PDF Implications of the Tevatron High E_T and η Jet Rates

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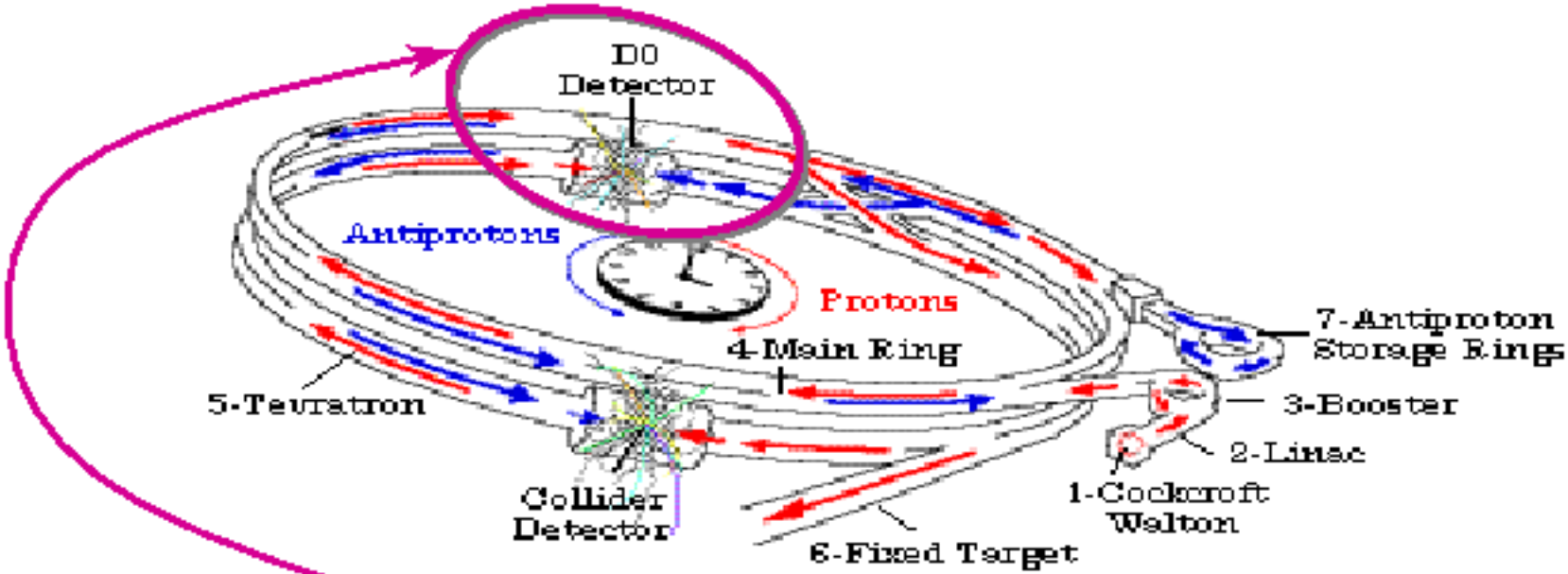
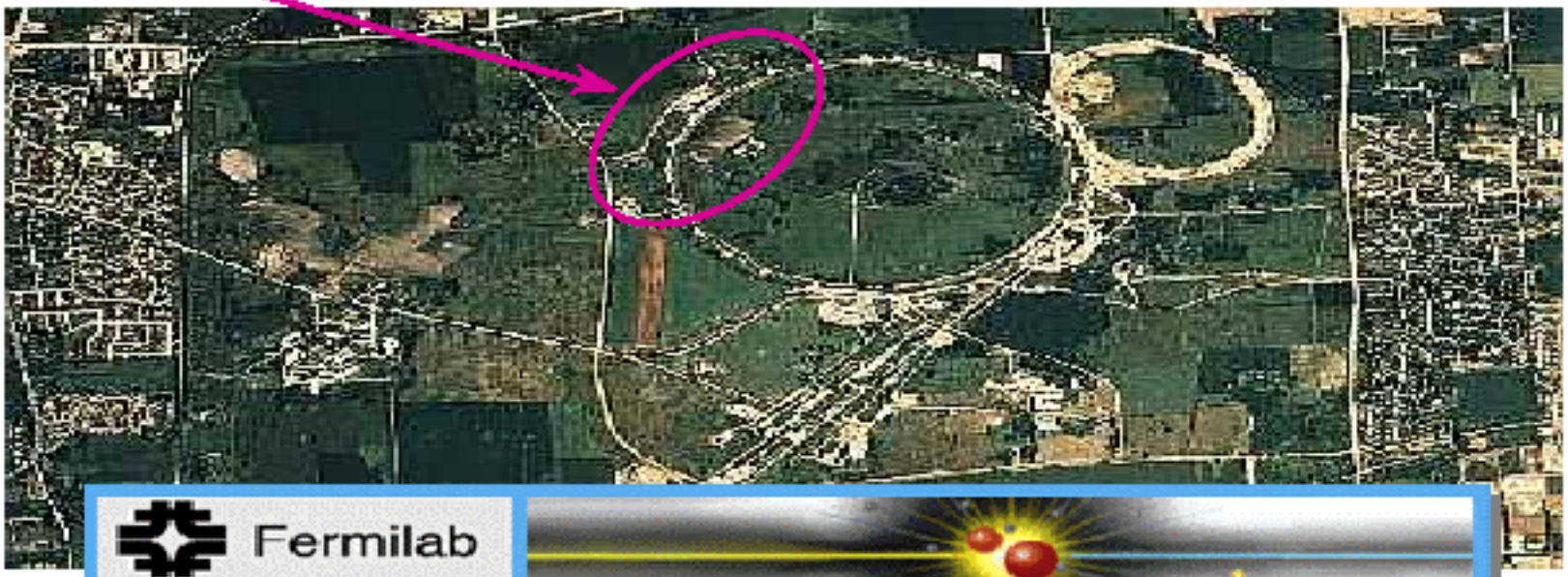
For the Collaboration

The DØ Collider Experiment at the Tevatron

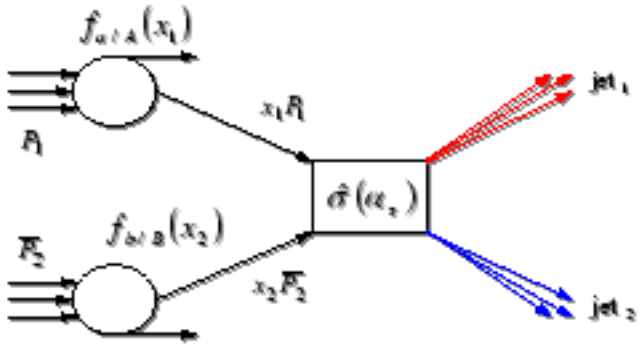




Fermilab

Discovering the Nature of Nature

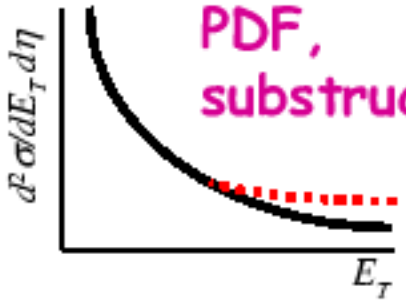
Inclusive Jet Cross Section - a Test of pQCD



$$\sigma(p_1\bar{p}_2 \to 2\,jets) = \sum_{abcd}\int dx_1 dx_2 f_{a/A}(x_1) f_{b/B}(x_2)\,\hat{\sigma}(ab \to cd)$$

Inclusive jets: $p\bar{p} \to jet + X$

$$\frac{1}{\Delta E_T \Delta\eta}\iint d\eta dE_T \frac{d^2\sigma}{dE_T d\eta} \longleftrightarrow \frac{N_{jet}}{\Delta E_T \Delta\eta \varepsilon \int Ldt} \text{ vs. } E_T$$



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

$\Delta E_T \to E_T$ bin size
$\Delta\eta \to \eta$ bin size
$N_{jet} \to$ # of jets in the bin
$\varepsilon \to$ selection efficiency
$L \to$ inst. Luminosity

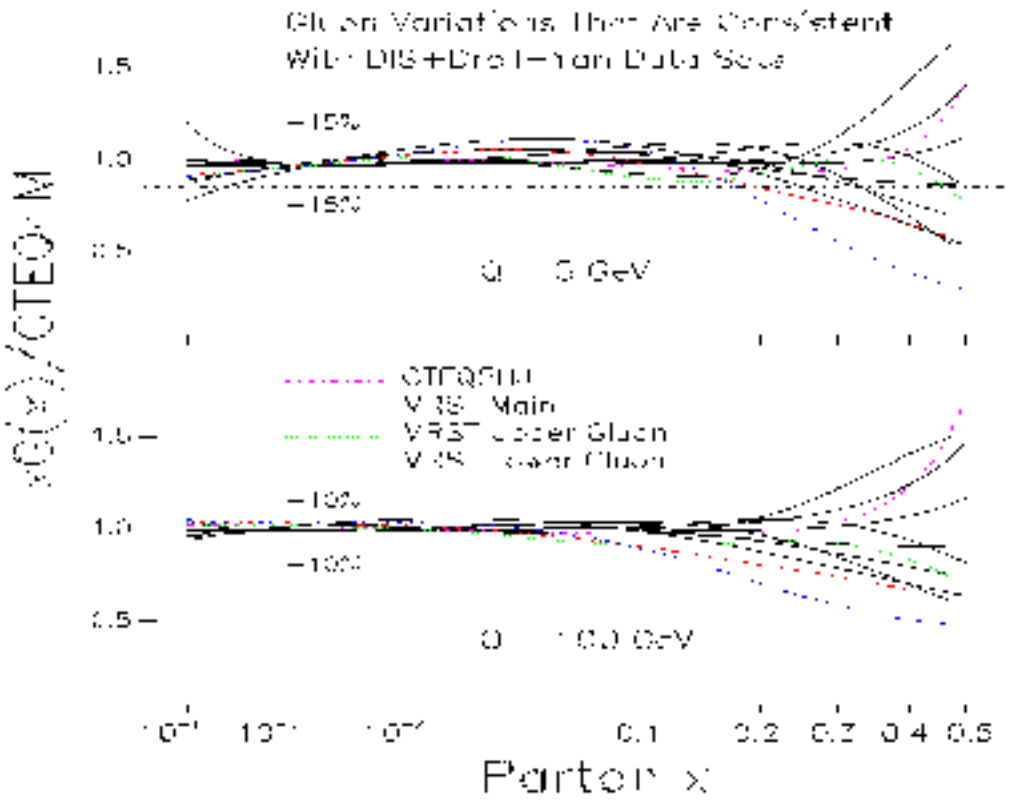
New Rapidity Dependence analysis extends previous measurements (which stopped at $|\eta| = 0.7$) to $|\eta|=3.0$:

5 $|\eta|$ regions

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

CTEQ Study of Gluon Uncertainty

- ∴ **Gluon distribution is least well known (but one of most important for physics processes at the Tevatron and LHC)**
- ∴ **Momentum fraction carried by quarks is very well known from DIS data; at Q_o=1.6 GeV**
  - **momentum fraction carried by quarks is 58%±2%; thus fraction carried by gluons is is 42%±2%**
  - → **if gluon increases in one range, it must decrease in another**
- ∴ **CTEQ study; vary gluon parameters in a global analysis and then look for incompatibilities with data**
- ∴ **Use only DIS and DY data sets where theoretical and experimental systematic errors are under good control**
- ∴ **Use standard parameterization for gluon distribution**
  - $A_o X^{A1}(1-x)^{A2}(1+A_3 x^{A4})$
  - **Vary A_1,A_2,A_3,A_4 each time refitting other quark, gluon parameters**



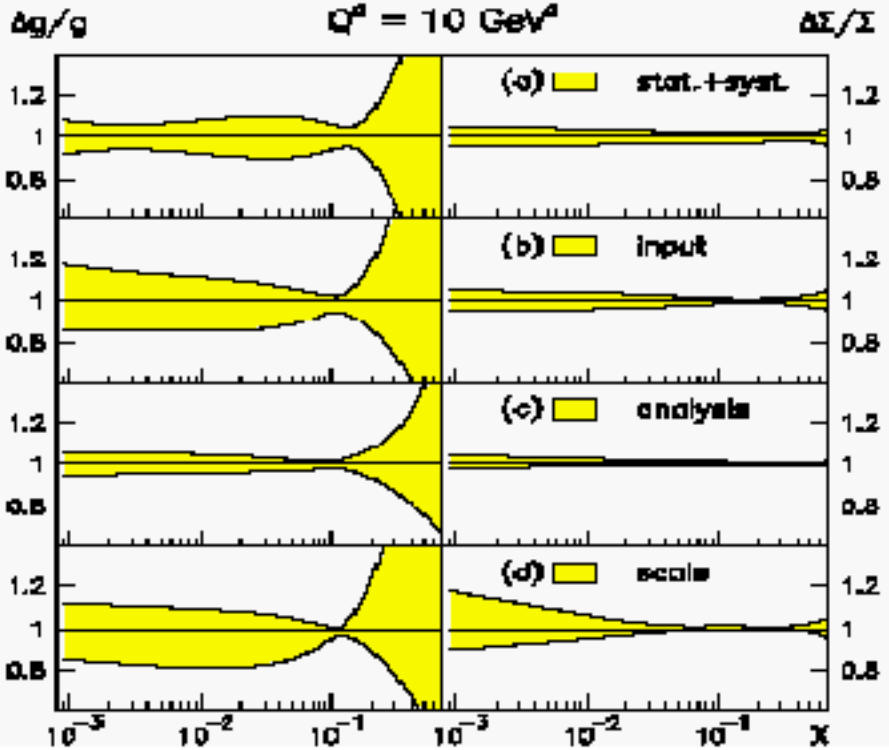
- Fairly tight constraints on the gluon distribution except at high x
- This has an impact on both fixed target direct photon production and on high E_T jet production at the Tevatron

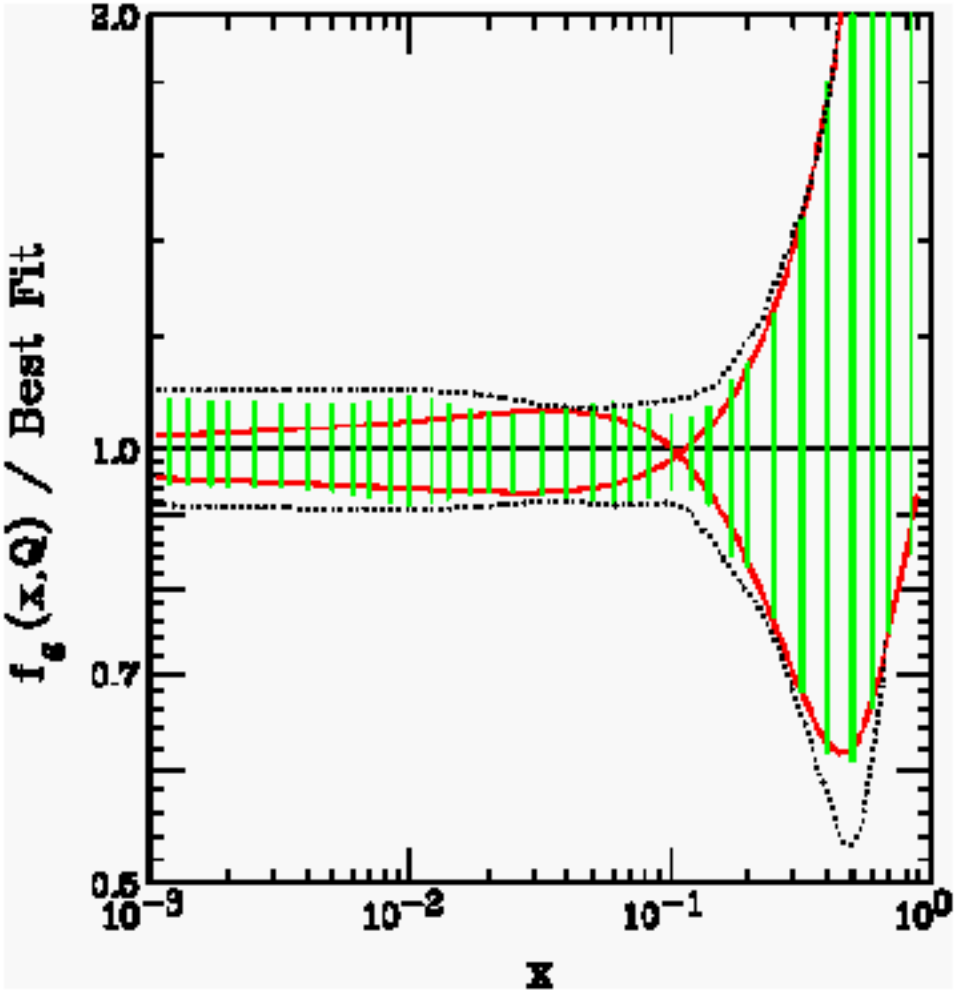
Gluon Uncertainties: Botje and CTEQ ...

Percentage Uncertainties of Parton Distributions (By M. Botje)

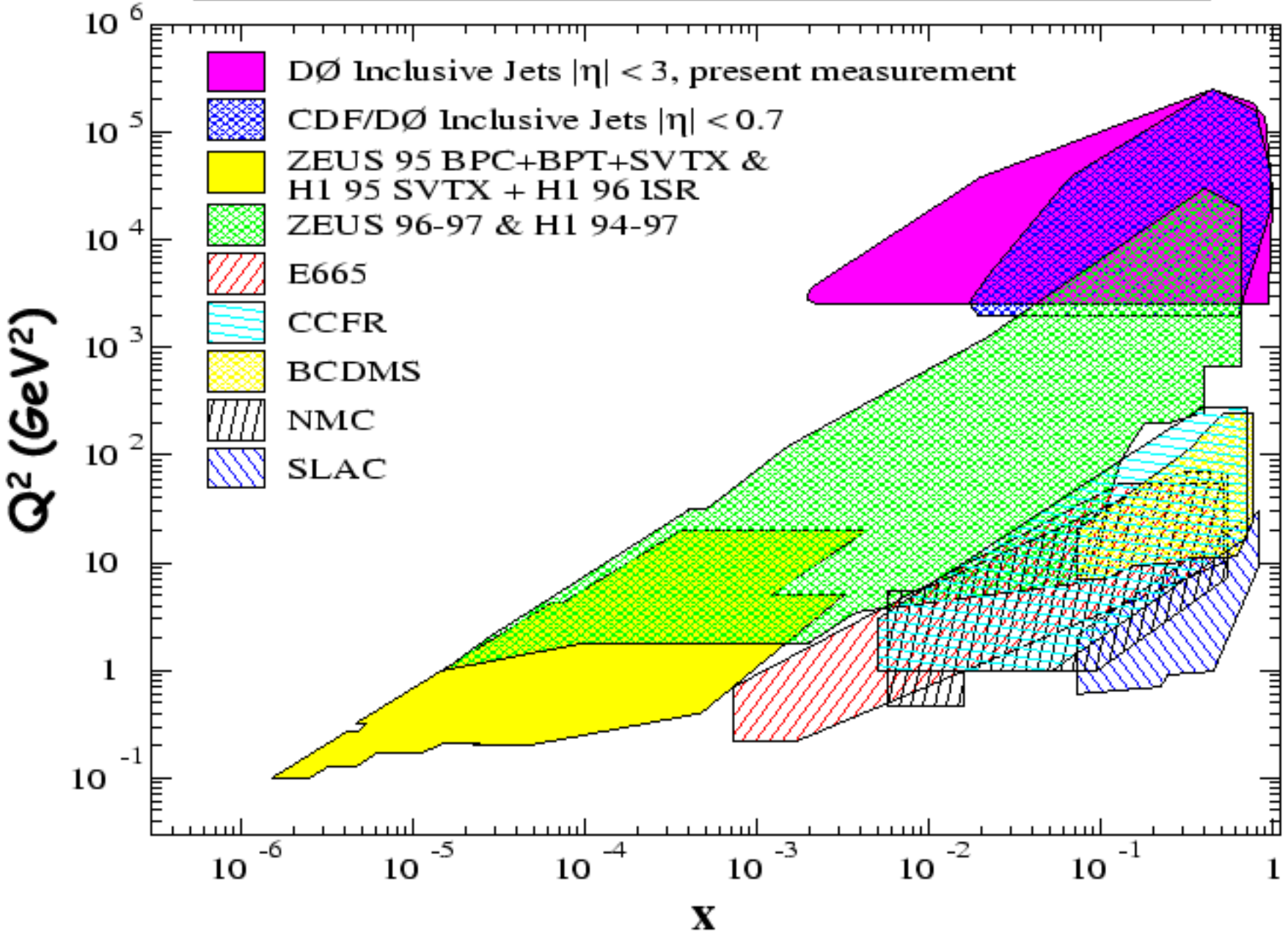
Sources of uncertainties:

- Experimental statistical and systematic errors;
- "input": various theoretical corrections;
- "analysis": phenom. analysis procedure;
- "scale": PQCD renor. and fact. scale-dependence





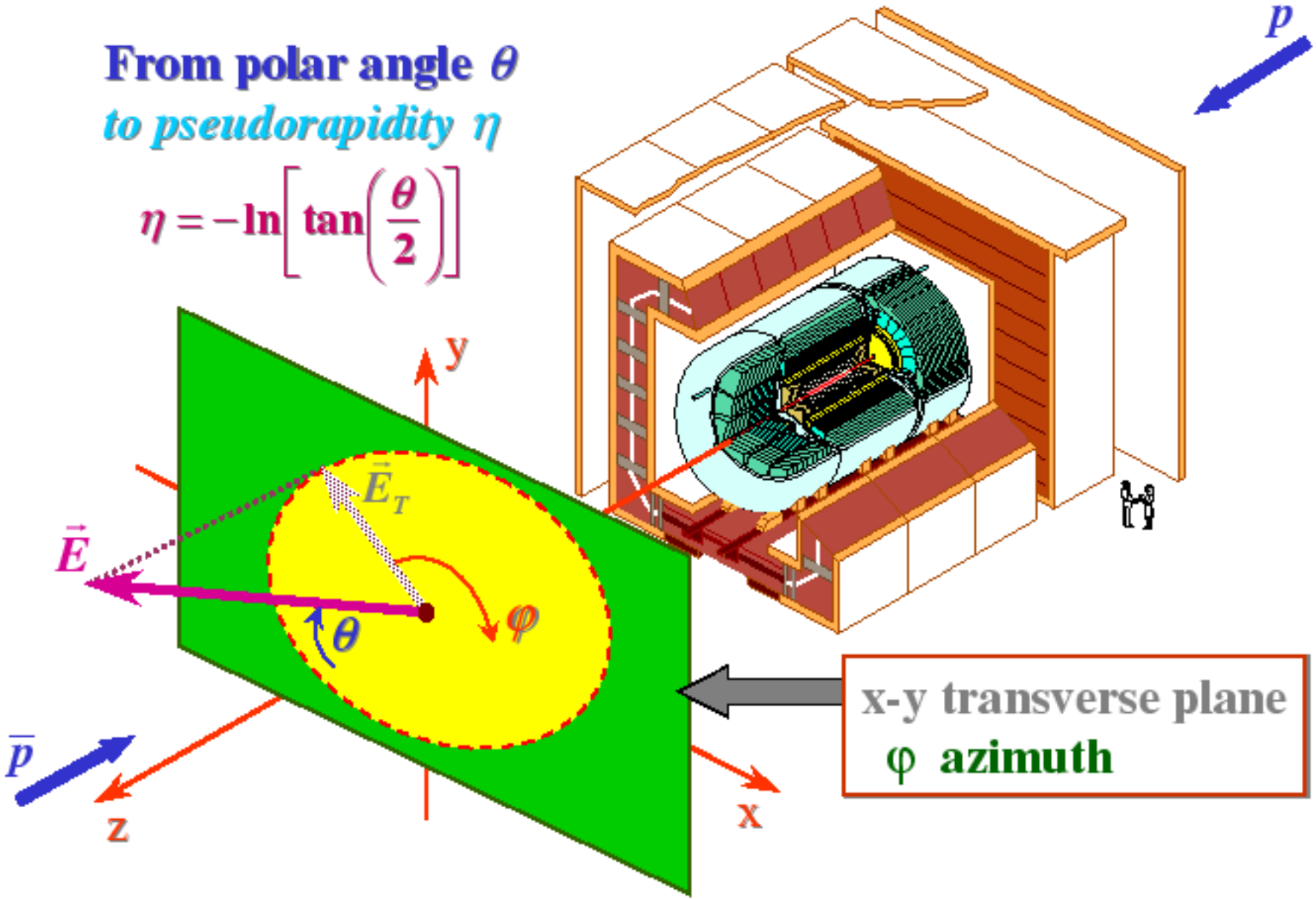
Significantly Extended x-Q^2 Reach



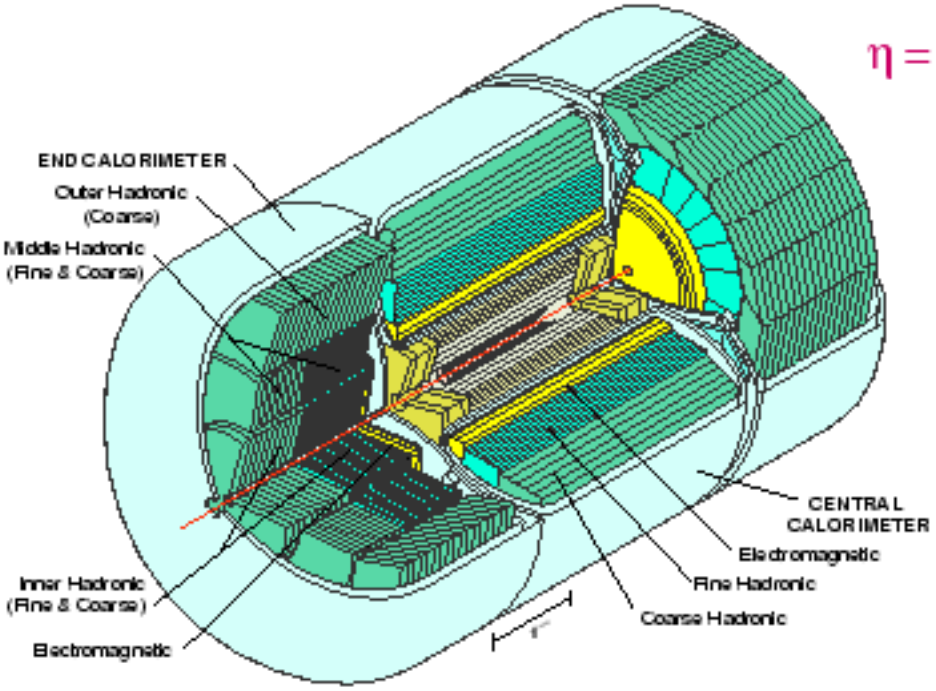
The Run I DØ Detector

From polar angle θ
to pseudorapidity η

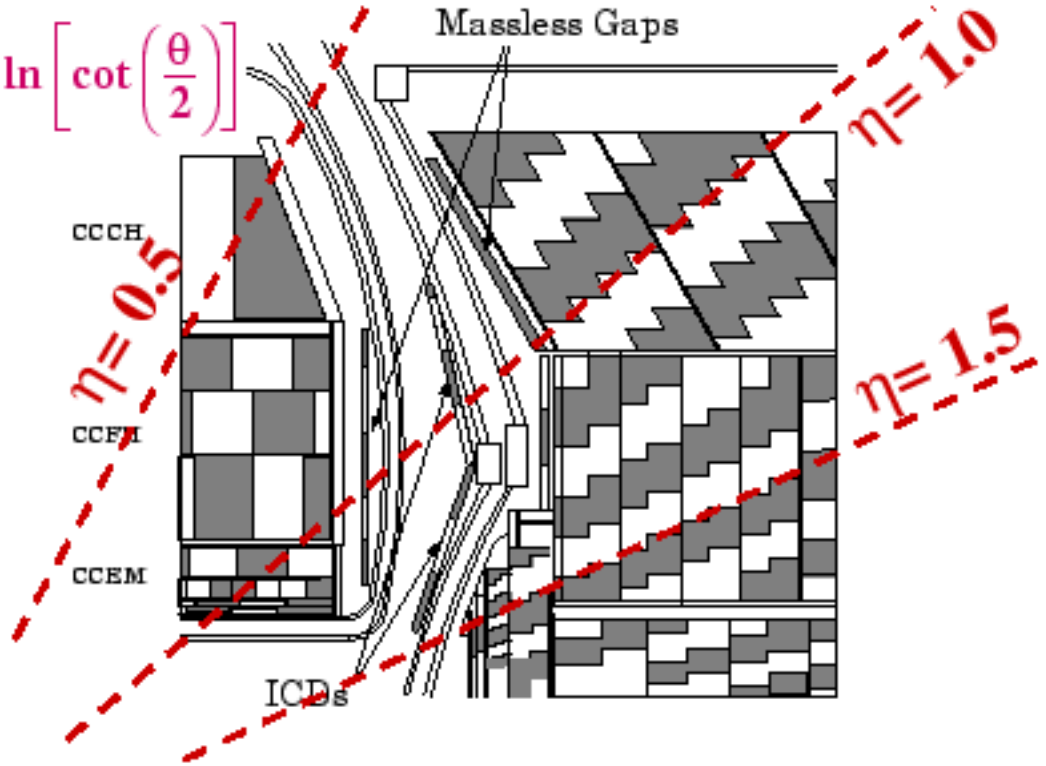
$$\eta = -\ln\left[\tan\left(\frac{\theta}{2}\right)\right]$$



DØ LAr/Ur Calorimeters



$$\eta = \ln\left[\cot\left(\frac{\theta}{2}\right)\right]$$



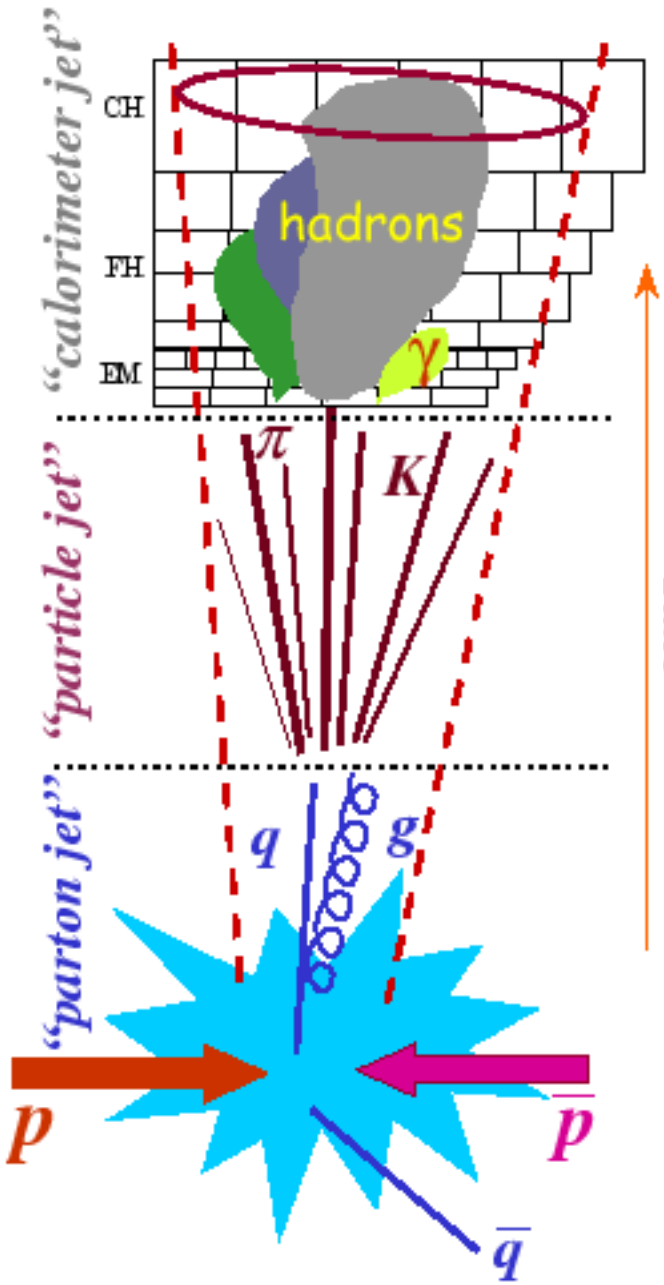
Calorimeter Resolutions

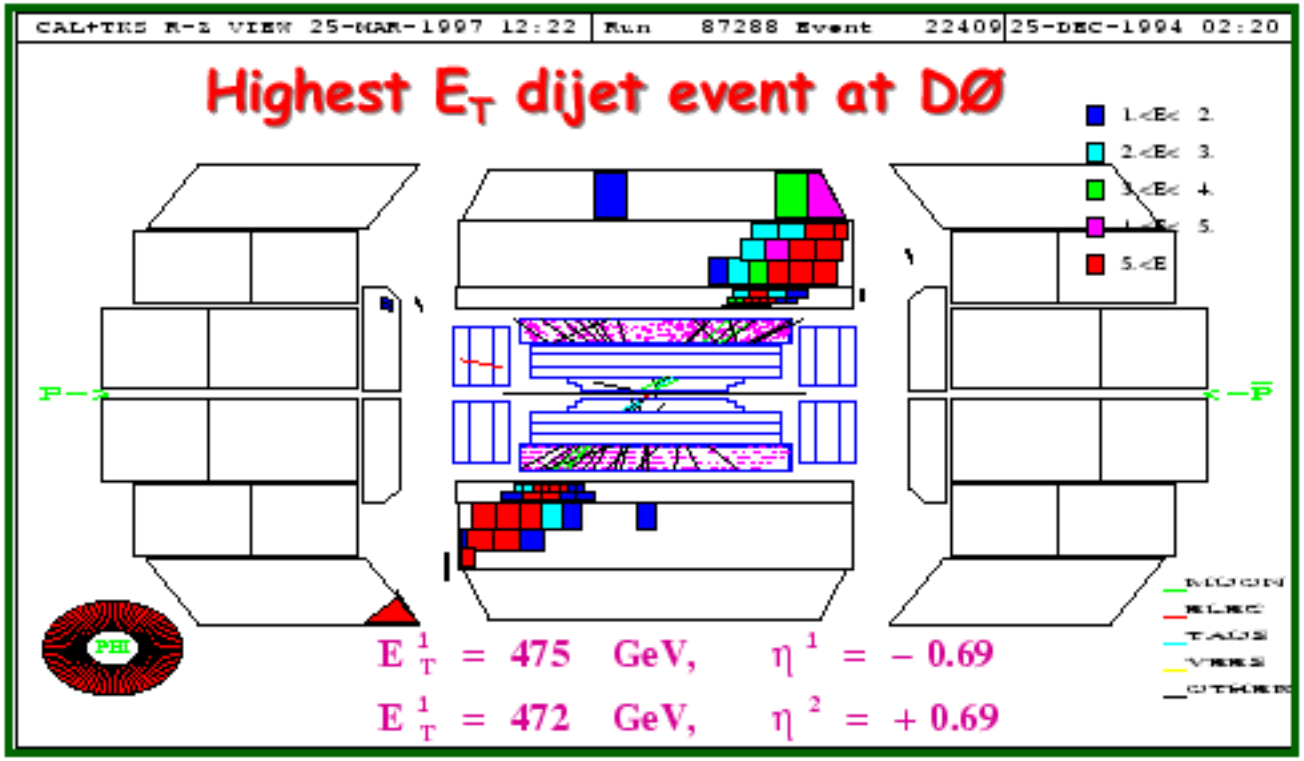
$$(\sigma_E/E)(\mathrm{EM}) \approx 15\%/\sqrt{E}$$
$$(\sigma_E/E)(\mathrm{HAD}) \approx 50\%/\sqrt{E}$$
$$(\sigma_E/E)(\mathrm{JET}) \approx 80\%/\sqrt{E}$$

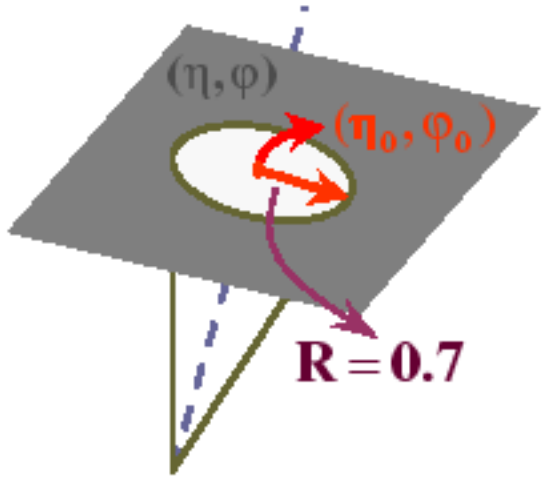
Compensating, hermetic, with full coverage

$$|\eta| \leq 4.2$$
$$\Delta\eta \times \Delta\varphi = 0.1 \times 0.1\,(\mathrm{rad})$$
$$\lambda_{int} > 7.2\,(\mathrm{total})$$

Jet Production and Reconstruction







- Fixed cone-size jets
- Add up towers

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

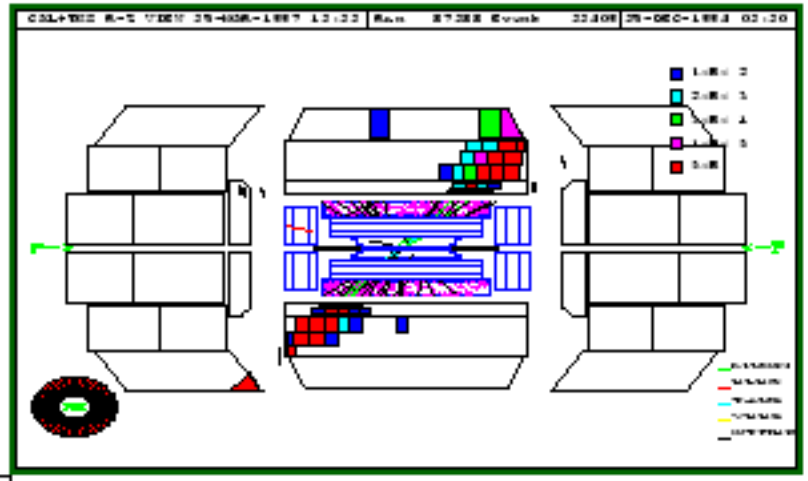
- Iterative algorithm
- Jet quantities:

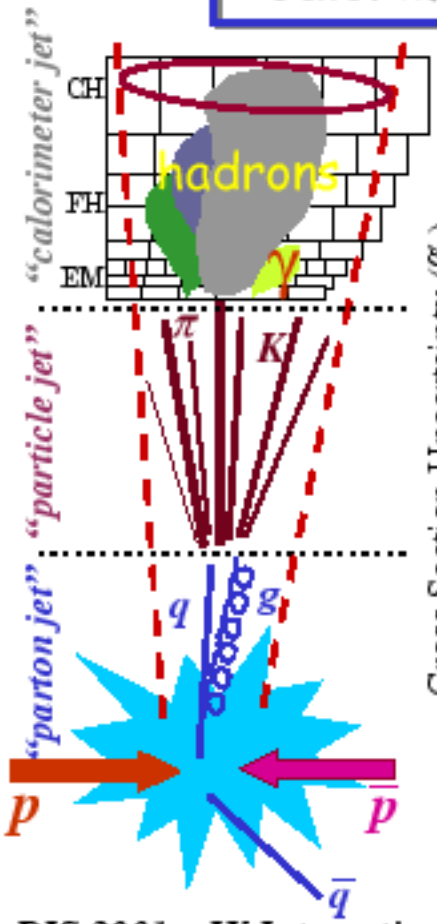
$$E_T, \eta, \varphi$$

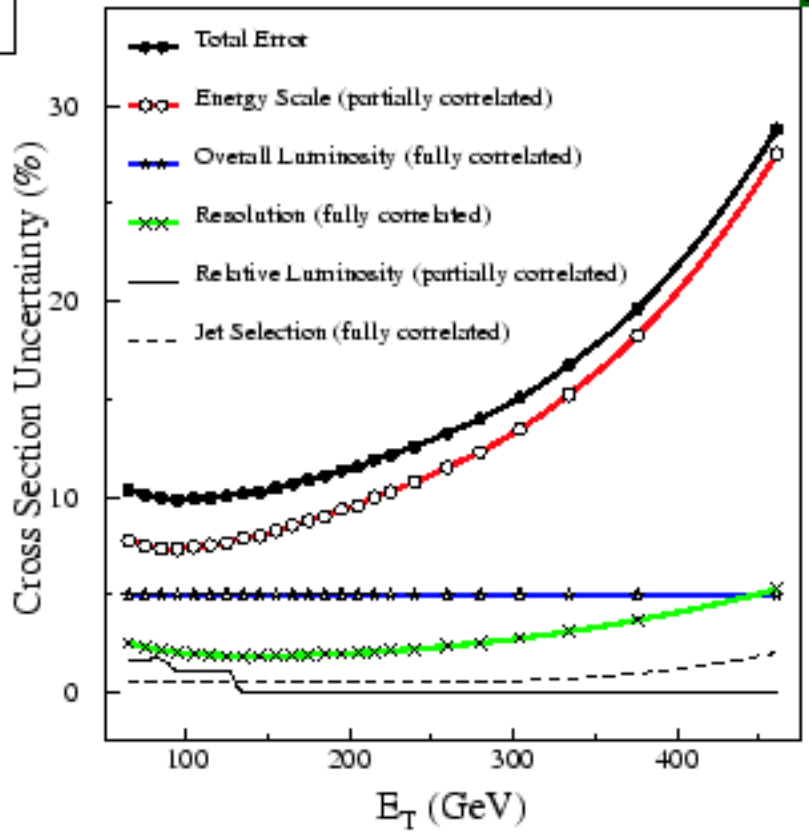
Data Selection and Corrections

- ∴ Acceptance cut on interaction vertex Z position
- ∴ Eliminate events with large missing transv energy
- ∴ Apply jet quality cuts

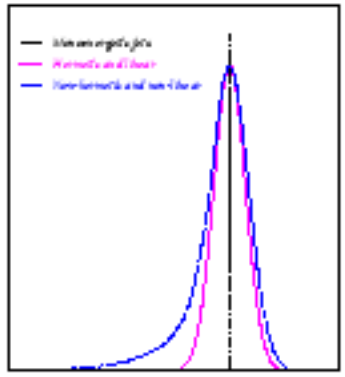
Jet energy scale correction: "calorimeter" → "particle" jet





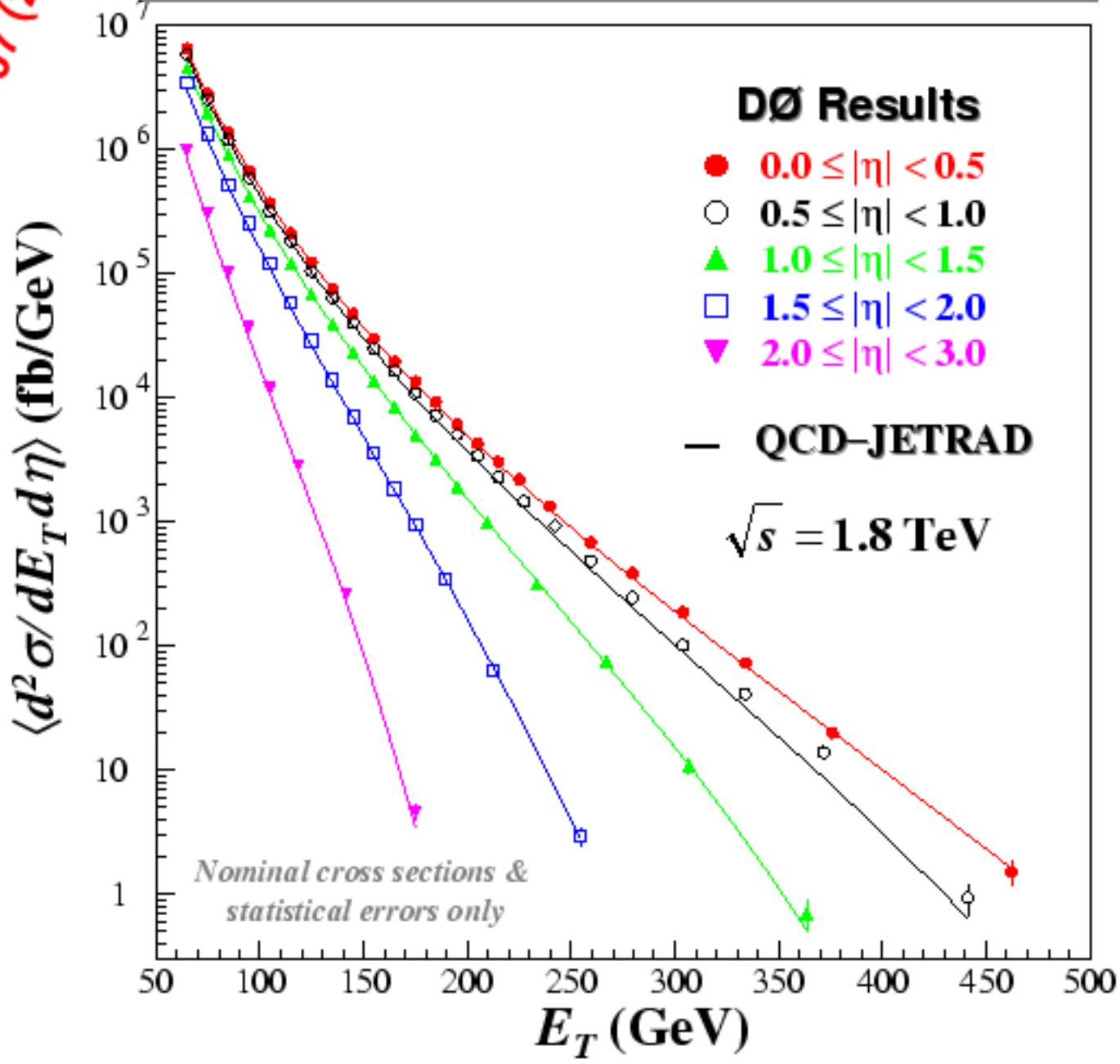


Unfold the effects of finite jet energy resolutions from very steeply falling inclusive jet cross sections

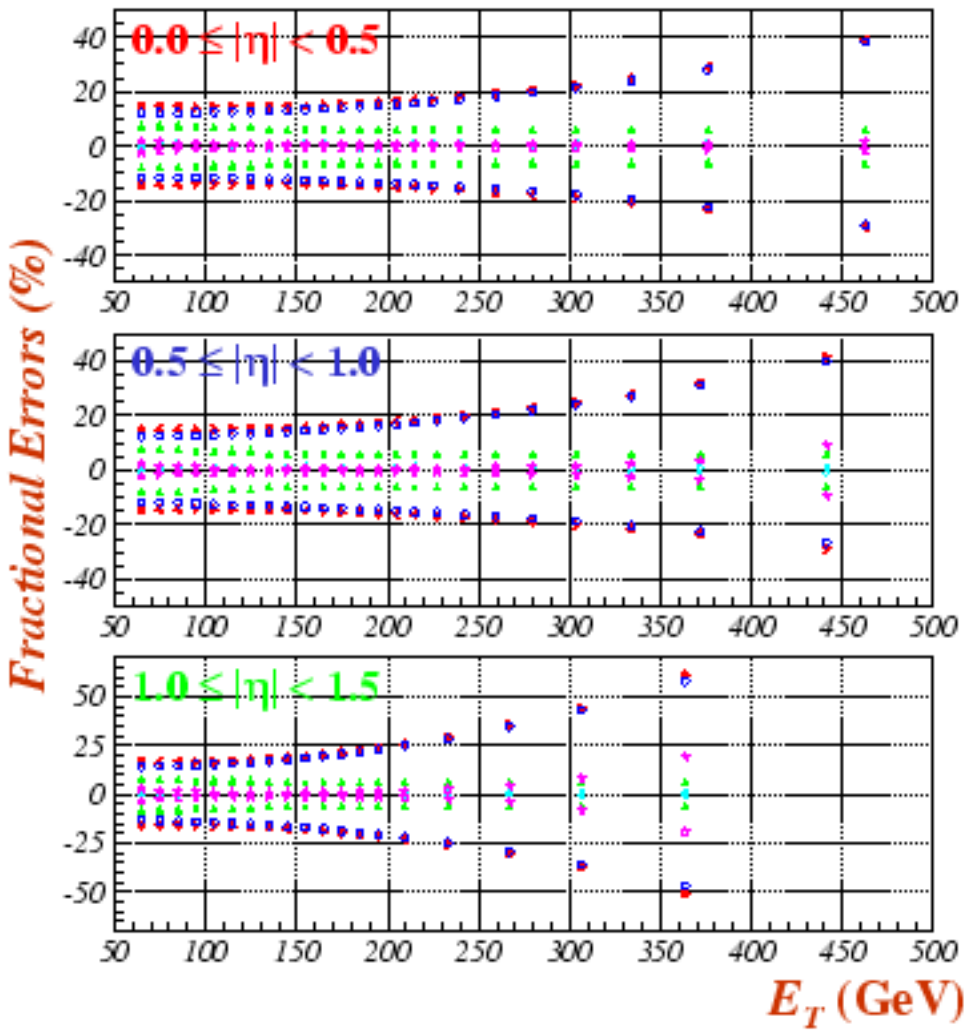


Inclusive Jet Cross Section

PRL in print
Phys. Rev. Lett. 86, 1707 (2001)

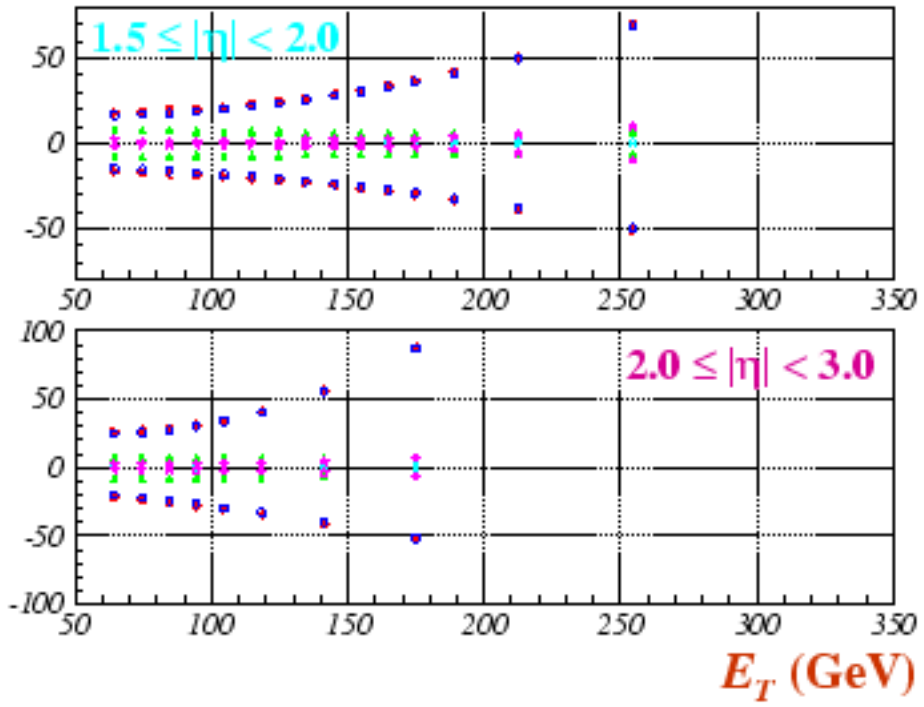


Sources of Systematic Uncertainties



DØ Run 1B

$\left(\int Ldt = 95\ \text{pb}^{-1}\right)$



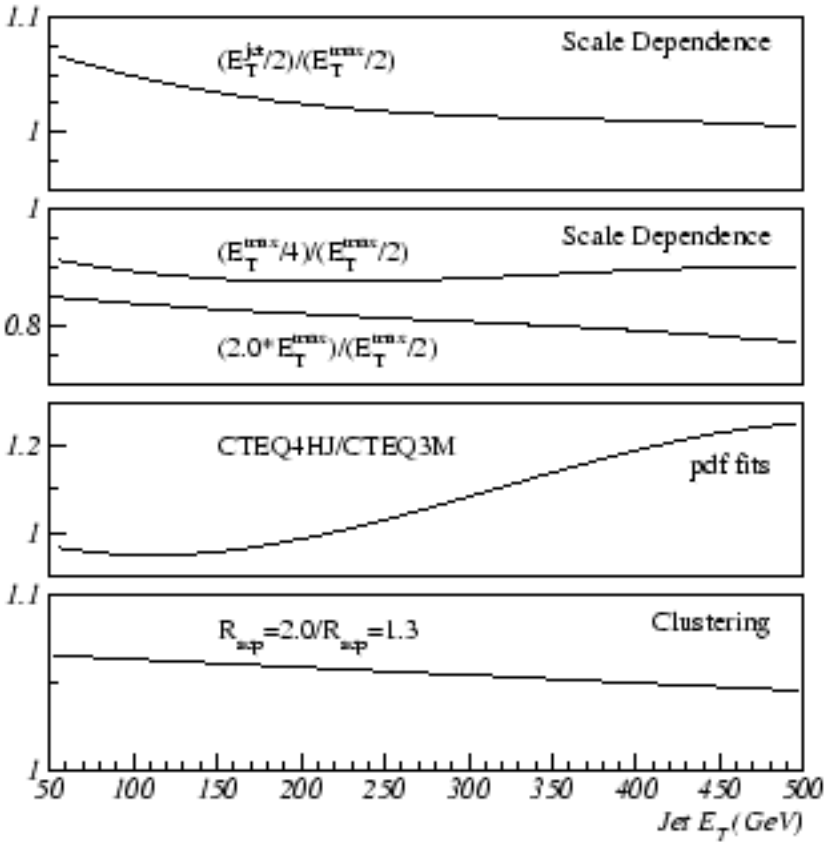
▲ Luminosity ○ Jet Energy Scale

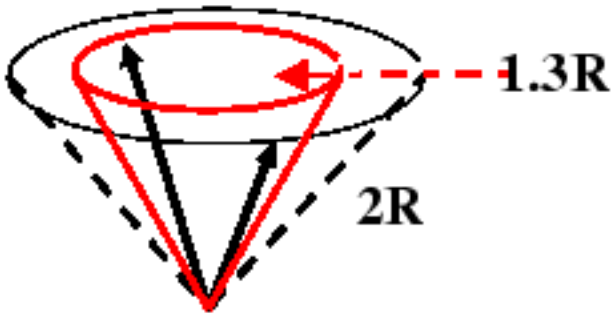
✧ Selection efficiency ☆ Resolutions & Unfolding

✻ Total

Uncertainties in Theoretical Predictions

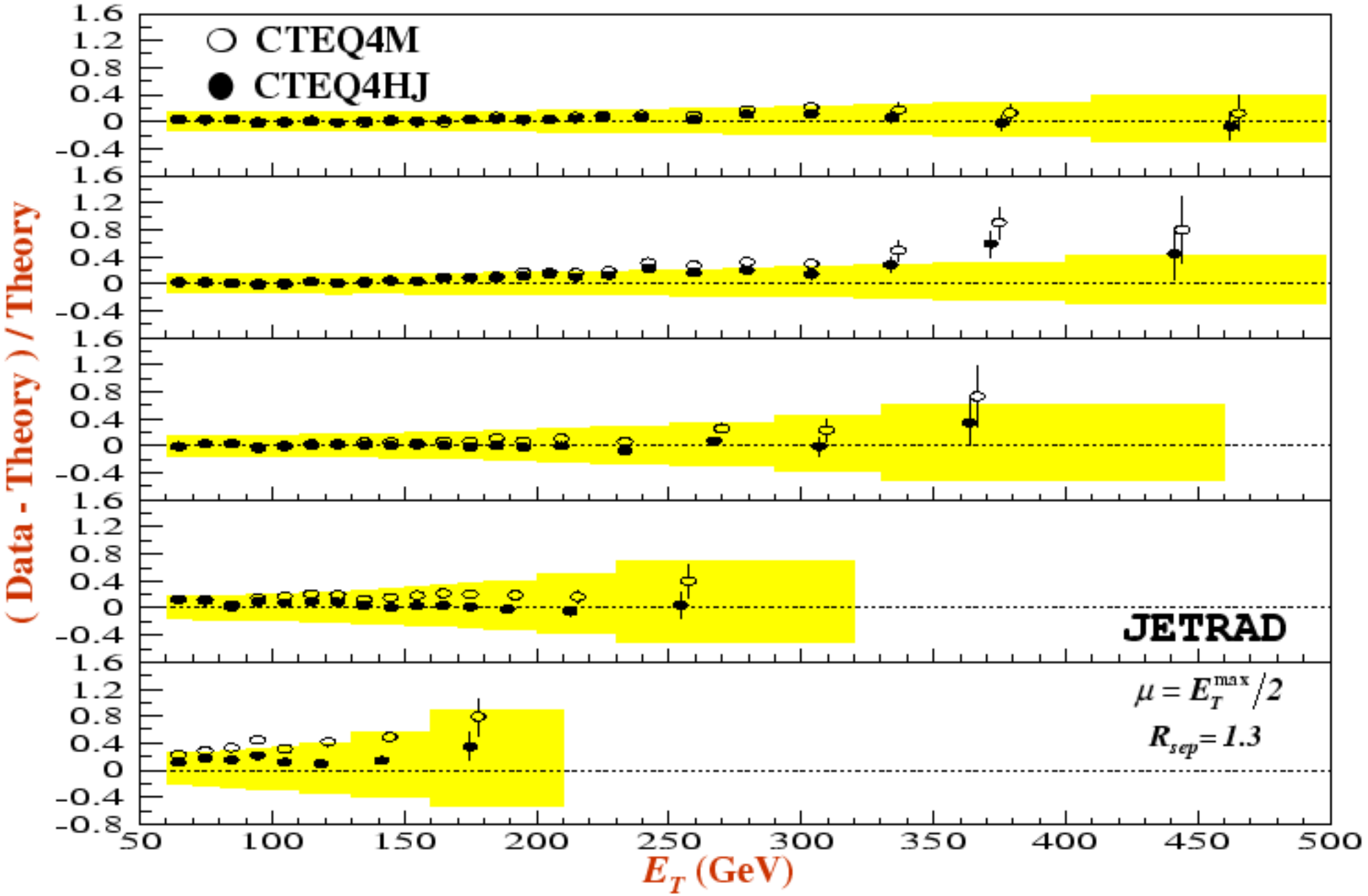
- NLO pQCD predictions (α_s^3):
  - Ellis, *et al.*, Phys. Rev. D, 64, (1990) EKS
  - Aversa, *et al.*, Phys. Rev. Lett., 65, (1990)
  - Giele, *et al.*, Phys. Rev. Lett., 73, (1994) JETRAD
- Choices (hep-ph/9801285, EPJ C5, 687, 1998):
  - Renormalization Scale (~10%)
  - PDFs (~20% with E_T dependence)
  - Clustering Alg. (~5% with E_T dependence)



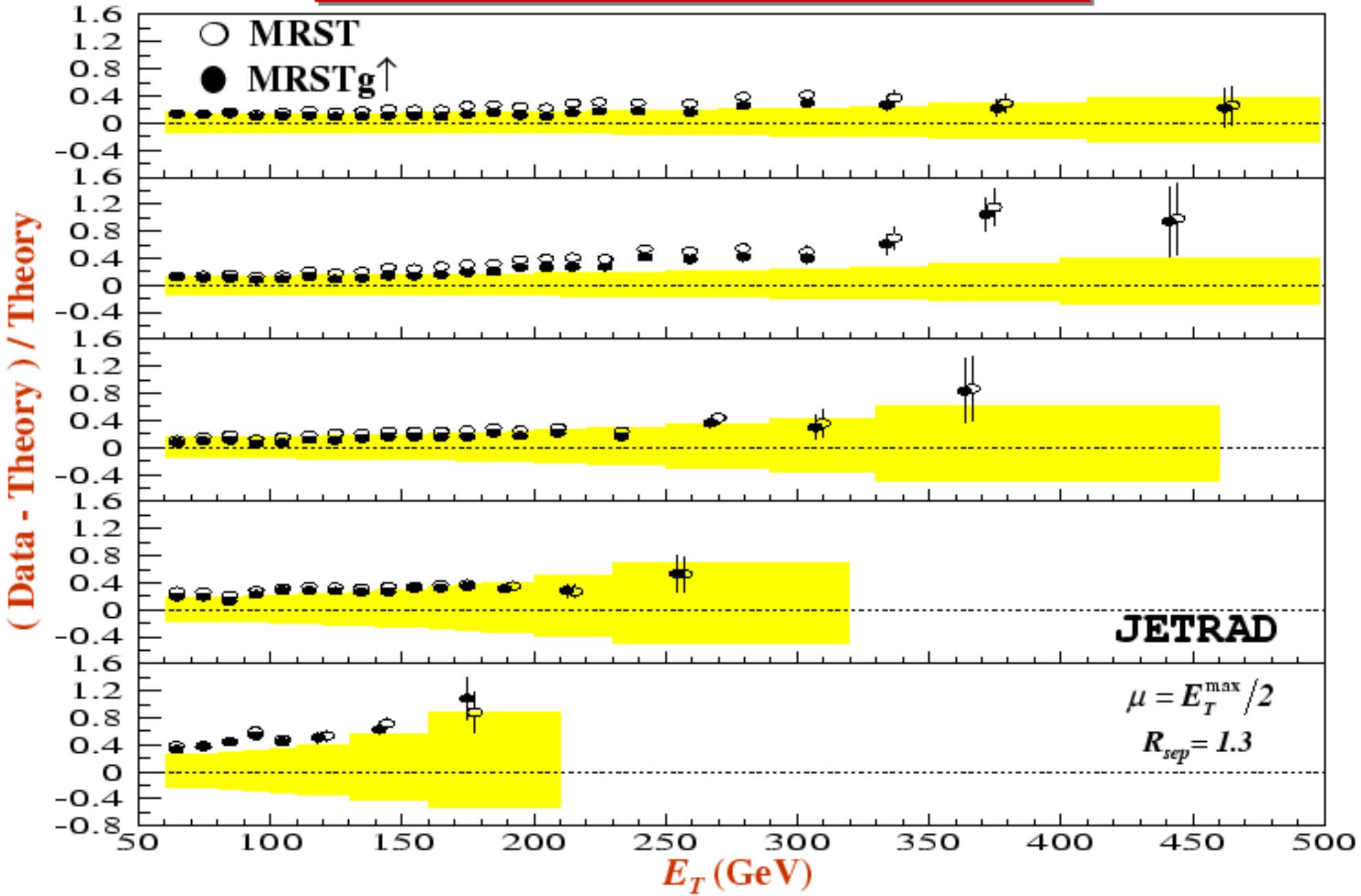


DØ uses: JETRAD, $\mu \equiv E_T^{max}/2$, R_{sep}= 1.3.

Comparisons to Predictions



Comparisons to Predictions



Building Full Covariance Matrix

For any error subcomponent α, define a covariance matrix:

$$\mathrm{Cov}^{\alpha}_{i,j} = \rho^{\alpha}_{i,j} \times \sigma^{\alpha}_{i} \times \sigma^{\alpha}_{j}$$

with correlation coefficients $\rho[-1,1]$ and standard errors σ;
and we take all five η regions together: i, j = 1, 90.

Then a Full Covariance (or Error) matrix is given by summing the covariance matrices of *all* error subcomponents, i.e.:

$$\mathrm{Cov}_{i,j} = \mathrm{Cov}^{\mathrm{Full}}_{i,j} = \sum_{\beta} \rho^{\beta}_{i,j} \times \sigma^{\beta}_{i} \times \sigma^{\beta}_{j}$$

In this analysis, in addition to error correlations in E_T, one should also address error correlations in pseudorapidity η.

PDF Discrimination / Derivation

World's best constraint on gluon PDF at high x

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

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

PDF	$\chi 2$	$\chi 2$/dof	Prob
CTEQ3M	121.56	1.35	0.01
CTEQ4M	92.46	1.03	0.41
CTEQ4HJ	59.38	0.66	0.99
MRST	113.78	1.26	0.05
MRSTgD	155.52	1.73	<0.01
MRSTgU	85.09	0.95	0.63

Variations of correlation coefficients within their uncertainties give a similar ordering of the χ^2, hence a similar relative preference of PDFs

Currently being incorporated in new global PDF fits by MRST group, CTEQ group next ...

Summary / Outlook

Reported a new measurement of η and E_T dependence of the inclusive jet cross section.

These results extend significantly the kinematic reach of previous studies and are consistent with pQCD calculations over the large dynamic range accessible to D∅ ($|\eta| < 3$).

Our results indicate preference of certain PDFs, particularly those with enhanced gluon content.

Once incorporated into revised modern PDFs, these measurements will greatly improve our understanding of the structure of the proton at large x and Q^2.

In upcoming Run II, due to higher energy and luminosity ($2fb^{-1}$) expect ~100 events with $E_T > 490$ GeV and ~1K events with $E_T > 400$ GeV. (In Run I, had ~16 events with $E_T > 410$ GeV.)

High x and Q^2 – place to look for new physics !