Jet Production at DØ

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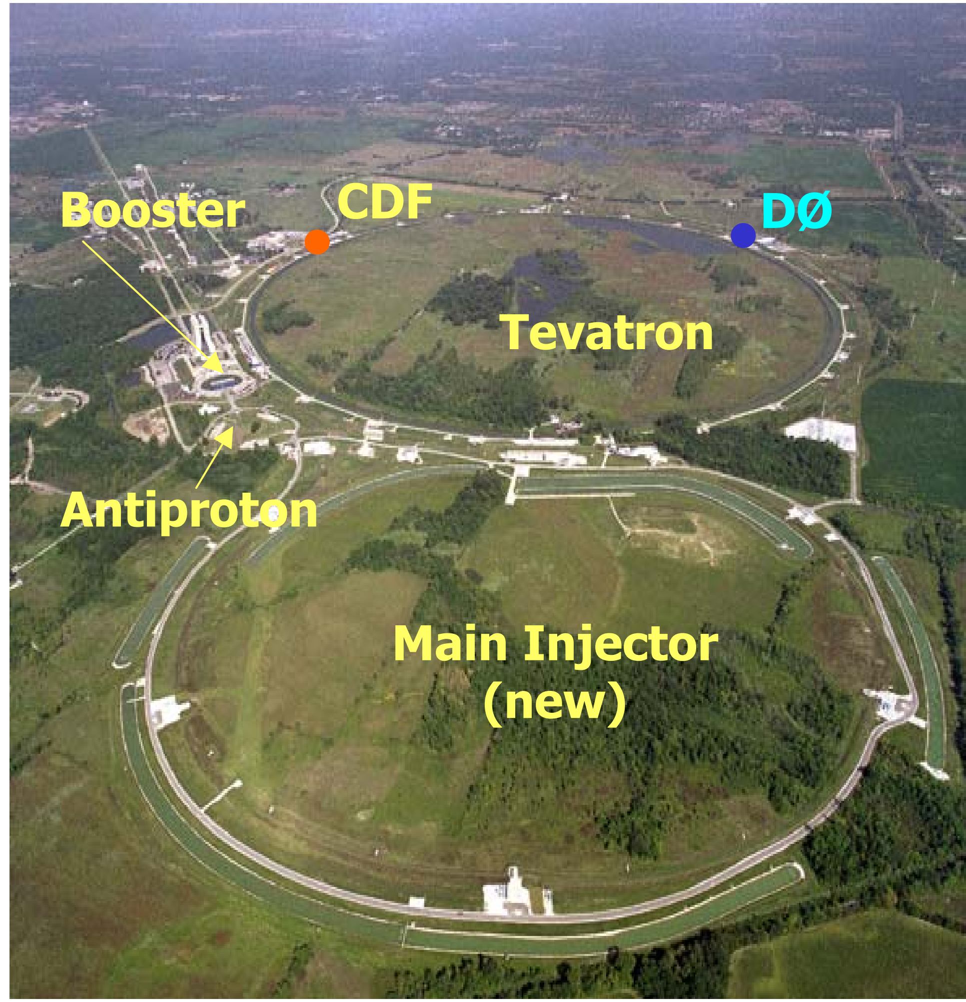
Overview Bird's Eye View

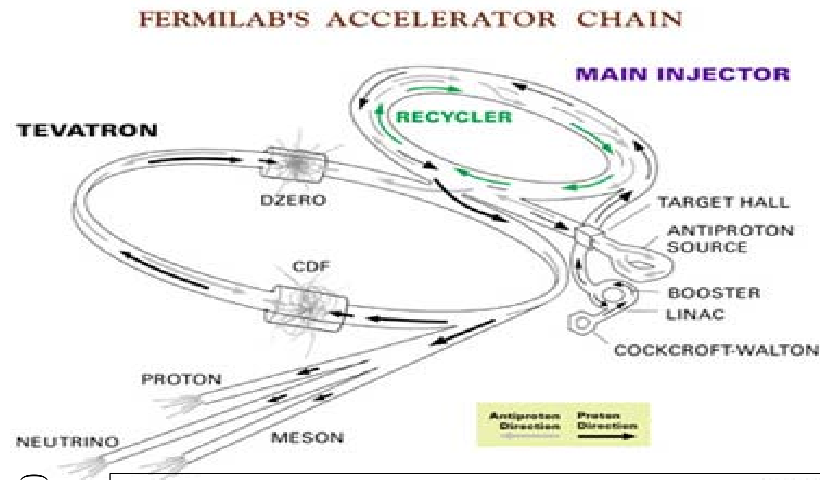
- Physics Goals / Tevatron
- DØ Calorimetry
- Jet Identification:
  - From partons to jets
  - Jet finding Algorithms
- Inclusive Jet Cross Section Results
  - using k_T algorithm
  - comparison to cone results
  - Influence on Run II algorithms
- RunII DØ Detector Upgrade
- Run II Preliminary Results
  - Triggering, Data Selection and Energy Scale
  - Preliminary Run II cross sections
- Summary



Physics Goals

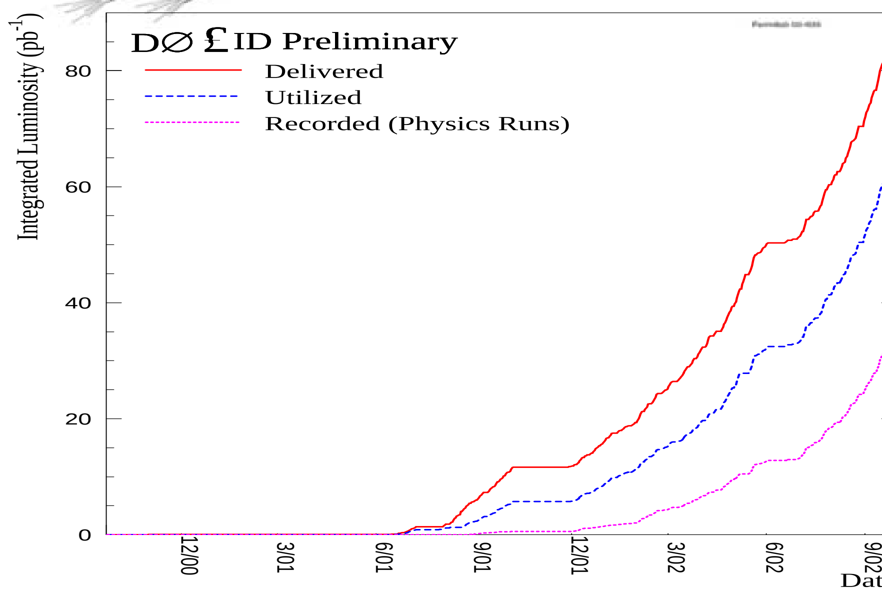
Physics goals:
- precision studies of weak bosons, top, QCD, B-physics
- searches for Higgs, supersymmetry, extra dimensions, other new phenomena

Require:
- electron, muon, and tau identification
- jets and missing transverse energy
- flavor tagging through displaced vertices and leptons
- luminosity, luminosity, luminosity…



	Run 1b	Run 2a	Run 2b
Bunches in Turn	6 × 6	36 × 36	140 ×103
√s (TeV)	1.8	1.96	1.96
Typical L ($cm^{-2}s^{-1}$)	1.6×10^{30}	8.6×10^{31}	5.2×10^{32}
∫ Ldt (pb^{-1}/week)	3.2	17.3	105
Bunch xing (ns)	3500	396	132
Interactions / xing	2.5	2.3	4.8

Run 1 → Run 2a → Run 2b
0.1 fb^{-1} → 2–4 fb^{-1} → 15 fb^{-1}



Last week: Record Luminosity 2.8×10^{31} $cm^{-2}s^{-1}$
Plan to reach Run 2a design in Spring 2003

Jet Physics Goals

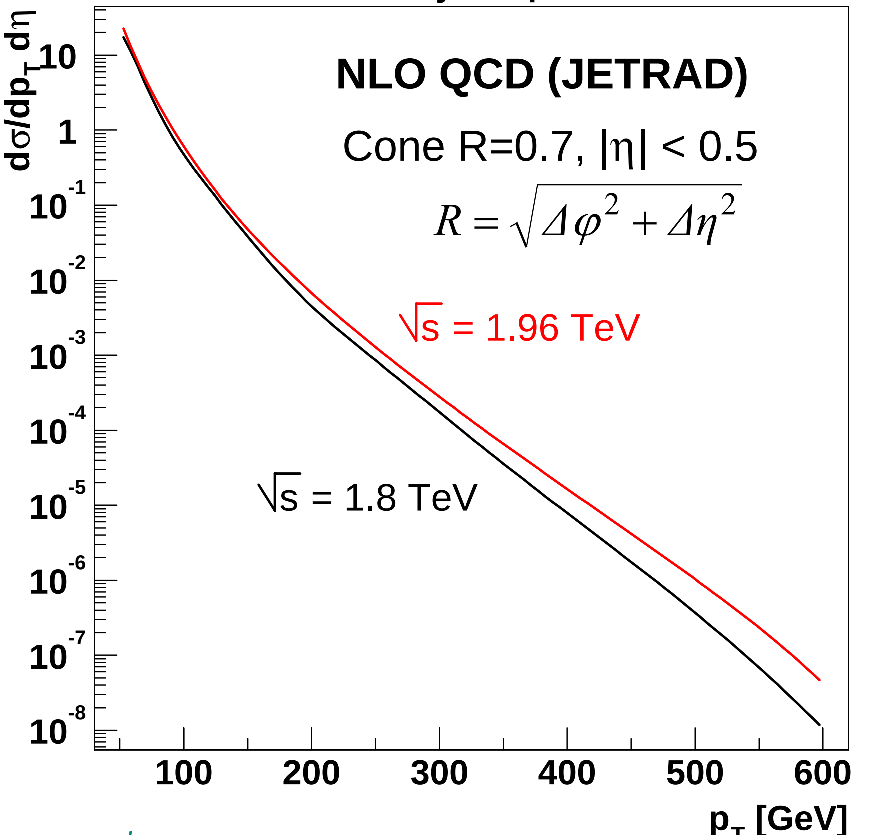
Run I: Began era in jet physics (δexp<δ theory)

- Implemented Cone & kT based jet algorithms
- Precision measurements at high E allow
  - Precise tests of pQCD, Input to pdf's, searches
- We learned:
  - Comparisons require a thorough understanding of the systematic errors and their correlations
  - Uniform choice of algorithms facilitates comparison
- Participation in "Joint CDF/DØ/Theory Jet Working Group" to agree upon Jet finding algorithms and conventions

Run II: Higher cm energy and higher statistics

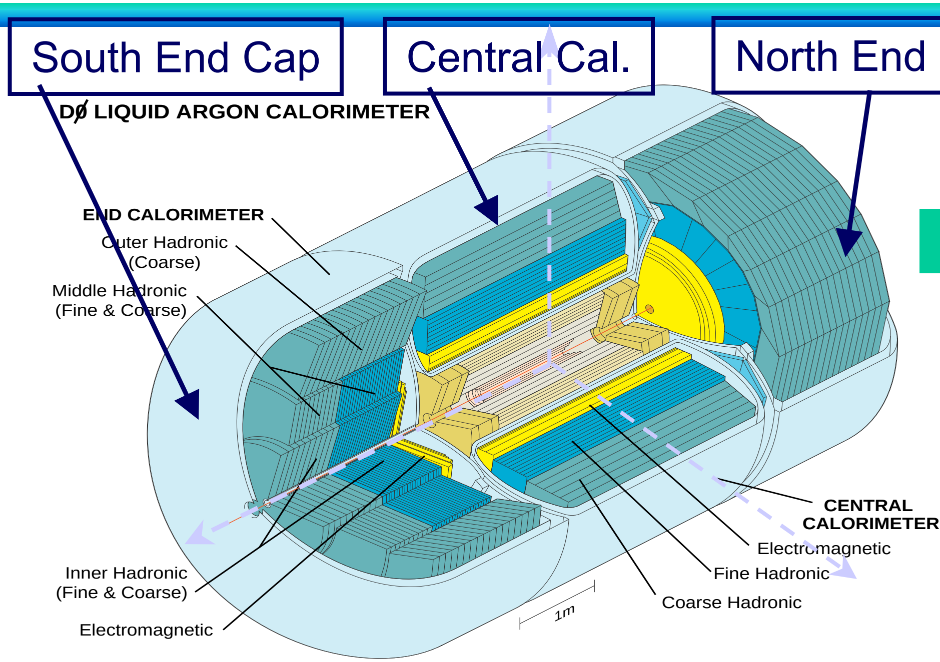
- Upgraded detector is commissioned, taking data
- Capable of a new level of precision comparisons
- Example: inclusive jet cross section

Inclusive jet spectrum



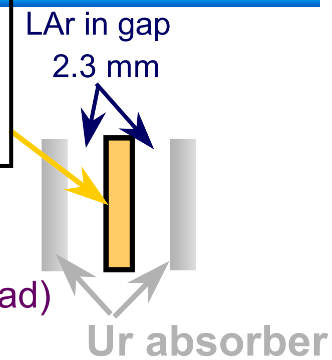
At $\sqrt{s}$=1.96 TeV, inclusive jet cross section 2x larger compared to Run 1 for jets with p_T > 400 GeV

Jets at DØ: Calorimetry



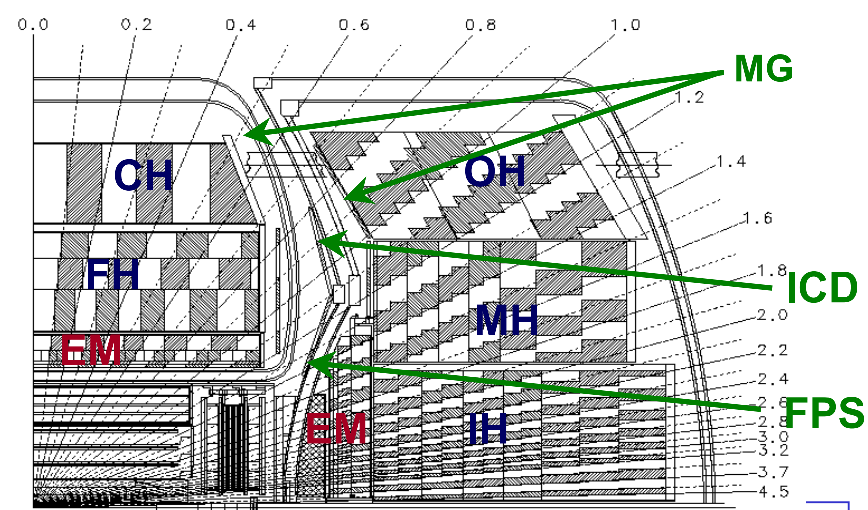
Readout Cell

Cu pad readout on 0.5 mm G10 with resistive coat epoxy



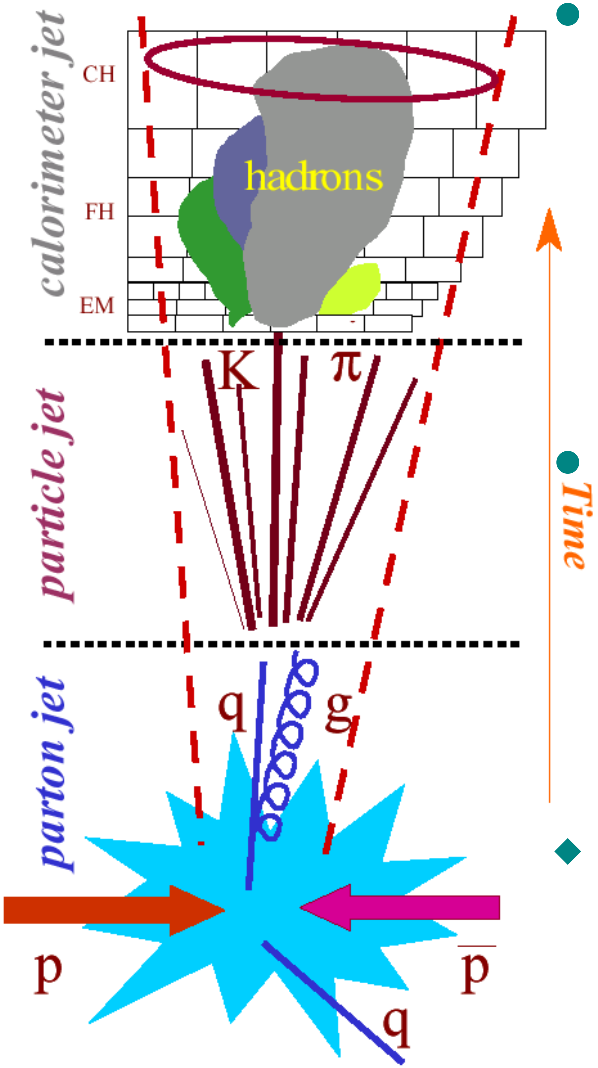
Drift time ~430 ns

- >50k readout cells (< 0.1% bad)
- Fine segmentation
  - 5000 pseudoprojective towers (0.1×0.1)
  - 4 EM layers, shower-max (EM3): 0.05×0.05
  - 4/5 Hadronic (FH + CH)
- L1/L2 fast Trigger readout towers



- **Liquid Argon sampling**
  - **uniform response, rad. hard, fine spatial segmentation**
  - **LAr purity important**
- **Uranium absorber (Cu/Steel CC/EC for coarse hadronic)**
  - **nearly compensating, dense ⇒ compact**
- **Uniform, hermetic with full coverage**
  - **$|\eta| < 4.2$ ($\theta \approx 2^o$), $\lambda_{int} \sim 7.2$ (total)**
- **Single particle energy resolution**
  - **e: $\sigma/E = 15\% / \sqrt{E} \oplus 0.3\%$ π: $\sigma/E = 45\% / \sqrt{E} \oplus 4\%$**

From Partons to Jets …



- Calorimeter jet
  - A Jet is collection of hit cells within a region
  - Jet reconstruction algorithm:
    - Forms a 'jet' by grouping hit cells by tower, cluster, or cone (with radius R)
    - Cone direction maximizes the total ET of the jet
  - Various cone/clustering algorithms
- Particle jet
  - After hadronization
  - A spray of particles running roughly in the same direction as the initial parton
  - Correct for finite energy resolution
  - Subtract underlying event
- Parton jet
  - Parton hard scattering and parton showers well described by pQCD

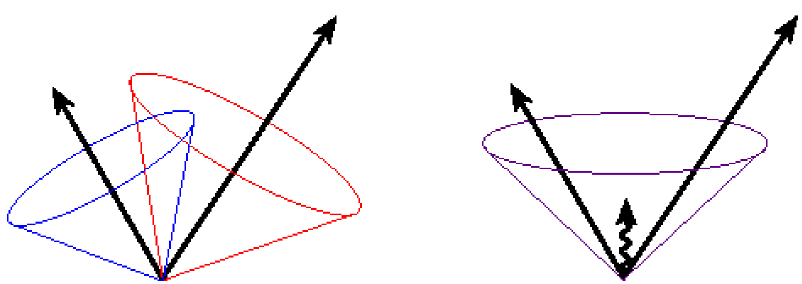
Run I: Jet Algorithms

- **Cone Algorithm**
  - Draw a cone of fixed size around a seed
  - Compute jet axis from ET-weighted mean and jet ET from ΣET's
  - Draw a new cone around the new jet axis and recalculate axis and new ET
  - Iterate until stable
  - Algorithm is sensitive to soft radiation
  - Split/Merge criteria invoked

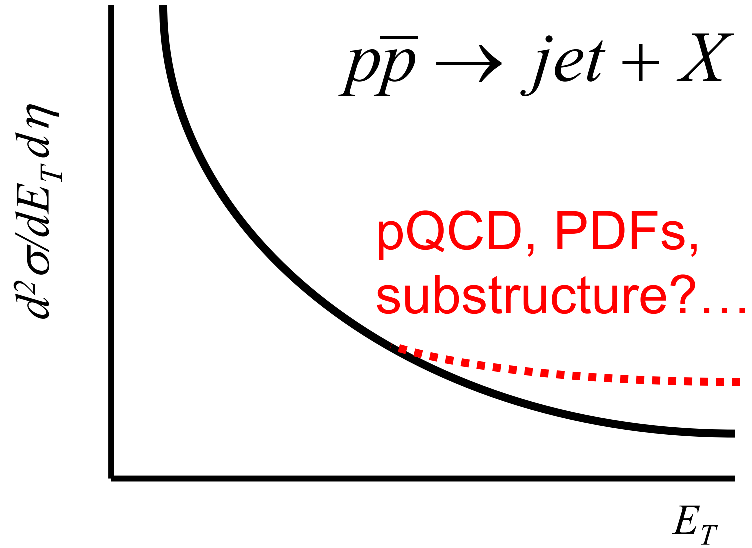
Used for majority of published Run I Jet results

- **k_T-algorithm**
  - Recombination algorithm based on relative transverse momentum between 'particles'
  - Theoretically favored, no split-merge, infrared safe to all orders in perturbation theory
  - To reduce computation time, start with 0.2 x 0.2 preclusters

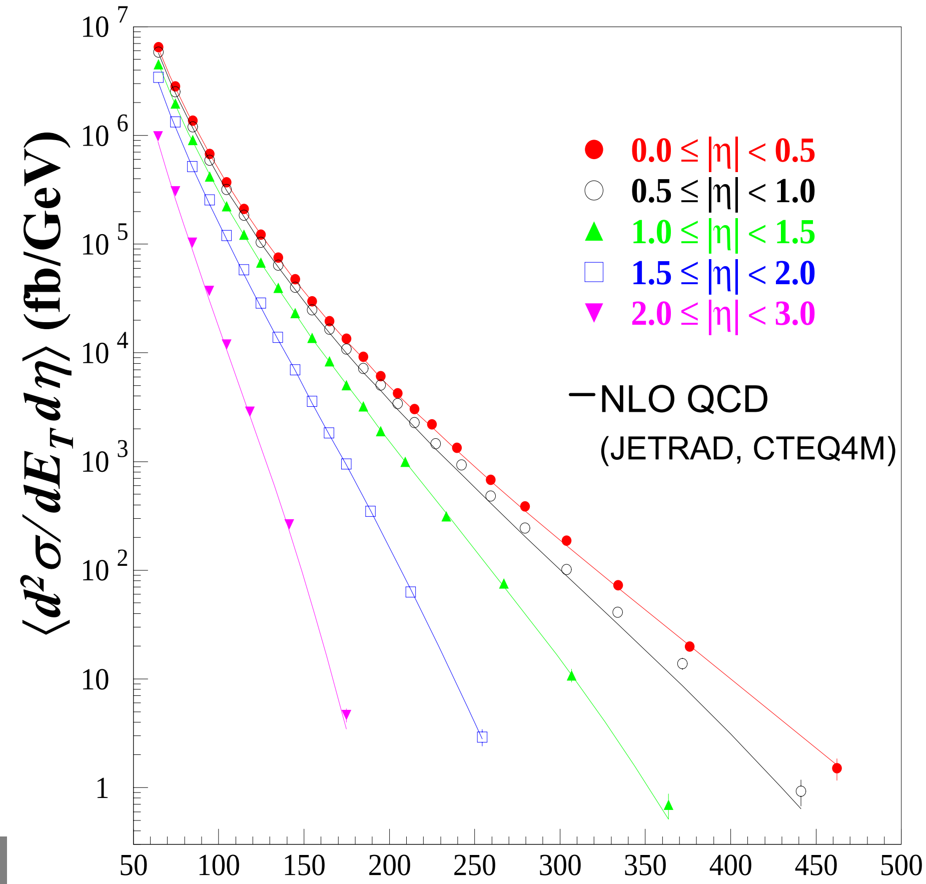
Used for a few more recent results



Inclusive Jet Cross Section at 1800 GeV using the Cone algorithm



- PRL 86, 1707 (2001)



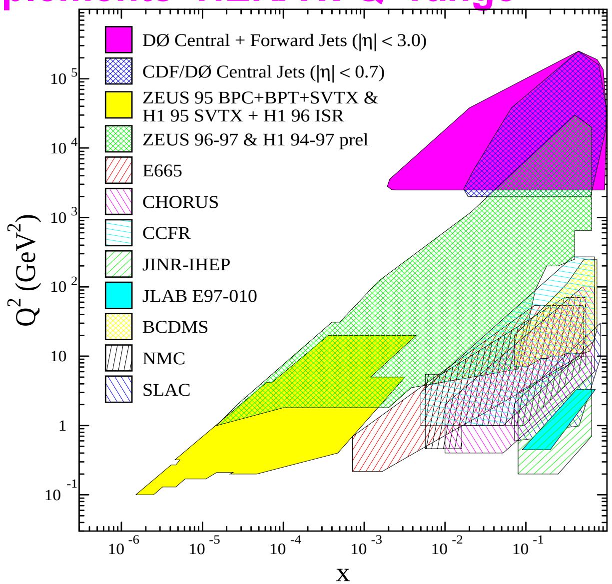
- How well do we know proton structure (PDFs) ?
- Is NLO (α_s^3) QCD "sufficient" ?
- Are quarks composite ?

$$\frac{d^2\sigma}{dE_T d\eta} = \frac{N_{jet}}{\Delta E_T \Delta\eta \varepsilon L} \text{ vs. } E_T$$

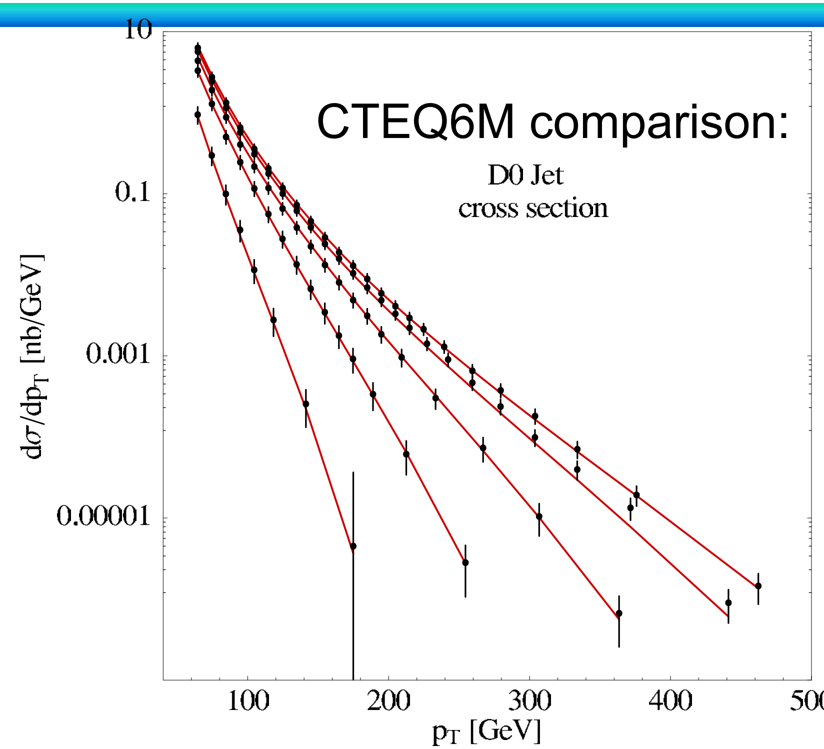
Good Agreement with NLO QCD

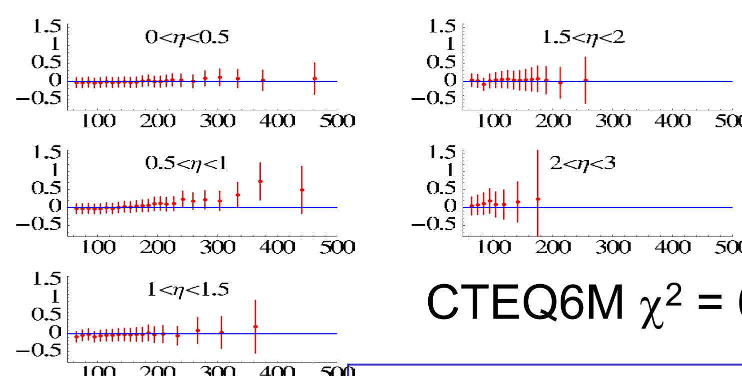
x-Q² reach of DØ's Inclusive Cross Section

- **DØ's most complete cross section measurement extends over |η| < 3.0**
  - complements HERA x-Q^2 range



- **90 data bins**
  - Full correlation of uncertainties
- **Used in CTEQ6 and MRST2001 fits to determine gluon at large x**
  - Enhanced gluon at large x

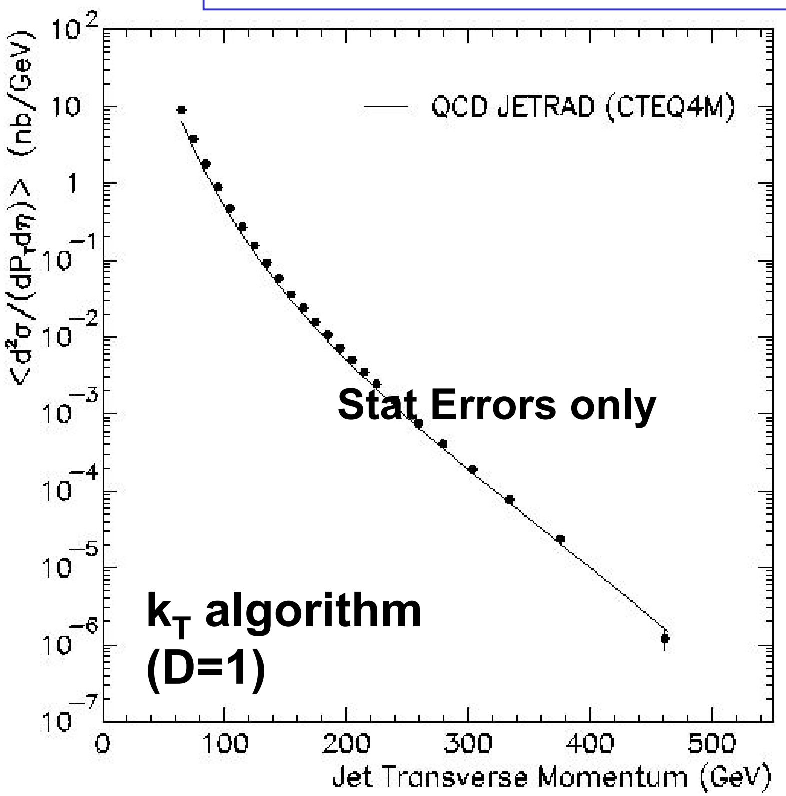


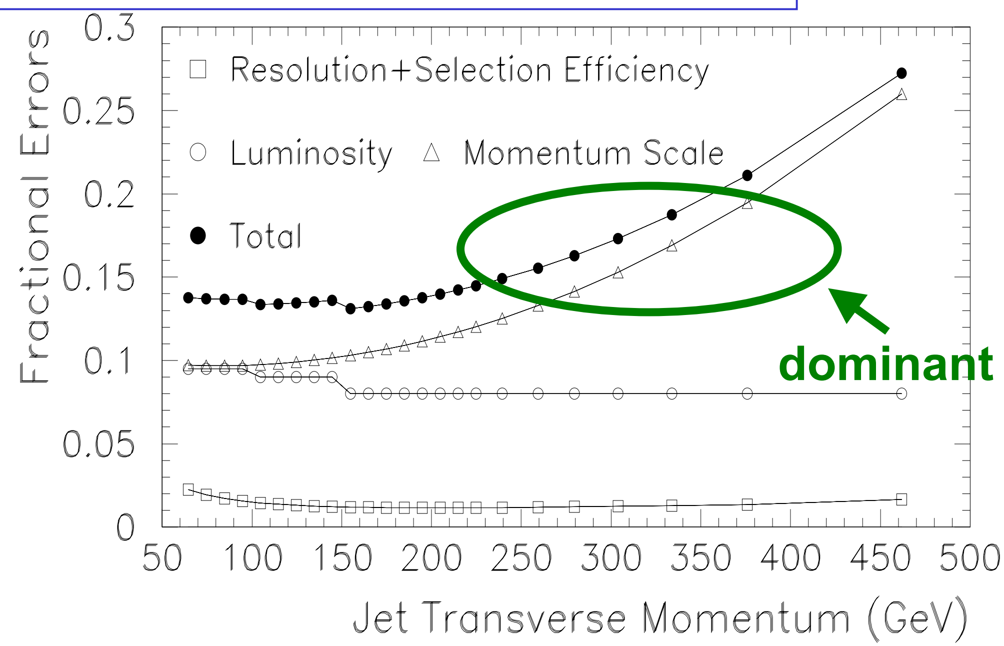


CTEQ6M χ^2 = 65

Run I: kT Inclusive Jet Cross Section

$$\left\langle \frac{d^2\sigma}{dP_T d\eta} \right\rangle (p\bar{p} \to jet + X) = \frac{N}{\Delta p_T \cdot \Delta\eta \cdot L} \cdot \frac{C_{JES} C_{Resol}}{\varepsilon_{ff}} \quad \text{versus} \quad P_T$$

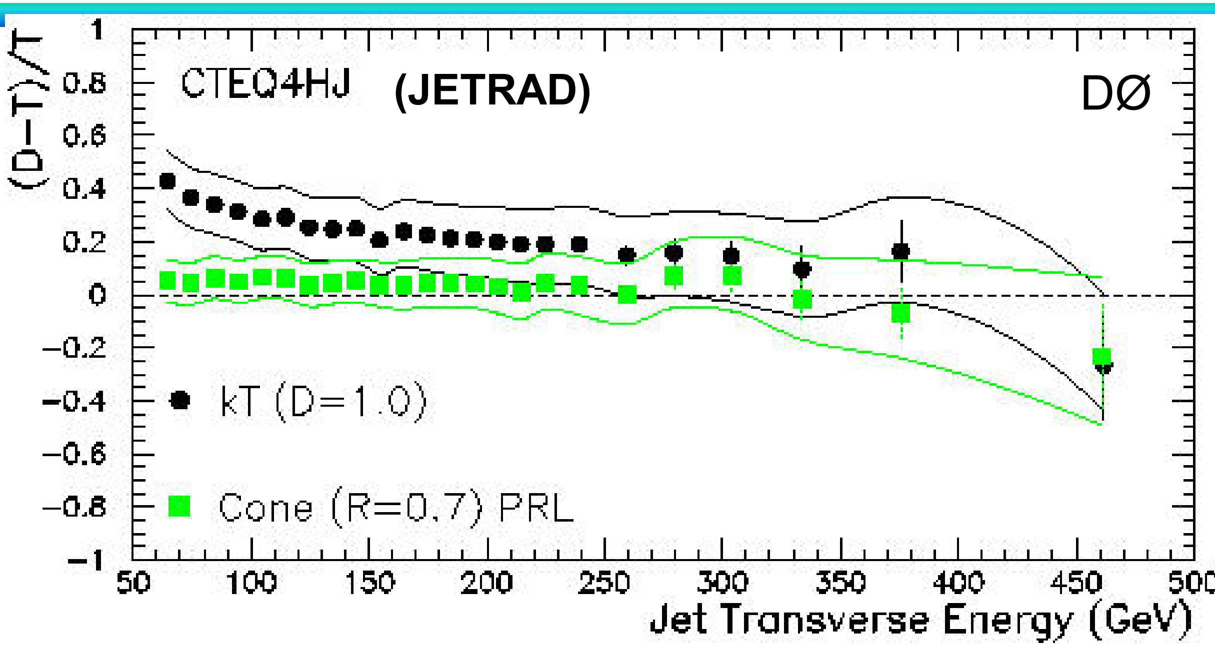




Tot. Err=14 (27)% at 60 (450) GeV

Phys.Lett.B525,2002

Run I: Compare kT with Cone Result



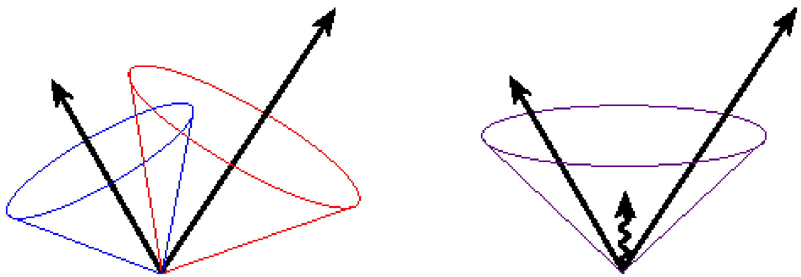
Each result is compared to its own NLO prediction

Unexpected 1-2σ deviation from cone and from predictions, mostly at low p_T

- kT .vs. cone and kT .vs. prediction - in agreement
  - shape – good; normalization – good but more marginal at low PT
  - Hadronization Effects may explain part, but not all of the difference.
- Cone algorithm in very good agreement with the theory
  - Postulation: the theory evolved with the cone algorithm

→These factors led to the decision to use a cone type algorithm in Run II as the primary jet finding algorithm

Run I/Run II Jet Algorithms



Run I Legacy Cone:

- Draw a cone of fixed size around a seed
- Compute jet axis from E_T-weighted mean and jet ET from ΣE_T's
- Draw a new cone around the new jet axis and recalculate axis and new E_T
- Iterate until stable
- Algorithm is sensitive to soft radiation

Run I kT:

- Recombination algorithm based on relative momentum between 'particles'
- Theoretically favored, no split-merge
- To reduce computation time, start with 0.2 x 0.2 preclusters

Improved Run 2 Cone :

"Joint CDF/DØ/Theory Jet Working Group"

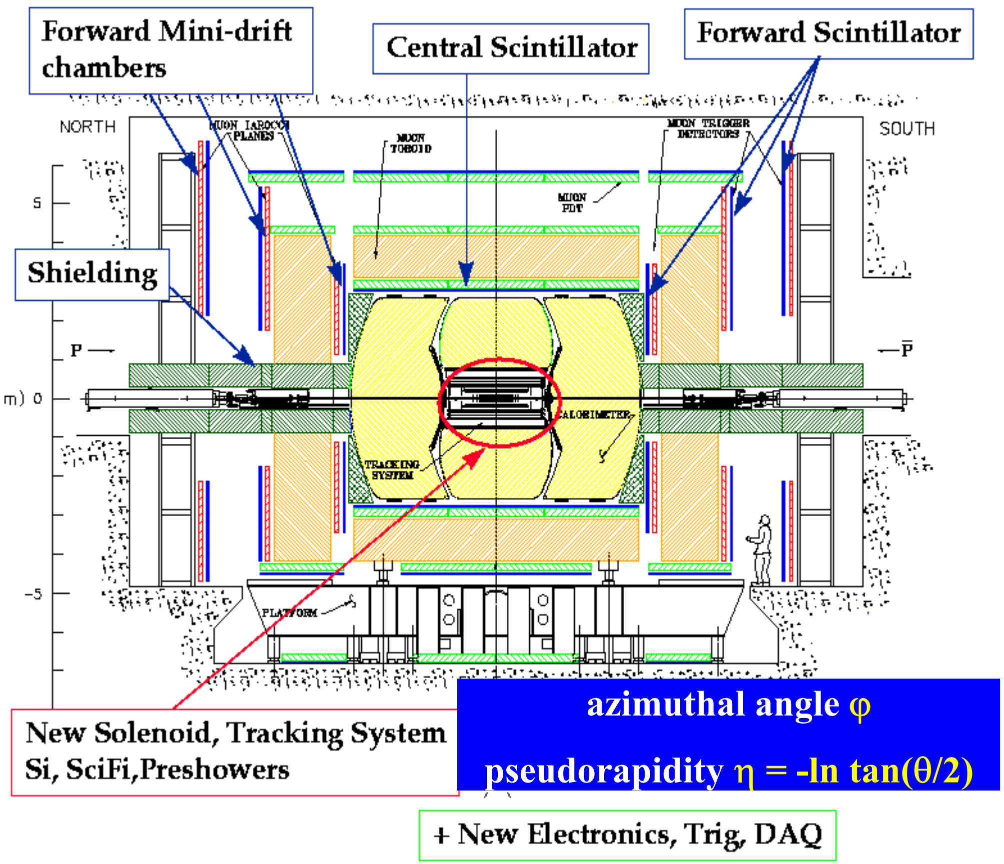
- Use 4-vectors instead of E_T
- Add additional midpoint seeds between pairs of close jets
- Split/merge after stable protojets found
- Algorithm is infrared safe

Run II: Other Algorithms under study:

- Run II k_T
- Preprocessors to kT or cone algorithm:
  - Cell Nearest Neighbor
  - Energy Flow algorithm (tracking)

Results using simple cone for now

Run 2a DØ Upgrade

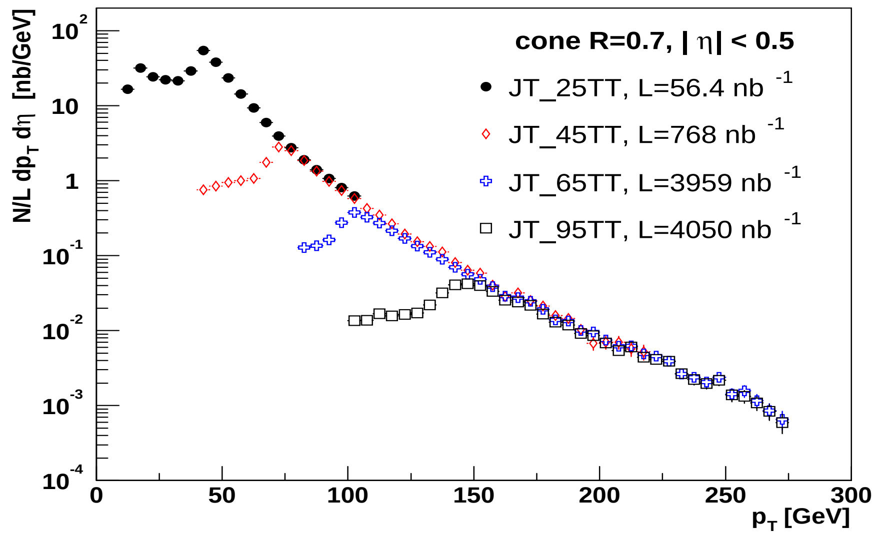


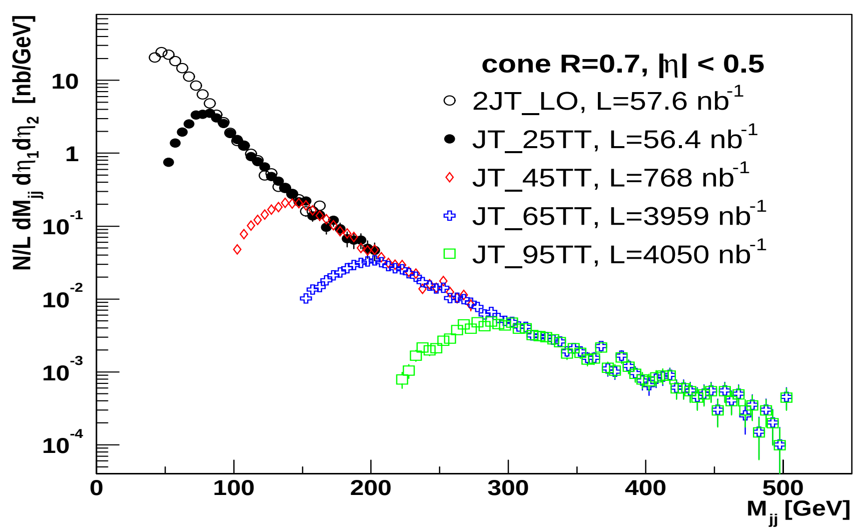
- Calorimetry:
  - LAR: electronics readout and trigger
  - Replace intercryostat detectors
  - Central/forward preshower detectors
- Muon
  - scintillator layers for fast triggering
  - extended drift chamber coverage
  - Beamline shielding
- Central tracking (tracking/momentum)
  - 2 Tesla Solenoid magnetic field
  - Silicon Microstrip Tracker
  - Scintillating Fiber tracker
- New trigger system and DAQ to handle higher event rate
- Forward Proton Spectrometer

✓ Muon, Calorimeter, Silicon fully commissioned and operational

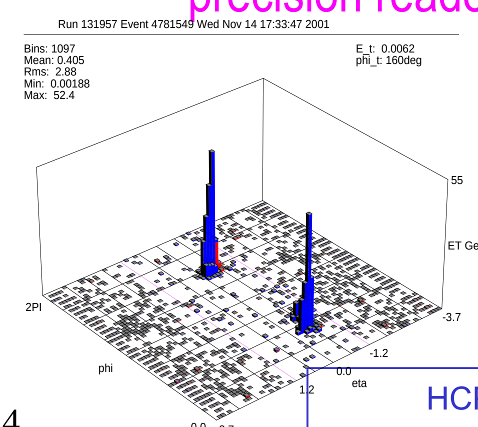
- Fiber tracker and preshowers fully instrumented. Central/ forward electronics complete, commissioning well underway

Jet Triggers in Run II





- **Hardware trigger (L1)**
  - Triggers on calorimeter towers
  - Fast readout
  - Multi-tower triggers
  - Trigger coverage now to $|\eta| < 2.4$!
- **Firmware trigger (L2)**
  - Cluster 3x3 or 5x5 trigger towers around L1 seed towers
- **Software trigger (L3)**
  - Simpified cone jet algorithm on precision readout



2-jet event

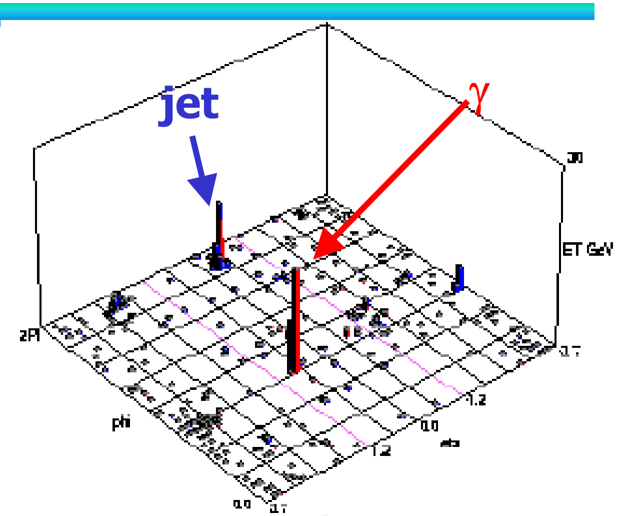
- E_T^{jet1}~230 GeV
- E_T^{jet2}~190 GeV

Run II: Jet Energy Scale

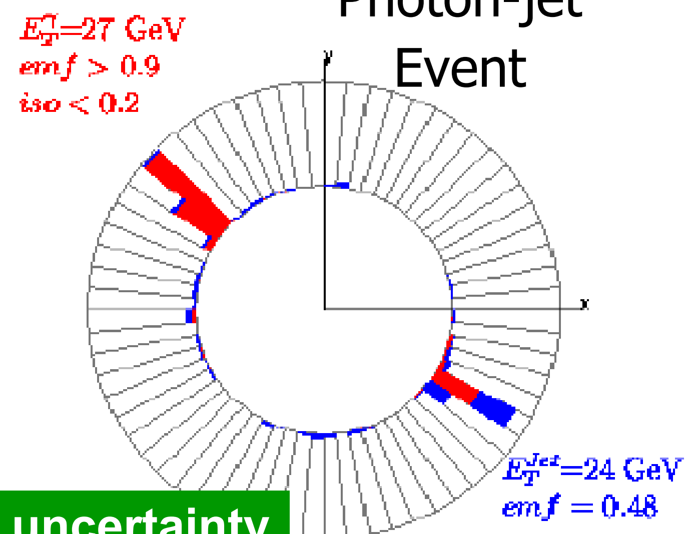
- Correct Jet Energy back to the particle level

$$E_{jet}^{ptcl} = \frac{E_{jet}^{meas} - E_{offset}}{R_{jet}^{calo} R_{jet}^{cone}}$$

- E_{jet} detector jet energy (use cone algorithm)
- E_{offset} energy offset from underlying event, pile-up, Uranium noise (use *Minimally Biased Events*)
- R^{calo} calorimeter response
  - *Calibrate EM response on Z→ee mass peak*
  - *Measure ET balance in γ+jet events*
- R^{cone} energy contained in jet cone
  - *Correct for losses due to out-of-cone showering*
  - *Use MC-energy in cones around the jet axis*



Photon-jet Event

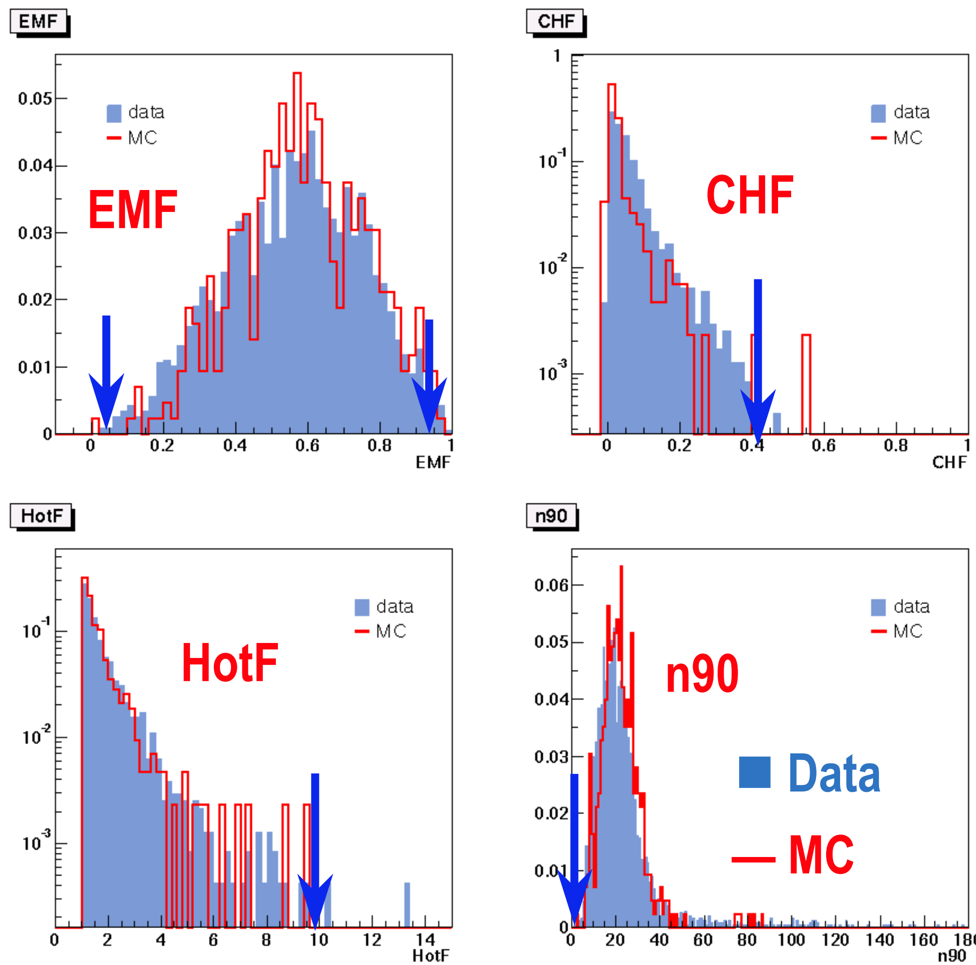


Preliminary correction applied with ~10% systematic uncertainty

Run II: Offline Jet Selection

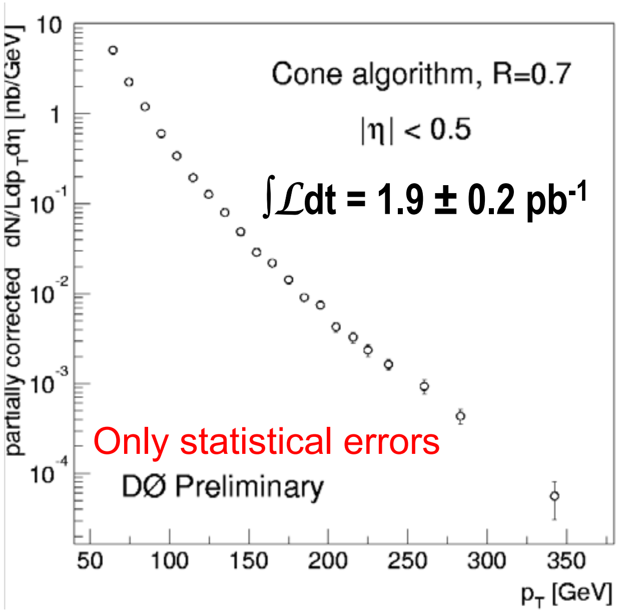
- Central jets (Run 2 cone, R=0.7)
- Event Quality Cuts
  - Number of jets ≥ 1
  - E_{total} in the calorimeter $\leq$ 2 TeV
  - Missing $E_T \leq 70\%$ of the leading jet p_T
  - $Z_{vtx} < 50$ cm
- Leading Jet Cuts
  - Jet $p_T > 8$ GeV (offline cut)
  - $0.05 \leq$ EMF $\leq$ 0.95
  - CHF $\leq$ 0.4 (0.25 tight)
  - HotF $\leq$ 10 (5 tight)
    (HotF = $E_T^{1st\ cell}$ / $E_T^{2nd\ cell}$)
  - n90 > 1 (number of towers that contain 90% of jet E_T)
- Efficiencies from MC
  - Loose: ~100% Tight: ~ 98%
  - ~Flat in η

DØ Run 2 Preliminary

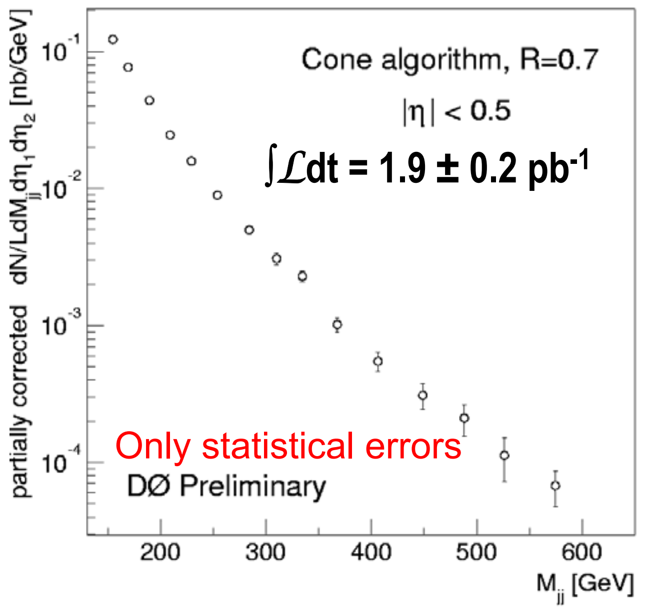


DØ First Run 2 QCD Physics

Inclusive jet pT spectrum at 1.96 TeV



Dijet mass spectrum at 1.96 TeV



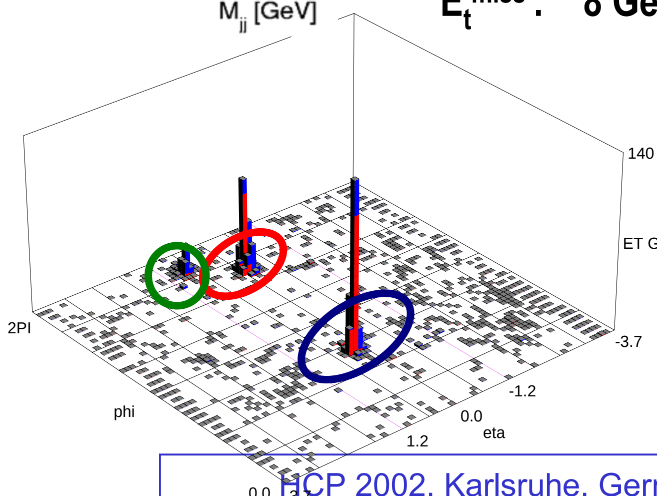
Highest 3-jet event

E_T^{jet1} : 310 GeV

E_t^{jet2} : 240 GeV

E_T^{jet3} : 110 GeV

E_t^{miss} : 8 GeV



- Central jets
- Not fully corrected distributions:
  - Preliminary correction for jet energy scale (but no unsmearing or resolution effects)
    - 30-50% systematic error in cross-section
  - No trigger selection efficiency corrections

Status and Summary

DØ Run I:

- Began new era of precision jet physics, where $\delta_{exp} < \delta_{theory}$
- Cone and kT type jet finding algorithms were successfully implemented and calibrated, making precision measurements of jets in a hadron collider
- Inclusive jet cross section measurements using both algorithms were consistent with NLO calculations, especially in the shape of the distribution.

Cone algorithm results in best agreement with NLO calculations in both shape,normalization over the entire Jet E_T range -- lead to decision to use a cone algorithm as primary jet finding algorithm in Run II

Participation in "Joint CDF/DØ/Theory Jet Working Group" to agree upon Jet finding algorithms and conventions

DØ Run II:

- DØ has been collecting physics quality data for many months in Run II
- First results (using Run II Cone algorithm) presented here:
  - Inclusive jet pT spectrum 60<pT<410 GeV
  - Dijet mass spectrum 150<Mjj<750 GeV
- Expect rich QCD physics program at this increase cm energy utilizing detector upgrades and exploiting large statistics we will have in Run II