
CTEQ4M	24.1	23.8
CTEQ4HJ	18.9	52.5
MRST	22.6	30.7

$\sigma(630)/\sigma(1800)$ vs X_T



Vary PDF

Vary μ-scale

- Uncertainties due to PDF's are significantly reduced in the ratio
- Better agreement with NLO QCD in shape than in normalization

PDF	χ^2 (20 dof)	Prob(%)
CTEQ3M	20.5	42.5
CTEQ4M	22.4	31.9
CTEQ4HJ	21.0	40.0
MRST	22.2	33.0

Summary

- DØ has measured the inclusive jet cross section in $p\bar{p}$ collisions at 630 GeV and 1800 GeV CM energies and their ratios
  - testing pQCD over large dynamic range and at highest Q^2
- Measurements show overall good agreement with NLO pQCD
  - The ratio of the dimensionless cross sections at 630 and 1800 GeV CM energies show disagreement in normalization with NLO
- Recently, DØ has significantly extended the η reach of the inclusive jet cross section measurement up to $|\eta| = 3.0$
  - Work is underway to understand error correlations in E_T and η in order to obtain a quantitative measure of agreement between this new measurement and pQCD predictions.