(III)

Kt-Jets and Jet Structure and Fragmentation at the Tevatron

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for the CDF and DØ Collaborations

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- Jet Substructure

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- Jet Mass

  DØ D. Lincoln

- Jet Fragmentation

  CDF A. Korytov

$k_\perp$ Algorithm

Arbitrary parameter D

- 1a $\quad d_{i,j} = \min(E^2_{\perp,i}, E^2_{\perp,j}) \frac{(\Delta\eta)^2 + (\Delta\phi)^2}{D^2}$
- 1b $\quad d_i = E^2_{\perp,i}$
- 2 $\quad$ find minimum of $d_{i,j}$ and d_i
- 3a $\quad$ if minimum is $d_{i,j}$
  form a new pseudo-particle k
  i and j removed from the list of particles
- 3b $\quad$ if d_i is the min
  the particle is not "mergable"
  particle forms a jet
- go to step 1

Use 4 momentum scheme to combine particles

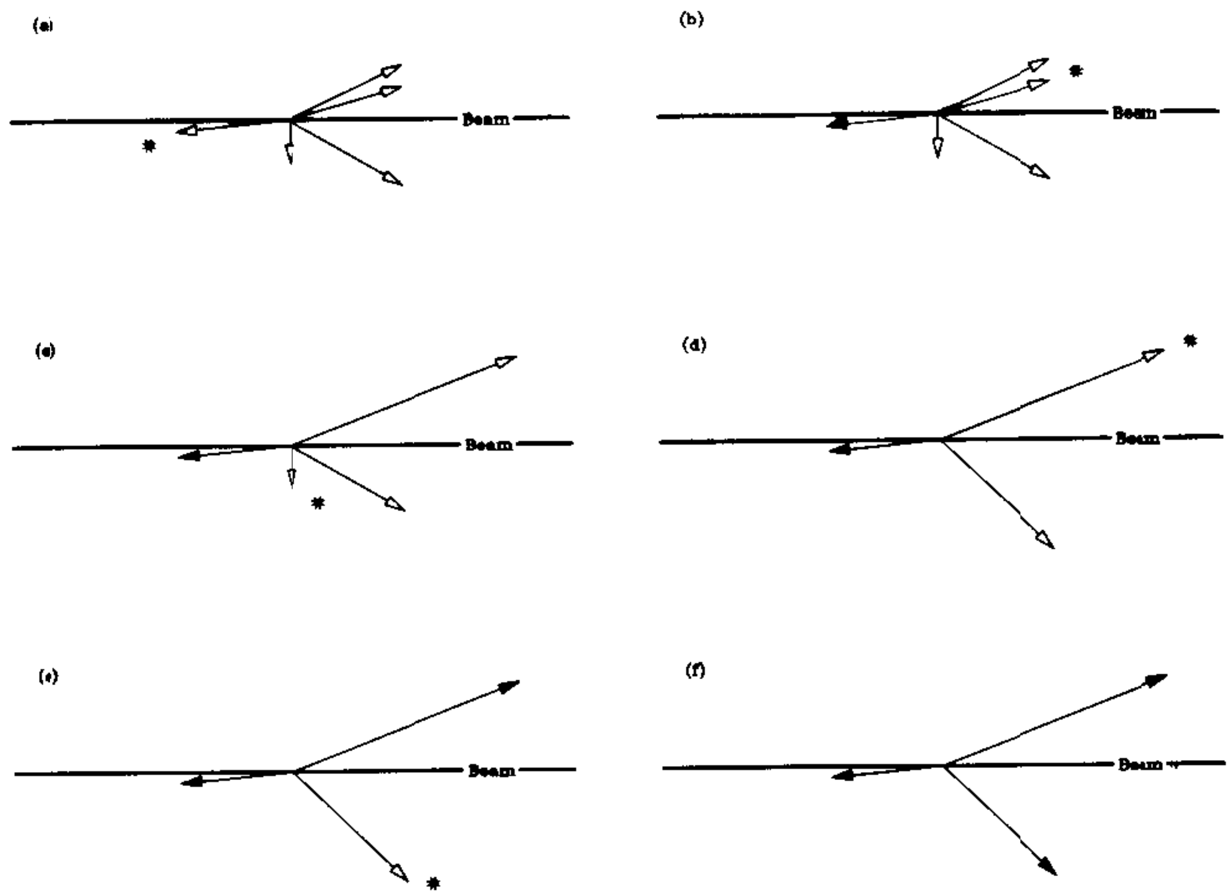
Use y(cut) to set scale for merging

$d_{i,j}/E^2_{\perp,\mathrm{Jet}}$

y(cut) = 1 no subjets

y(cut) $\rightarrow$ 0 each particle is a subjet

Example of Successive Recombination



k_t at DØ

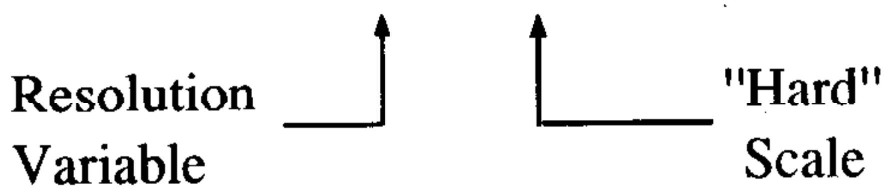
- ★ Order n^3 algorithm (slow)
- ★ 6000 cells $\longrightarrow$ reduce size $\longrightarrow$ 200 precluster
- ★ Precluster $\sqrt{\Delta\eta^2 + \Delta\phi^2} < 0.2$

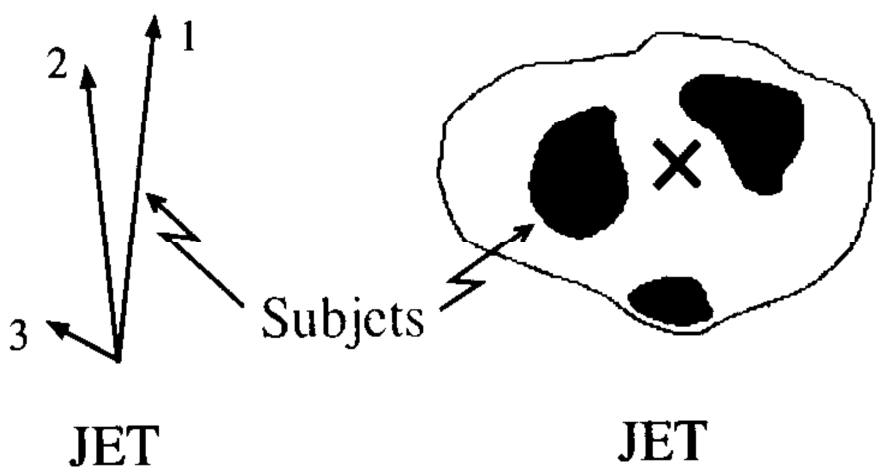
SUBJETS

Rerun K_T algorithm within jet.

Merge minima until all

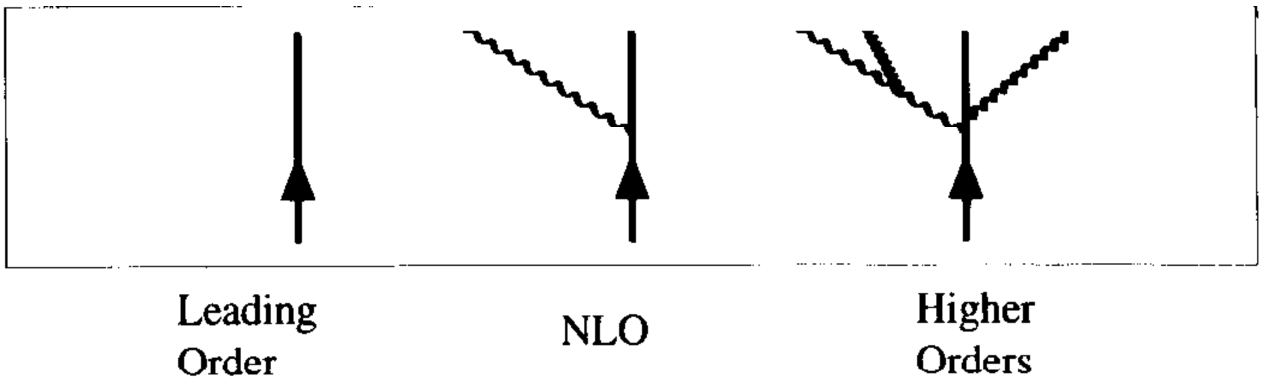
$$d_{i,j} > y_{cut}\ E_{T,jet}^2$$

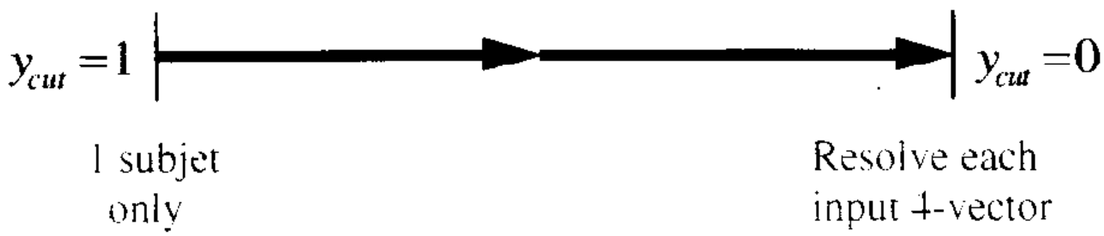




Resolve: large angle soft radiation
small angle hard radiation

Jet Structure

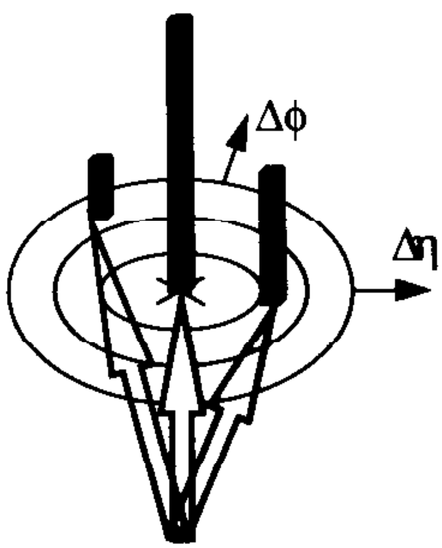


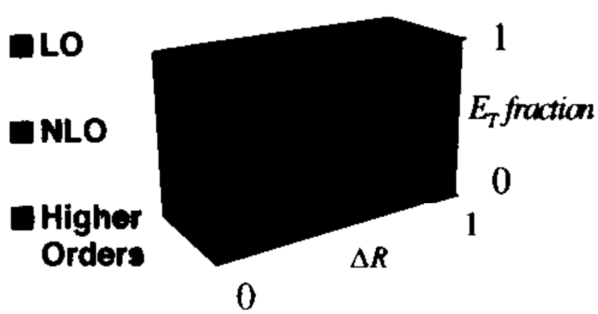


Measure:

1) $< N_{subjet} > \quad vs. \quad y_{cut}$

2) Subjet radial distributions within jet





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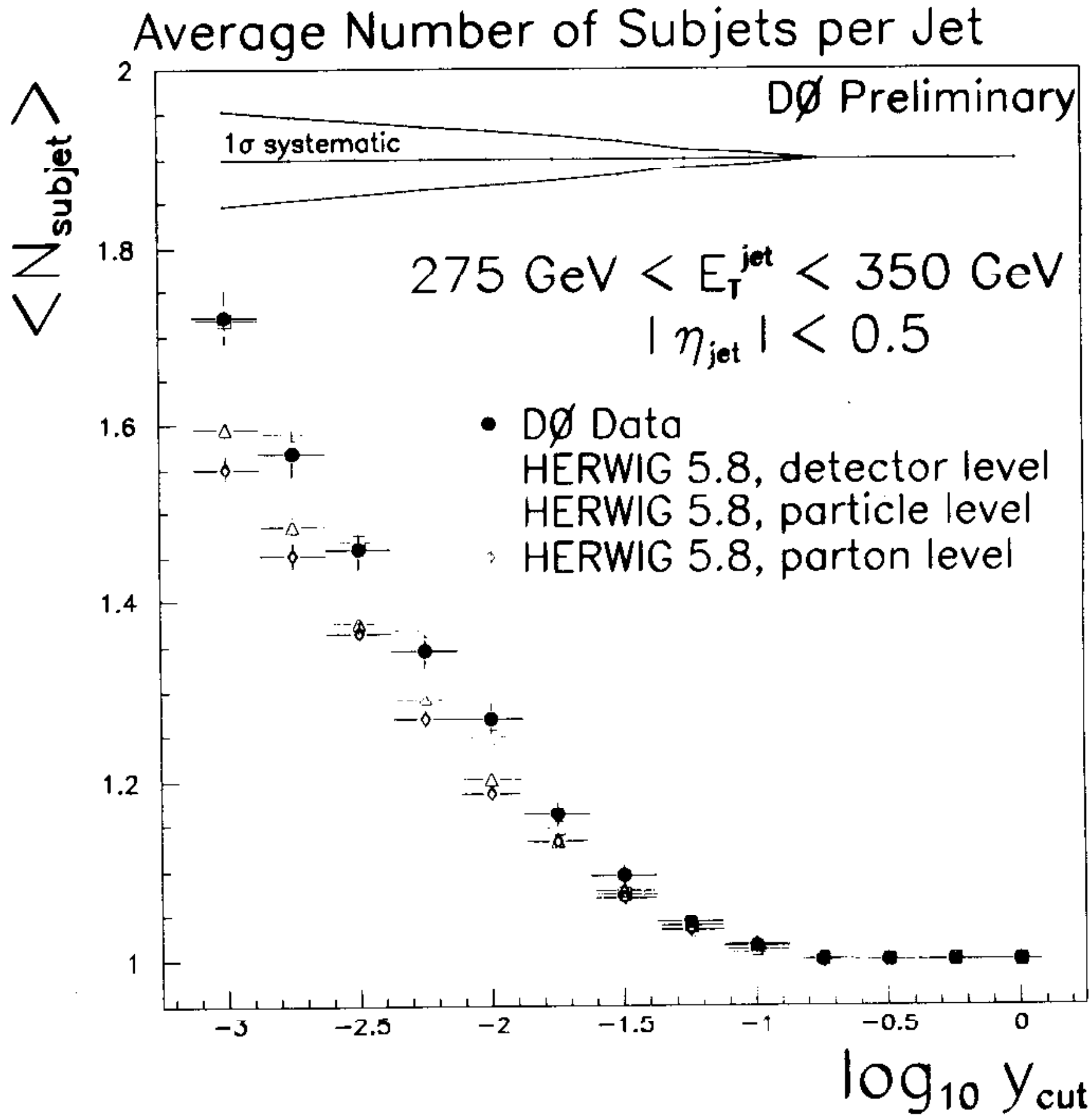
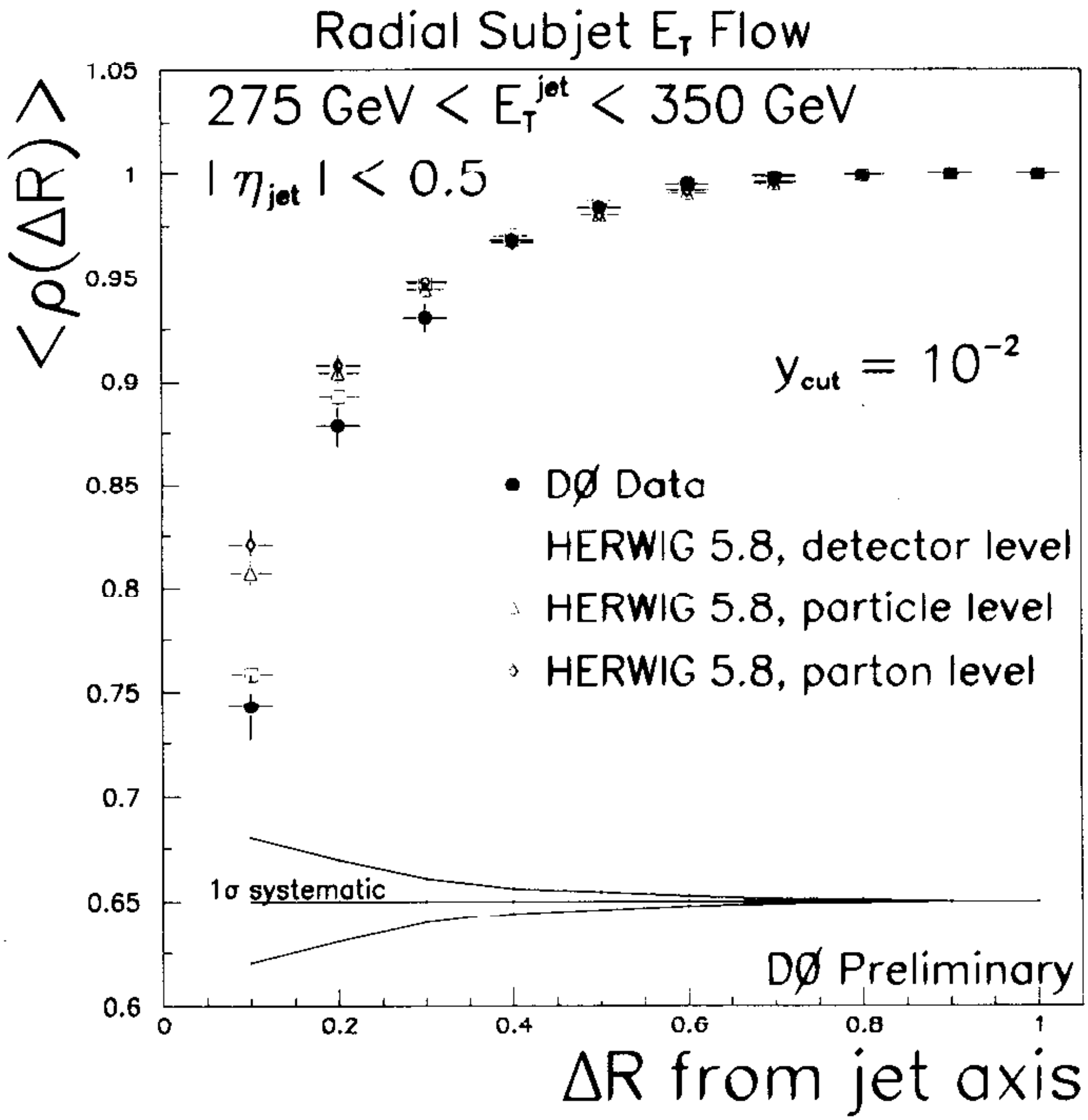

Average Number of Subjets per Jet
DØ Preliminary
1σ systematic
275 GeV < E_T^jet < 350 GeV
| η_jet | < 0.5
DØ Data
HERWIG 5.8, detector level
HERWIG 5.8, particle level
HERWIG 5.8, parton level
<N_subjet>
log10 y_cut
2
1.8
1.6
1.4
1.2
1
−3
−2.5
−2
−1.5
−1
−0.5
0

$$\rho(\Delta R) = \frac{\sum_i p_\perp^{subjet}(\leq \Delta R)}{\sum p_\perp^{subjet}(\leq 1.0)}$$



Conclusions

- DØ has extended its measurement of subjet structure in high E_T jets with the 1995-96 data sample.
- $< N_{subjet} > \approx 1.25$ at $y_{cut} = 10^{-2.0}$

  for 275 GeV $< E_T^{Jet} <$ 350 GeV
- HERWIG 5.8 + detector simulation in good agreement with DØ data
- More subjets in MC at detector level than particle & parton for $y_{cut} \leq 10^{-2.0}$

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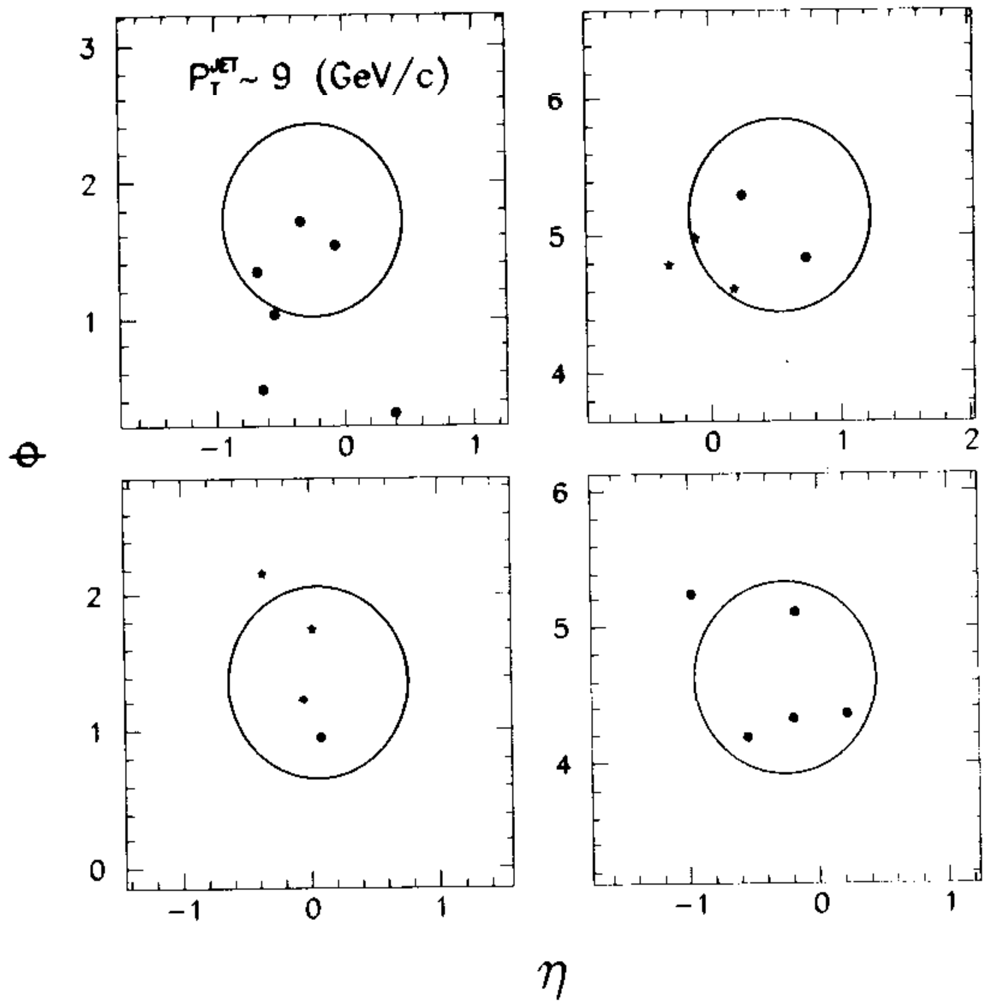
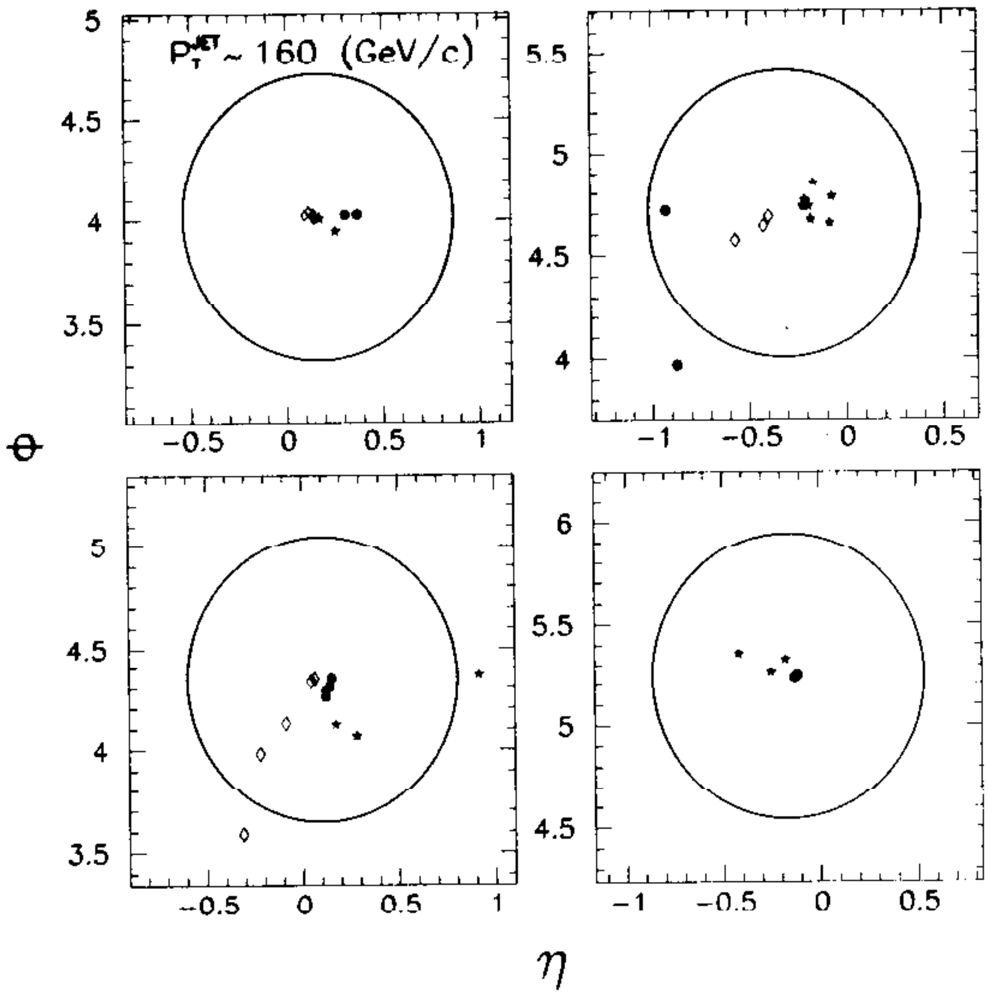
CDF Preliminary



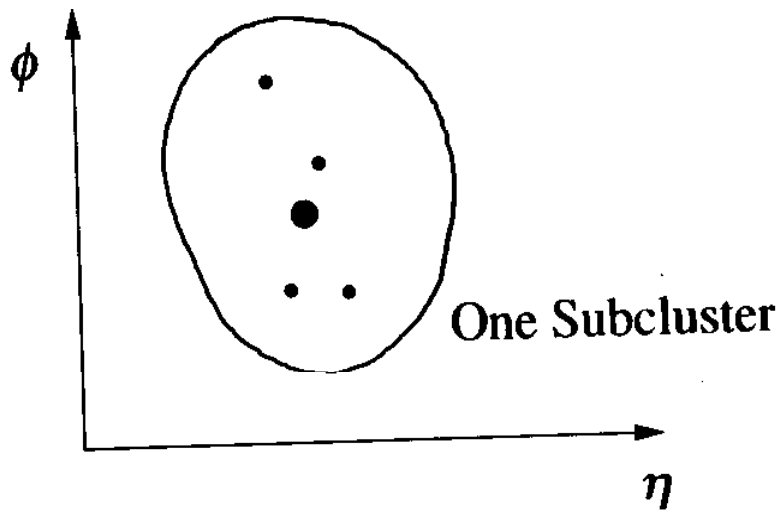
η - ϕ coordinates of charged particles in jet of $P_T^{jet} \sim 9$ GeV/c. Subclusters within a jet ($k_\perp$ algorithm) are indicated by the same symbol.

CDF Preliminary



η - ϕ coordinates of charged particles in jet of $P_T^{jet} \sim 160$ GeV/c. Subclusters within a jet ($k_\perp$ algorithm) are indicated by the same symbol.

Definition of r_{RMS}

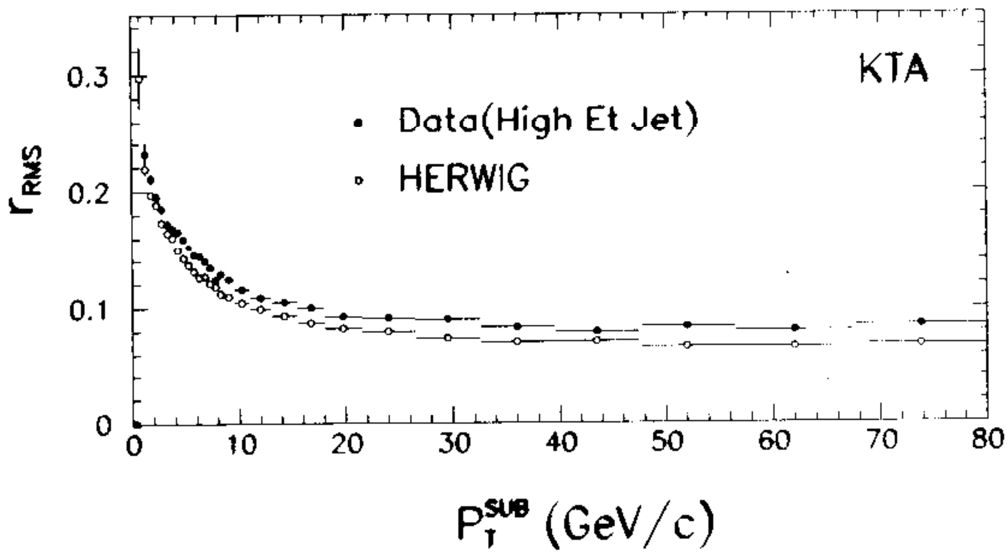


- Subcluster Axis $(\bar{\eta}, \bar{\phi})$
- Track (η_i, ϕ_i)

$$r_{RMS} = \frac{1}{n}\sqrt{\sum_{i=1}^{n}(\phi_i - \bar{\phi})^2 + (\eta_i - \bar{\eta})^2}$$

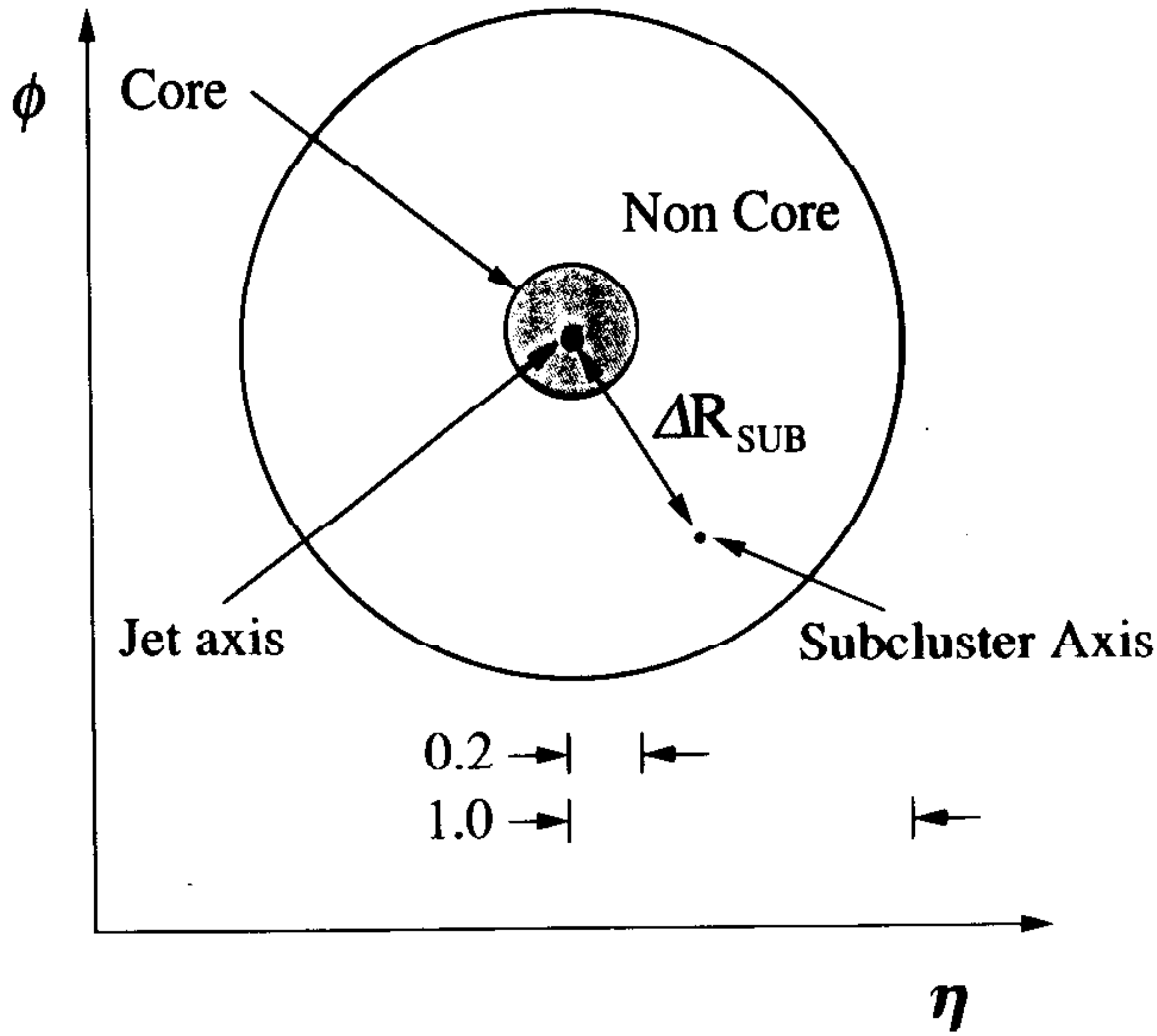
n: number of tracks in a subcluster

CDF Preliminary



Subcluster rms radius versus subcluster P_T (relative to the beam) for jet of $E_T^{jet} > 140$ GeV/c.

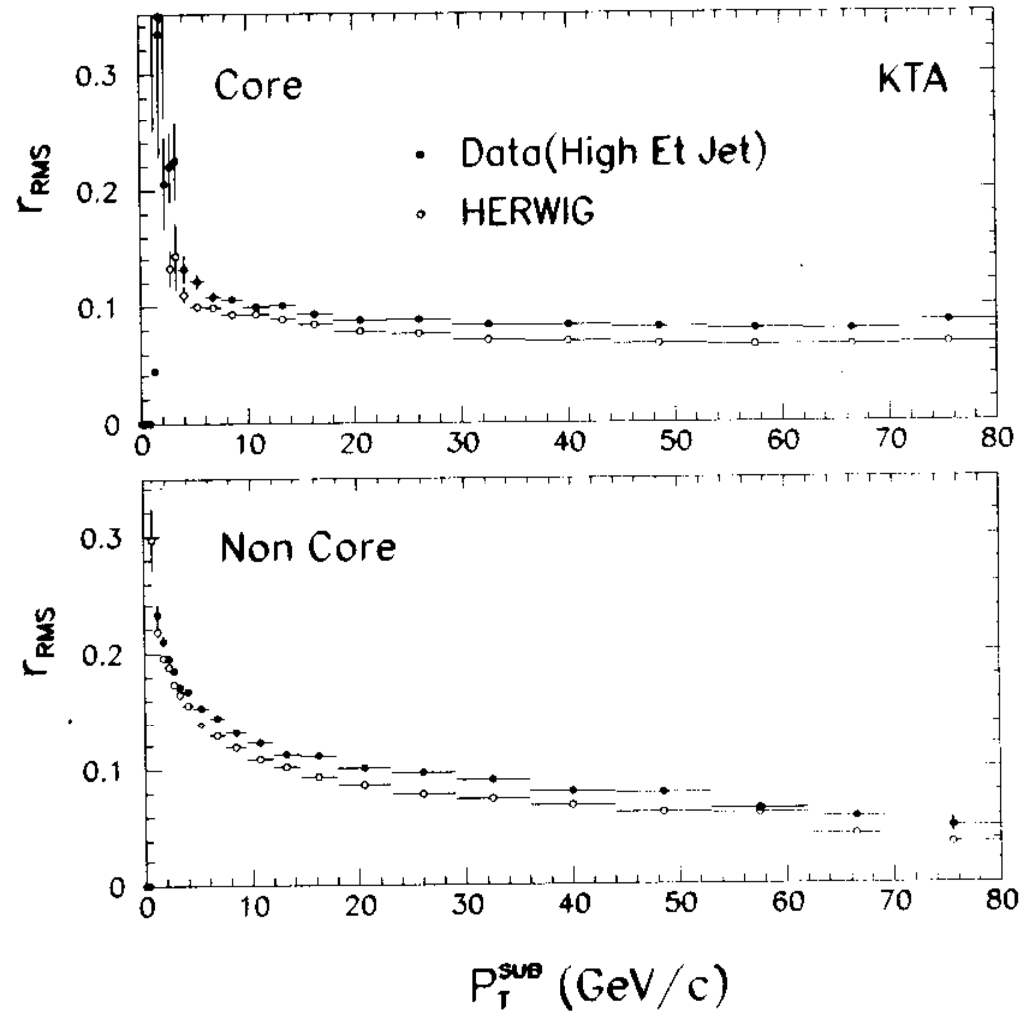
Core and Non Core



Core: $0 \leq \Delta R_{SUB} \leq 0.2$

Non Core: $0.2 < \Delta R_{SUB} \leq 1.0$

CDF Preliminary

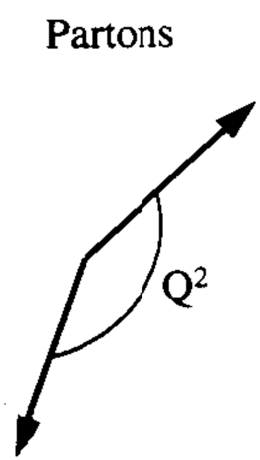


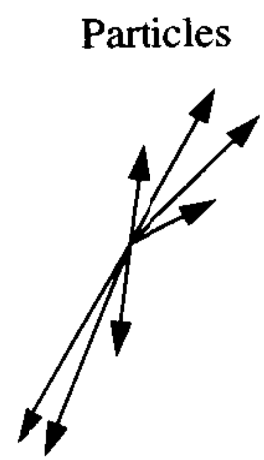
Subcluster rms radius versus subcluster P_T (relative to the beam) for jet of $E_T^{jet} > 140$ GeV/c.

Motivation

- Cone jet algorithm has known deficiencies (jet overlap problem,etc.)
- k_t algorithm more trackable theoretically
- Jet structure studies probe physics not modelled in next-to-leading order theory
- Jet mass explores parton shower regime

Case 1



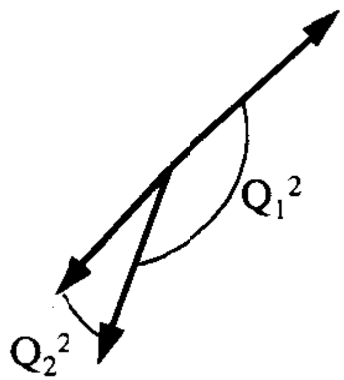


Hard (high Q^2) Physics
Well separated partons
Well separated jets

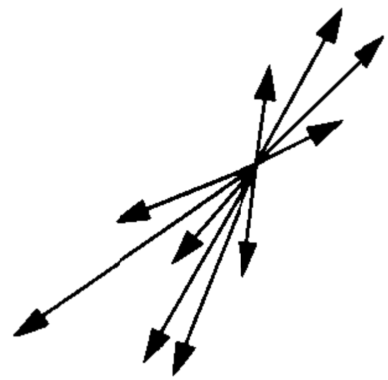
Cone algorithms adequate for this type of physics.

Case 2

Partons



Particles

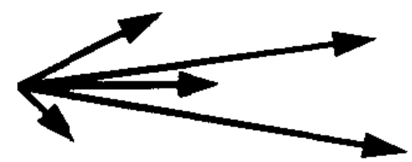


Softer (lower Q^2) physics or
multi-scale physics
Moderately well separated partons
Not all jets equally resolvable

Cone algorithms do not
perform well in
such circumstances

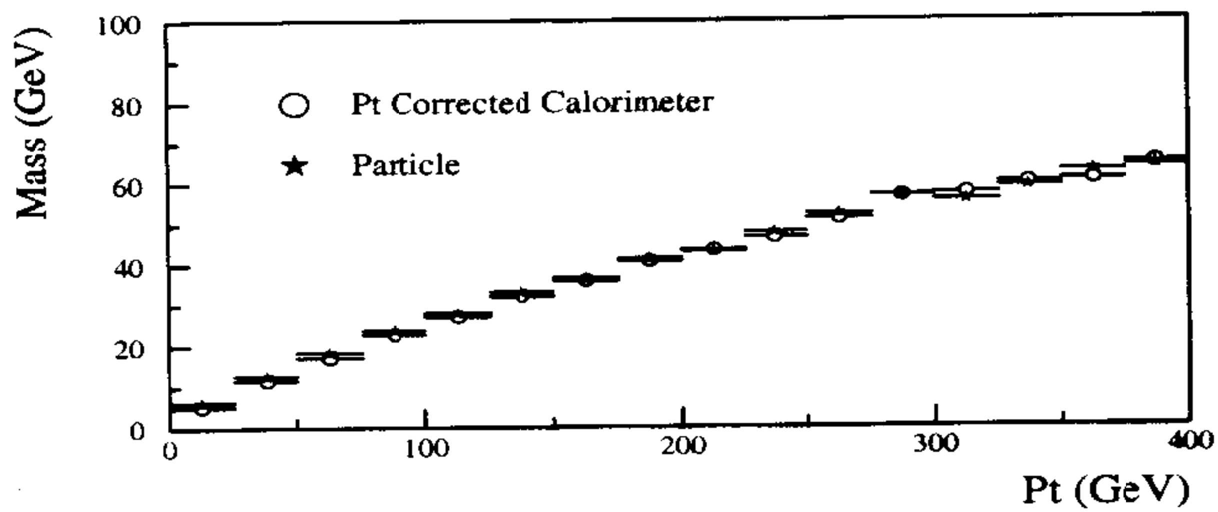
Note: 'Split & Merge' is a trivialization of important underlying physics.

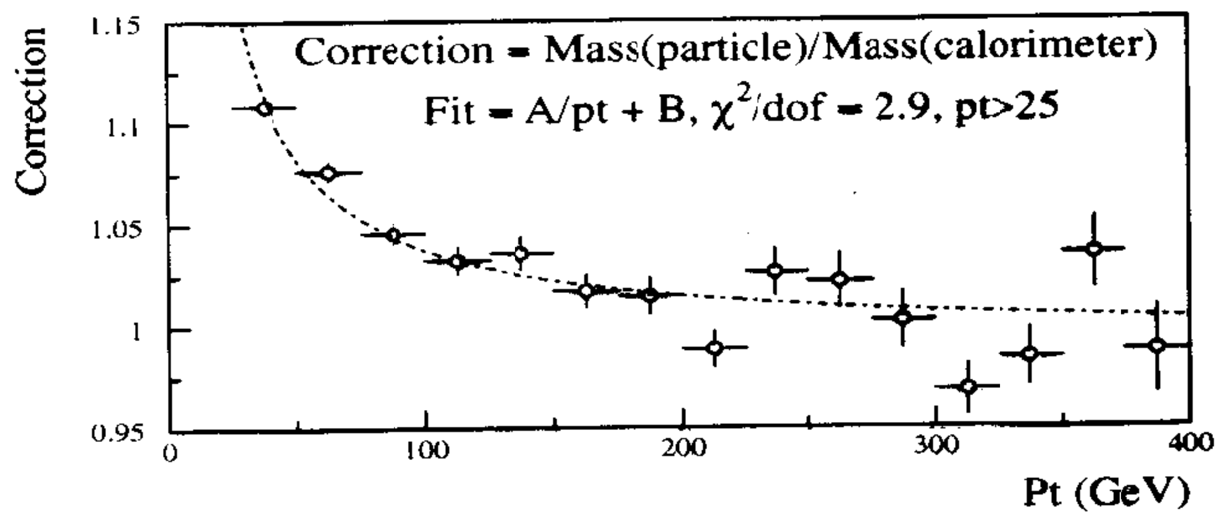
Jet Mass with the k_t Algorithm



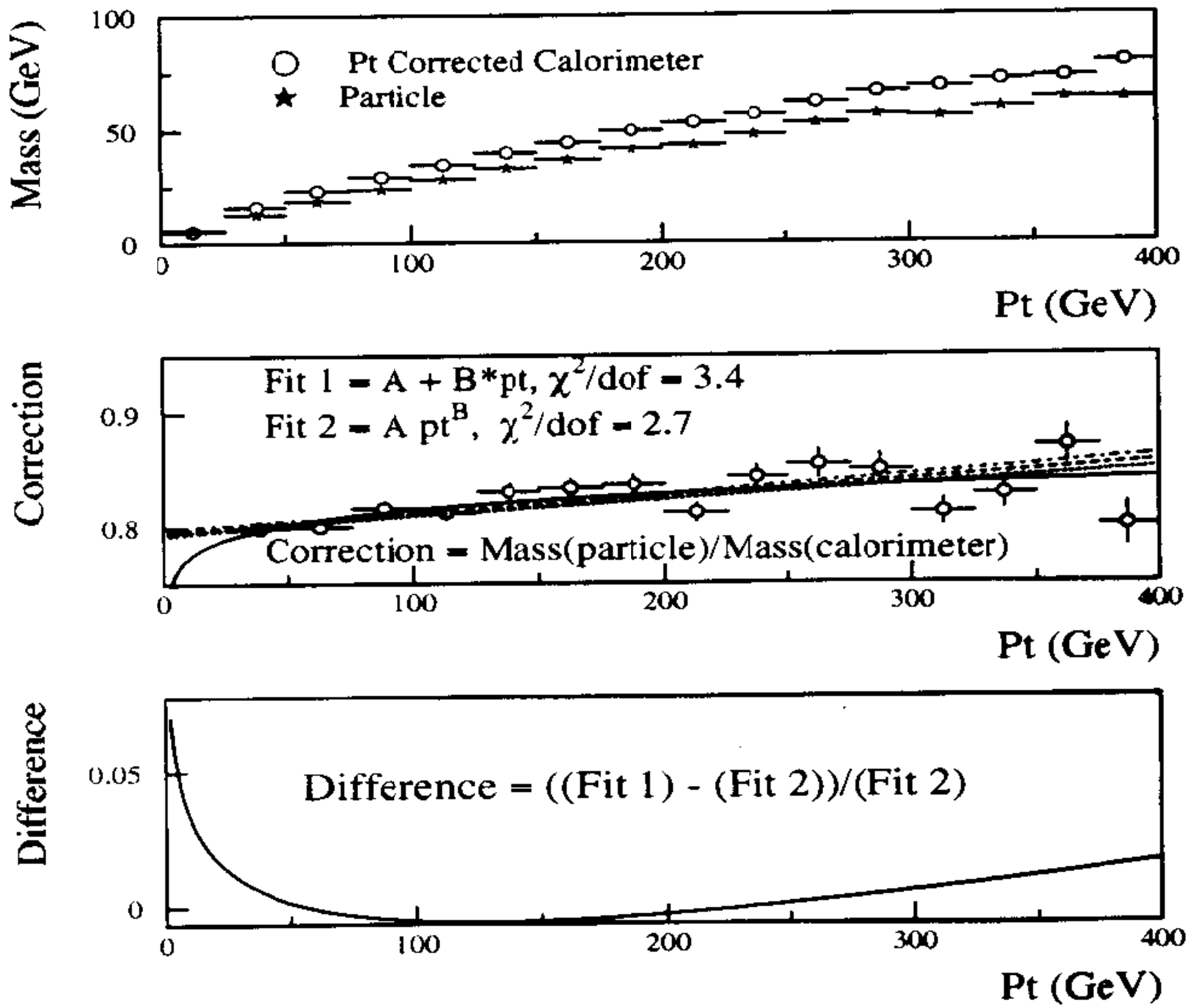
- ★ $E = \Sigma E$, $\vec{p} = \Sigma \vec{p}$
- ★ $E \neq p$, further $E_t \neq p_t$ (use p_t)
- ★ $m \equiv \sqrt{(E^2 - p^2)}$
- ★ Note: jet mass is not a unique way to describe the difference between E & p: m, E/p, & σ all work.
- ★ Note further: $m \sim \sqrt{2}\,\sigma\, p_t$

Mass Correction, w/o Noise (HERWIG 5.8)





Residual Mass Corrections (HERWIG 5.8)



Systematic Error Estimates

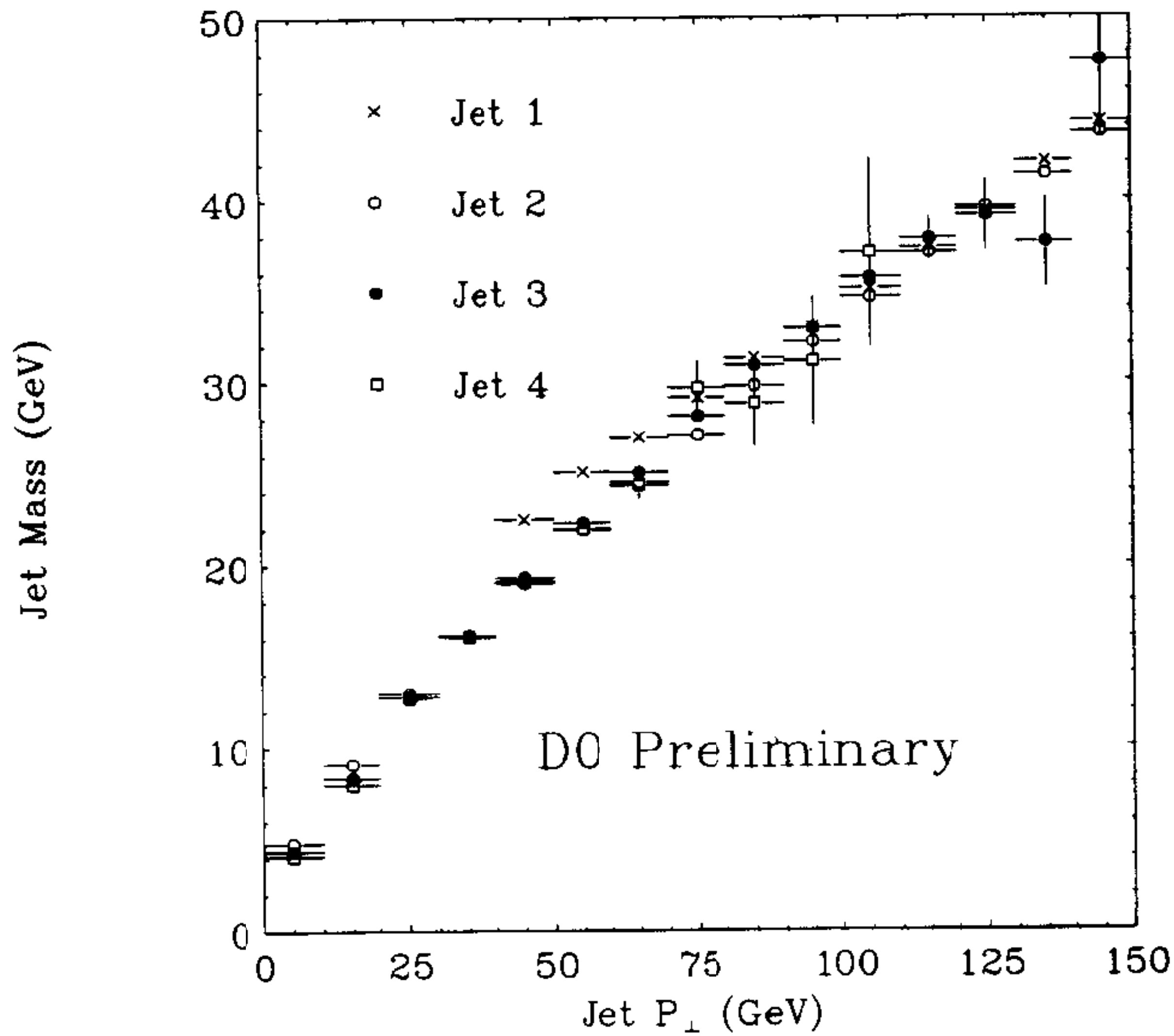
★ p_t scale $(m'/m) \sim \sqrt[3]{(p_t'/p_t)}$ (~ 1.2%)

★ Mass scale linear effect, fit error ~ 1%

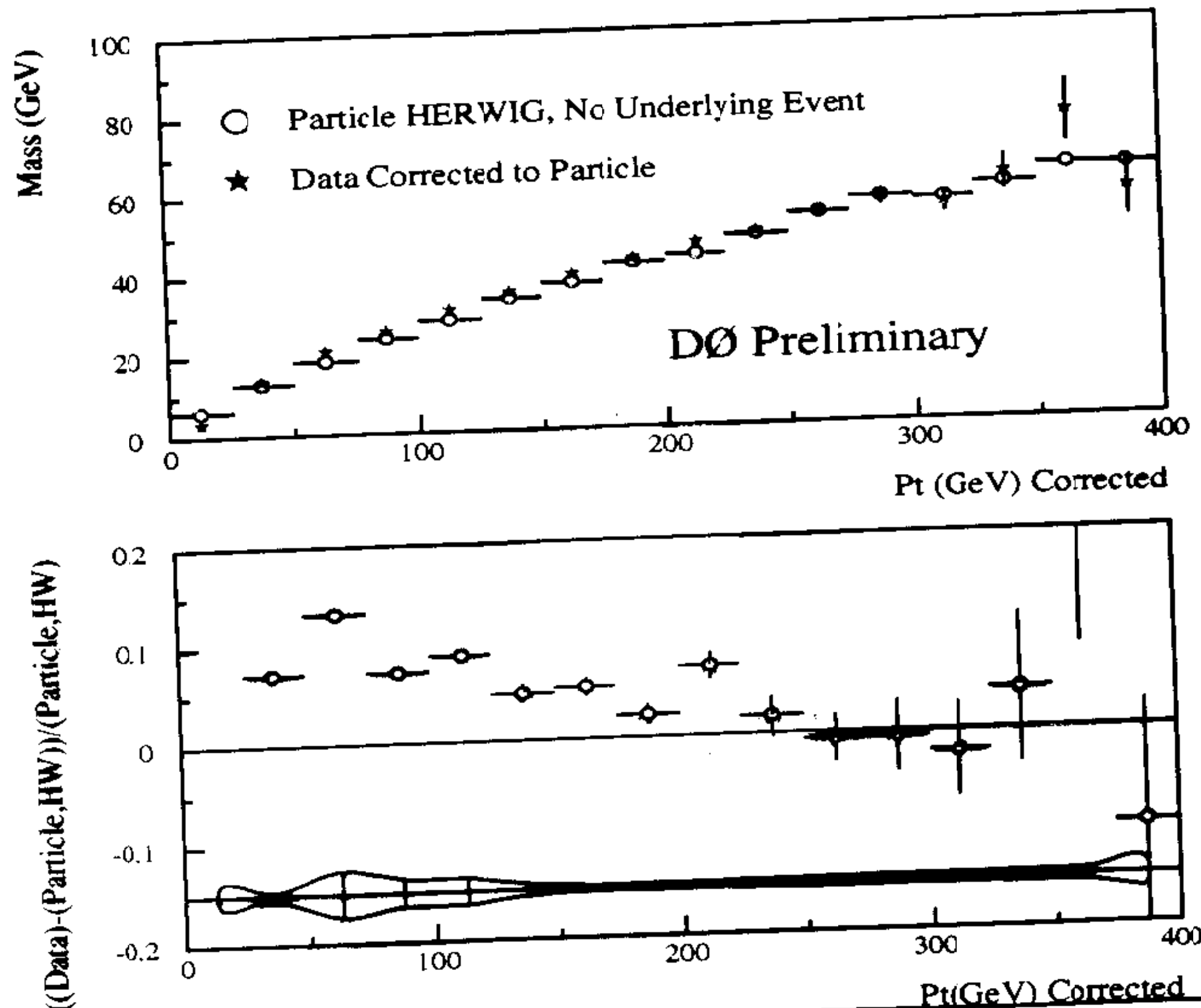
★ Luminosity negligible (Mult. Int. cut works)

★ Jet rank differences (p_t dependent)

Jet 1 vs. Others Differences



Jet Mass as a Function of p_t



TWO STAGES OF JET EVOLUTION:

I - perturbative QCD ($k_\perp > Q_0$)

II - phenomenlogical hadronization

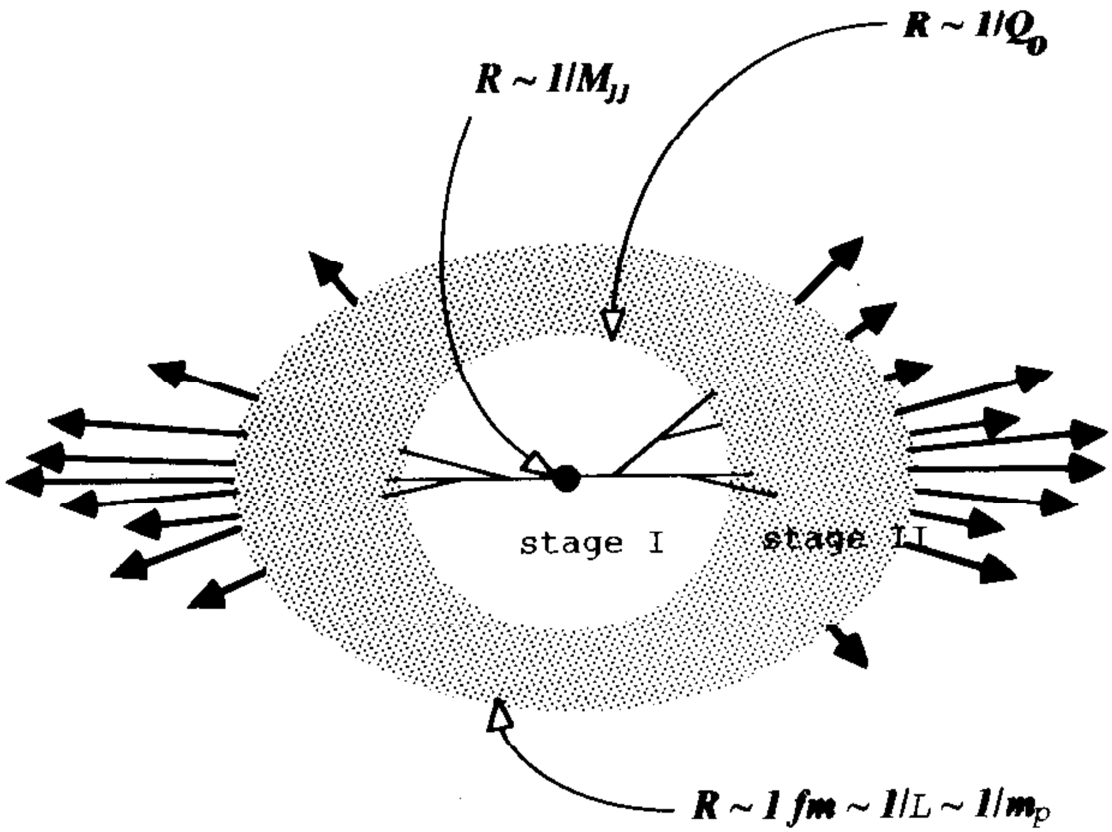


Fig. 1(a). A symbolic depiction of the jet fragemntation with a fuzz which, perhaps, may be handled by perturbative QCD and the stage hadronization. The fuzzy boundary between the stages is, [redacted] a usually associated with K_T cut-off scale Q_0.

Modified Leading Log Approximation
MLLA

- soft divergences $\frac{dk}{k}$
- collinear divergences $\frac{dk_{\mathrm{T}}}{k_{\mathrm{T}}}$
- angle ordering of subsequent emissions
- Theory has two parameters

  $\mathrm{Q_{eff}}$

  Effective cutoff for pertubative evolution

  $\mathrm{const} = \frac{N_{\mathrm{hadrons}}}{N_{\mathrm{partons}}}$

  number of hadrons per parton
  when perturbative evolution stops
- Formula (with 2 parameters) for the inclusive momentum distribution
- $\mathrm{E_{jet}} \times \theta$ (Scaling Law)

  $\mathrm{E_{jet}} = \mathrm{M_{JJ}}/2$

Inclusive Momentum Distributions
Run 1b (1994-1995)
Triggers QCDB_JET4_20, QCDB_JET3_50
and QCDA_JET_140

- 9 Dijet Mass Samples

  $72 < \mathrm{M_{JJ}} < 94$ GeV/c^2

  $94 < \mathrm{M_{JJ}} < 120$ GeV/c^2

  ...

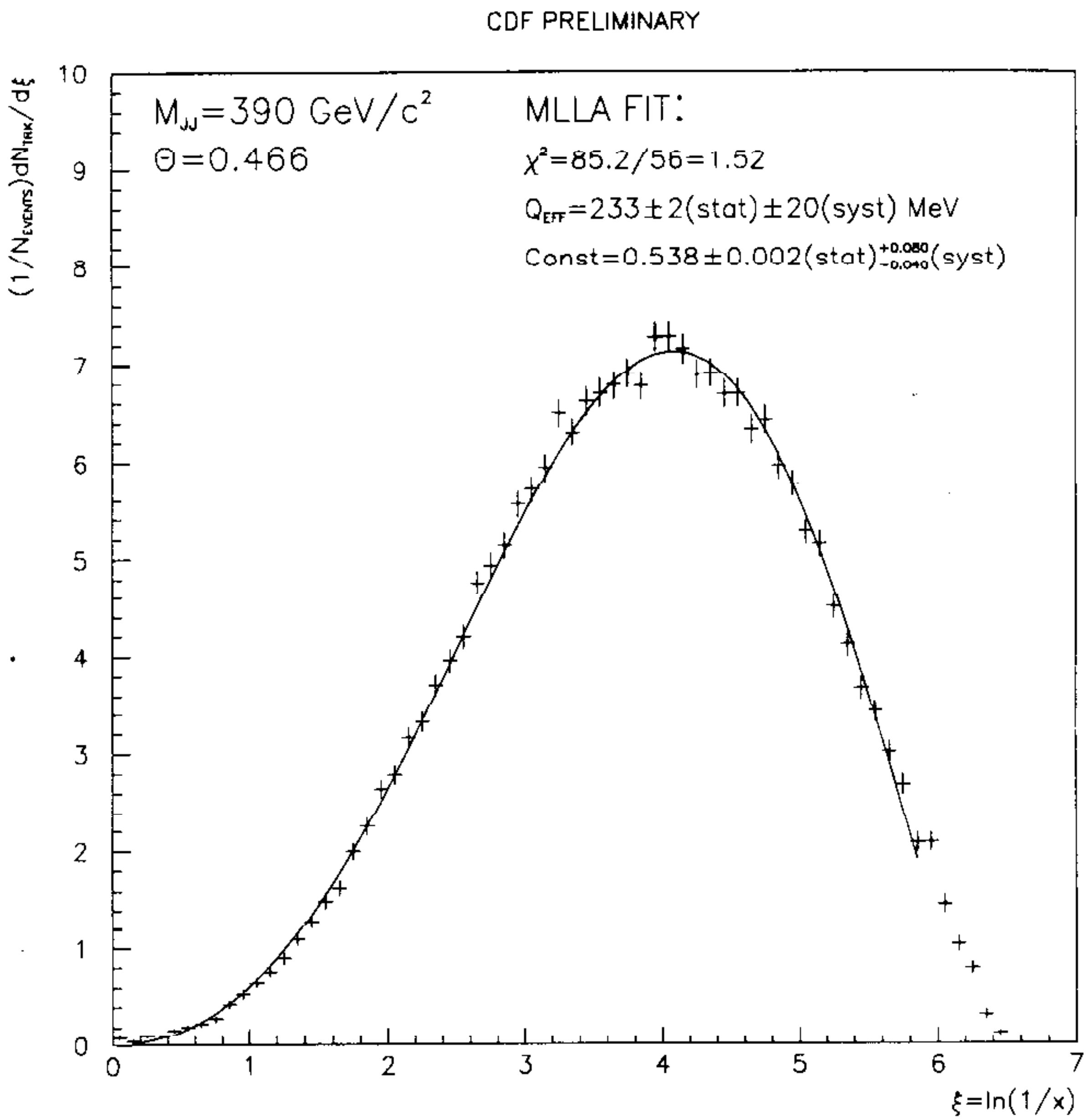
  $570 < \mathrm{M_{JJ}} < 740$ GeV/c^2

- 5 different cone sizes

  $\theta_{\mathrm{cone}} = 0.168, 0.217, 0.280, 0.361, 0.466$

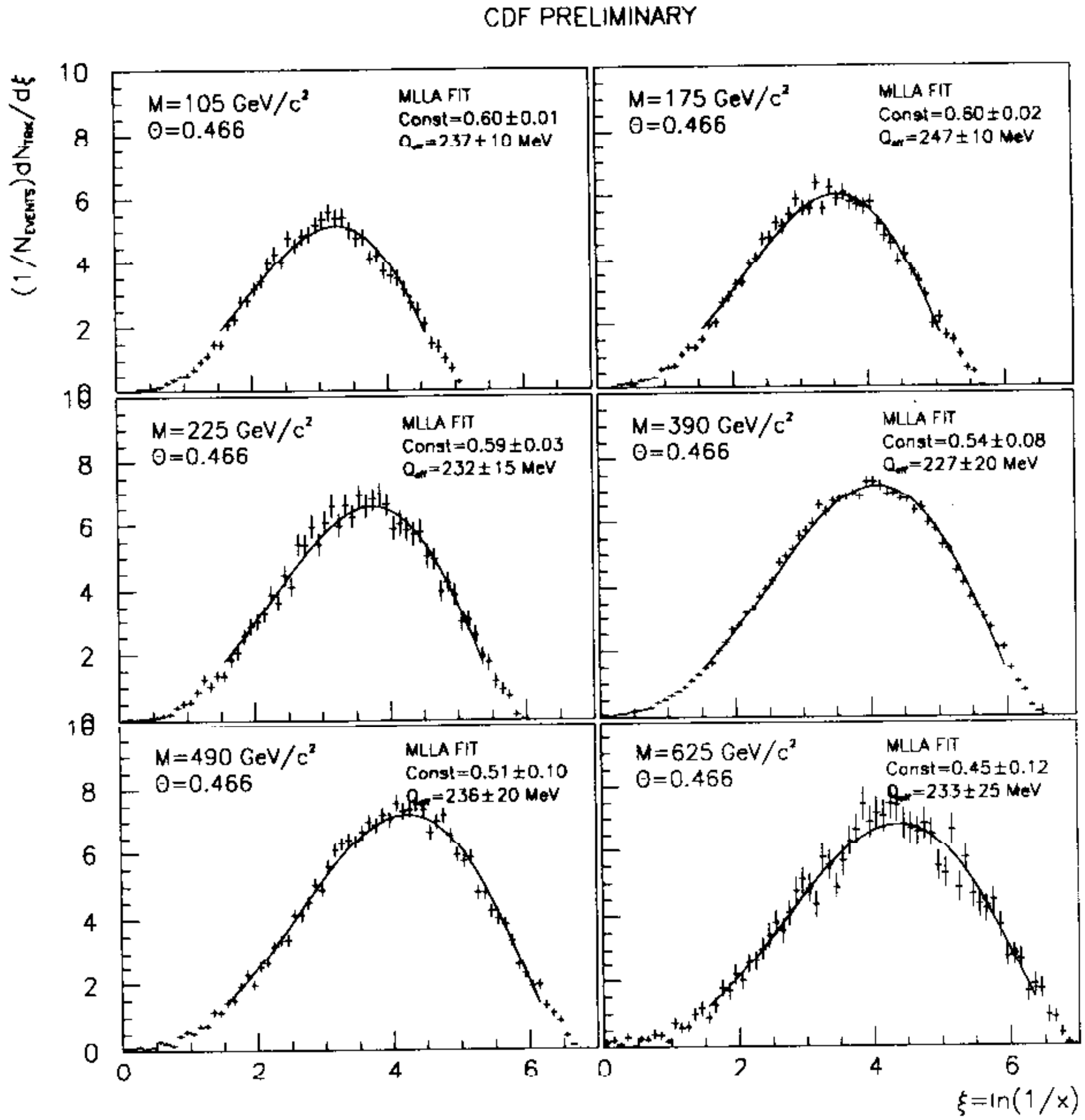
- Cuts Jet_140 3.4

only 1 or 2 vertices	0.44
$\mid z_{vertex} \mid < 60$ cm	
$\mid z_1 - z_2 \mid > 10$ cm	0.88
only 2 energy deposition clusters	0.22
$\mid \eta_{jet} \mid < 0.9$	0.50
well balanced jets	0.83



$$\xi = \ln\left(\frac{E_{jet}}{p_{track}}\right)$$

Fix cone, vary two-jet mass (and hence jet energy)

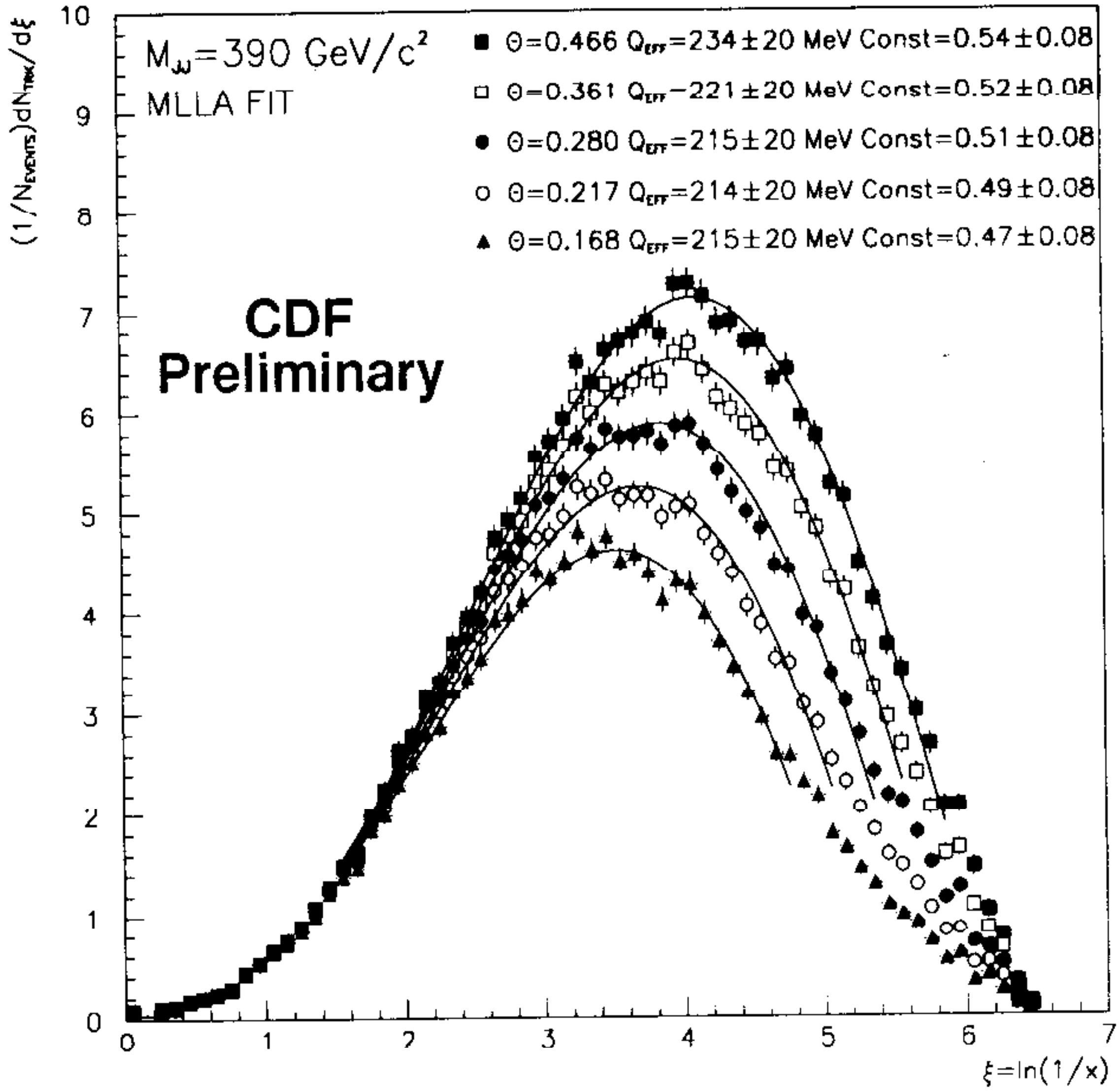


$$\xi = \mathrm{Ln}\,(E_{Jet} / P_{Track})$$

All fits consistent with common values of Qeff ~ 230 MeV and const ~ 0.5 particles/parton

Jet Fragmentation Function compared with QCD Modified Leading Log (MLLA) Predictions

Fix two–jet mass (hence jet energy) and vary cone containing charged tracks:

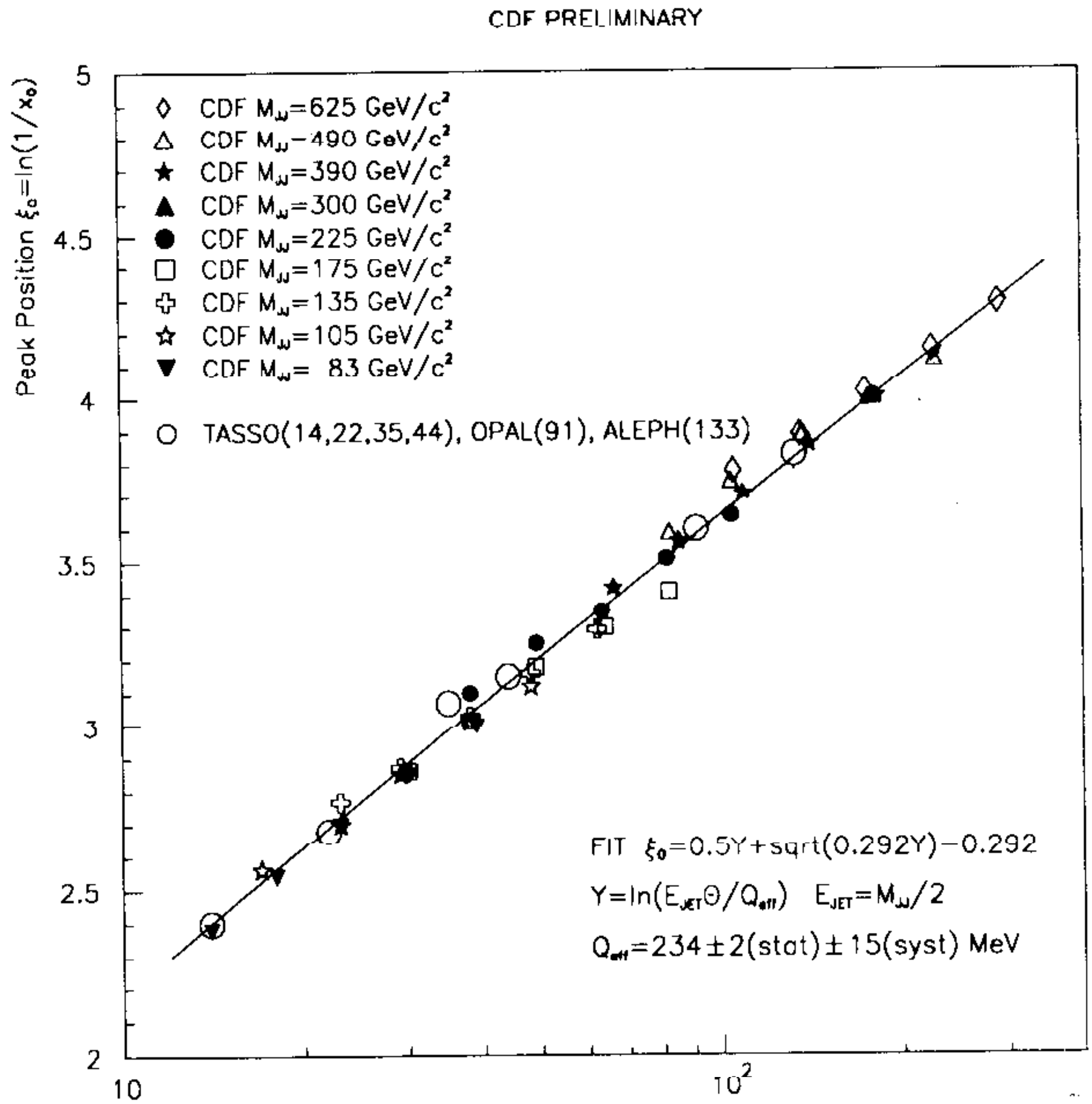


$$\xi = \mathrm{Ln}\,(E_{Jet} / P_{Track})$$

Note: MLLA –> 2 parameters:

Perturbative cutoff scale: Qeff
Normalization = number particles/parton: const

MLLA Scaling seems OK



$M_{JJ}\cdot\ \theta$ (GeV)

Conclusions
Modified Leading Log Approximation
MLLA

- Theory has two parameters

  1 Effective cutoff for pertubative evolution

  $Q_{eff} = 230 \pm 20$ MeV

  2 Number of hadrons per parton when perturbative evolution stops

  $\text{const} = \frac{N_{hadrons}}{N_{partons}} = 0.5\text{-}0.6$

- Formula (with 2 parameters) for the inclusive momentum distribution

  Fits have good χ^2

- $E_{jet} \times \theta$ (Scaling Law)

  $E_{jet} = M_{JJ}/2$

  Scaling is observed