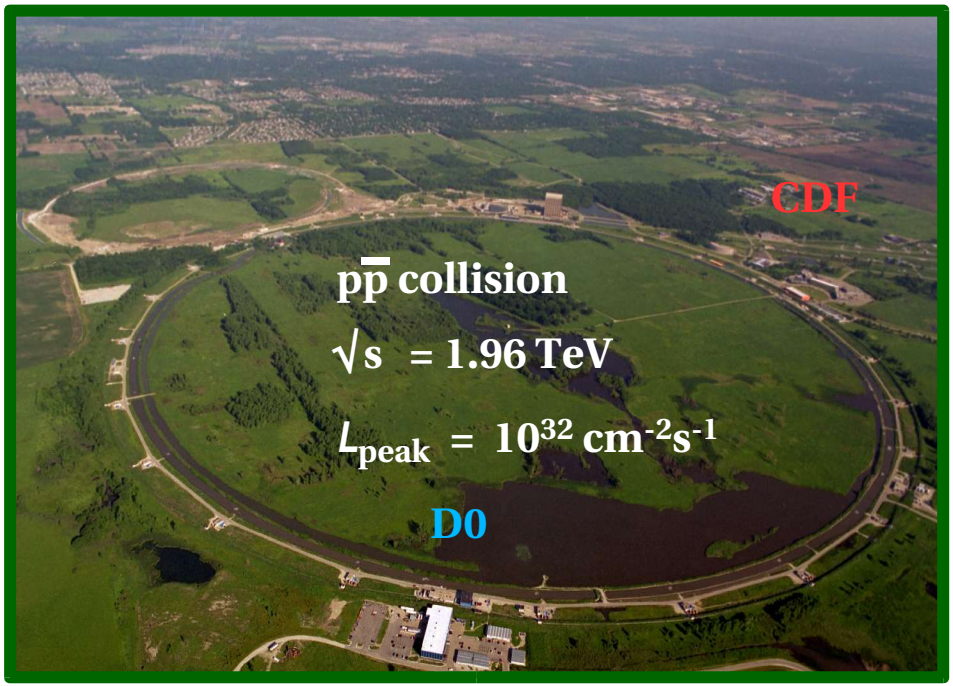
Jet Fragmentation Studies at CDF



Lester Pinera

UNIVERSITY OF FLORIDA

for CDF Collaboration

Overview

Momentum distributions of particles in jets

- PRD 68 (2003) 12003

Multiplicity of particles in jets (including g/q-jet differences)

- PRL 94 (2005) 17802
- PRL V87 No.21 (2001) 211804

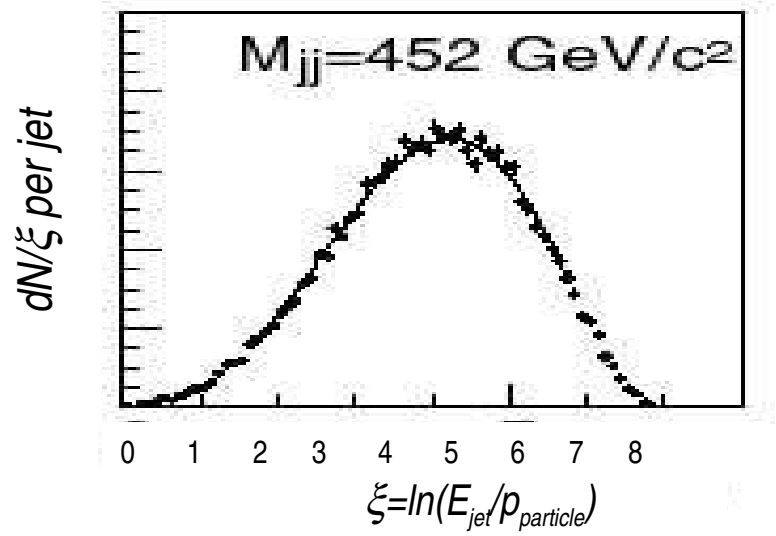
Momentum correlations of particles in jets

k_T-distribution of particles in jets (k_T with respect to jet axis)

Past CDF Results

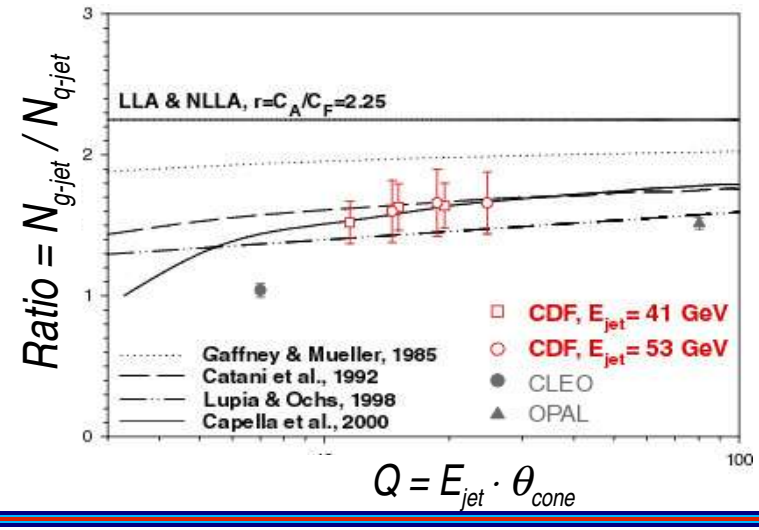
Momentum distribution of charged hadrons in jets:

- Well described by MLLA
  - dijet mass range 80-600GeV
  - cutoff $Q_{eff} = 230 \pm 40$ MeV
  - $N_{(\pm)Hadrons} / N_{Partons} = 0.56 \pm 0.10$



Ratio of charged hadron multiplicities in gluon & quark jets:

- Agrees with NNLLA
  - r = 1.6 (measured)



Implications:

- pQCD calculations carried out down to scale $Q \sim \Lambda_{QCD} \sim 200$MeV
- Local Parton-Hadron Duality

Momentum Correlations in Jets

Theory: C.Fong & B. Webber
(1990) Phys.Lett. B241:255

→ Consider all particle pairs in a small cone around jet axis

$$R(\xi_1,\xi_2) = \frac{\left(\frac{dN}{d\xi_1 d\xi_2}\right)}{\left(\frac{dN}{d\xi_1}\right)\left(\frac{dN}{d\xi_2}\right)} \quad \text{where} \quad \xi = \ln\left(\frac{E_{jet}}{p_{particle}}\right)$$

mixes together momentum correlations and multiplicity fluctuations

Effects are decoupled using binomial moments from theory

Independant of Multiplicity Fluctuations →

$$C(\xi_1,\xi_2) = \frac{\left(\frac{dn}{d\xi_1 d\xi_2}\right)}{\left(\frac{dn}{d\xi_1}\right)\left(\frac{dn}{d\xi_2}\right)} = R(\xi_1,\xi_2)\frac{\langle N\rangle^2}{\langle N(N-1)\rangle}$$

Distributions normalized to unity

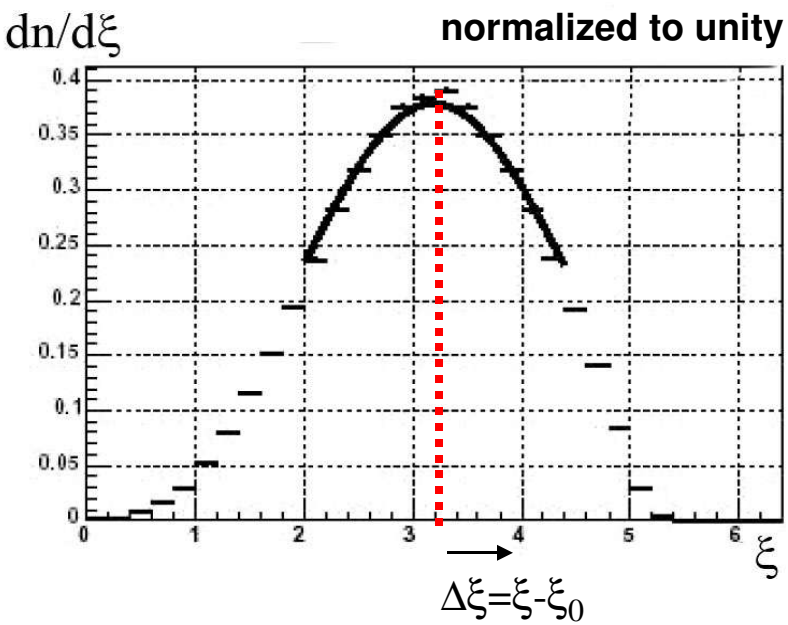
Momentum Correlations: Theory

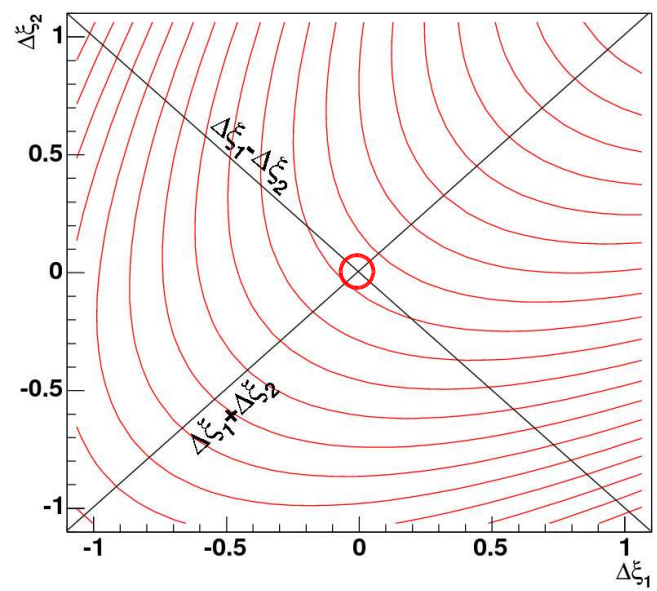
Around the peak of the inclusive momentum distribution, Fong & Webber predict:

$$C(\xi_1,\xi_2) = C_0(E_{jet}) + C_1(E_{jet})\cdot(\Delta\xi_1+\Delta\xi_2) + C_2(E_{jet})\cdot(\Delta\xi_1-\Delta\xi_2)^2$$

→ C_0 & C_1 always positive
→ C_2 always negative

Ridge-like structure:
- Particles with like momenta correlate
- Correlation is stronger for soft particles





Momentum Correlations: Measurement

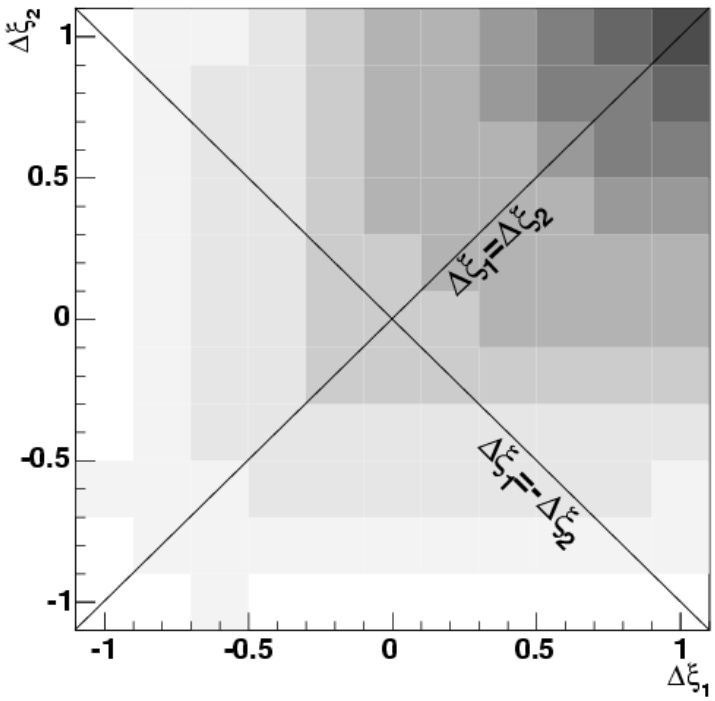
Strategy:

- Consider well balanced dijet events (M_{jj} = 60-600GeV)
- Jet axis in the central region $|\eta| < 0.9$
- Cone jet algorithm with R = 1.0
- Events with only one vertex
- Measurement is done in the dijet center-of-mass frame
- Consider tracks within cone of $\theta_c = 0.5$
- Remove secondaries (conversions, etc. . .)
- Unfold a small underlying event contribution (complementary cone)

Momentum Correlations: Data (1)

Particle correlations follow the pattern predicted for partons!

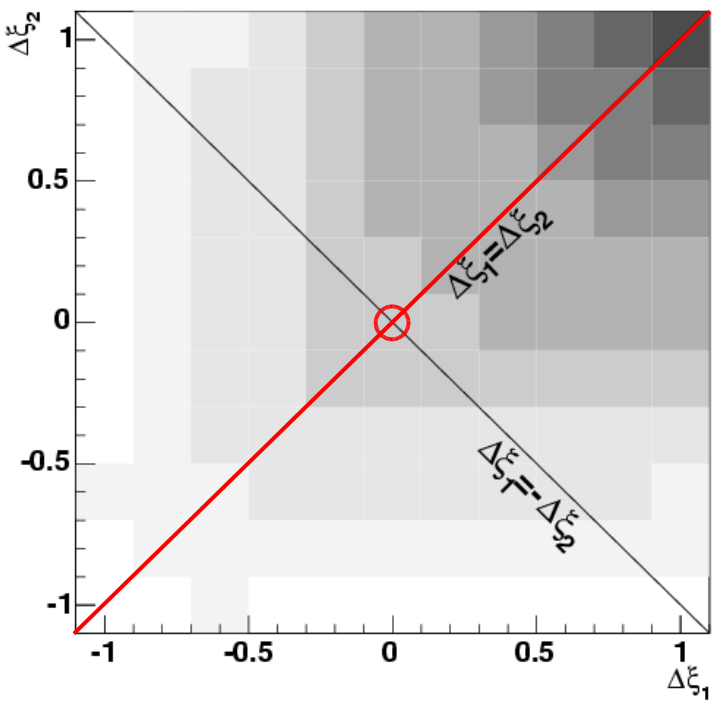
$$C(\xi_1,\xi_2) = C_0(E_{jet}) + C_1(E_{jet})\cdot(\Delta\xi_1+\Delta\xi_2) + C_2(E_{jet})\cdot(\Delta\xi_1-\Delta\xi_2)^2$$

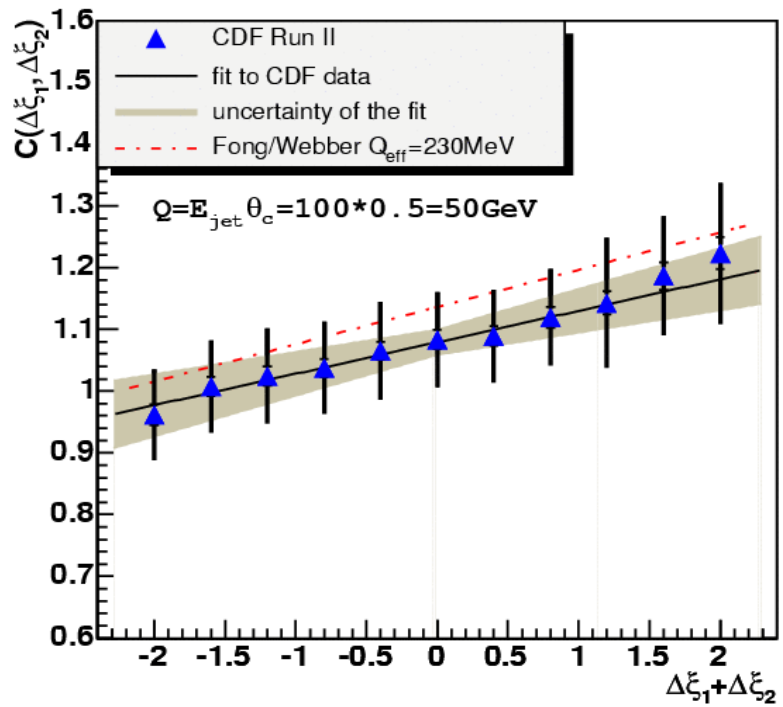


Momentum Correlations: Data (2)

Hadron Correlations follow the pattern predicted for partons!

$$C(\xi_1,\xi_2) = C_0(E_{jet}) + C_1(E_{jet})\cdot(\Delta\xi_1+\Delta\xi_2) + \cancel{C_2(E_{jet})(\Delta\xi_1 - \Delta\xi_2)^2}$$

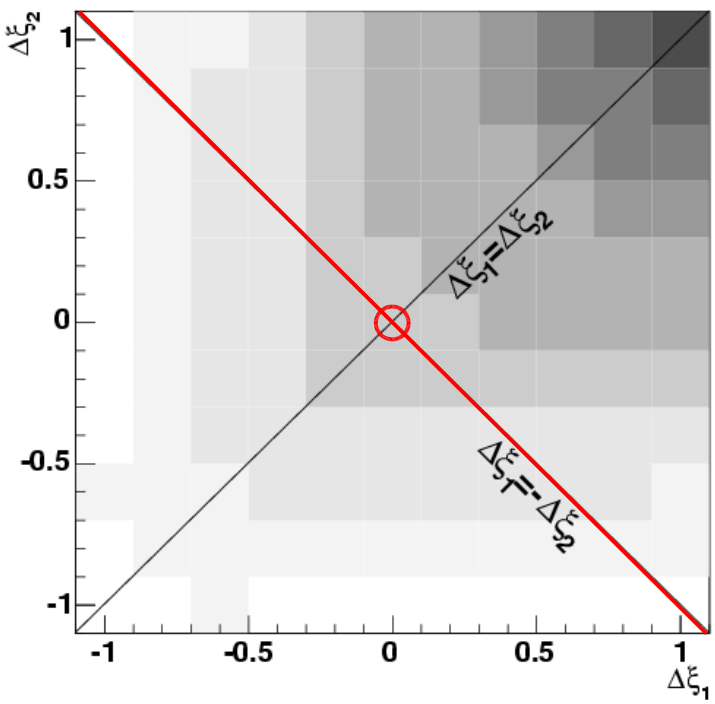


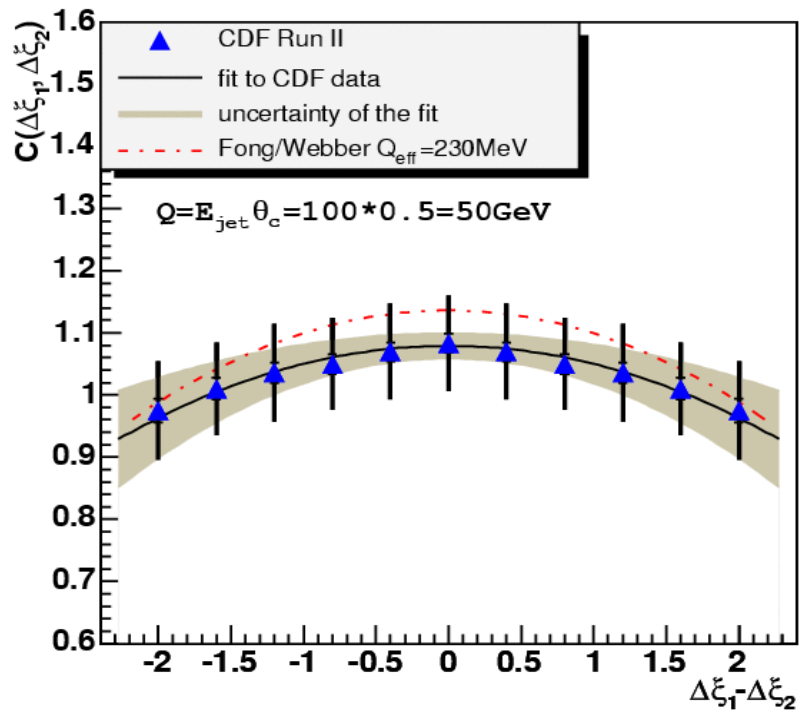


Momentum Correlations: Data (3)

Hadron Correlations follow the pattern predicted for partons!

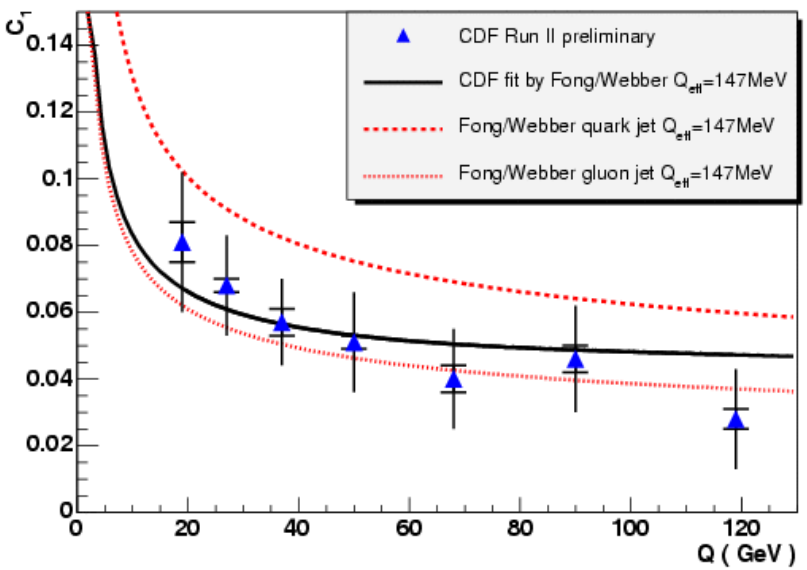
$$C(\xi_1,\xi_2) = C_0(E_{jet}) + \cancel{C_1(E_{jet})(\Delta\xi_1+\Delta\xi_2)} + C_2(E_{jet})\cdot(\Delta\xi_1-\Delta\xi_2)^2$$

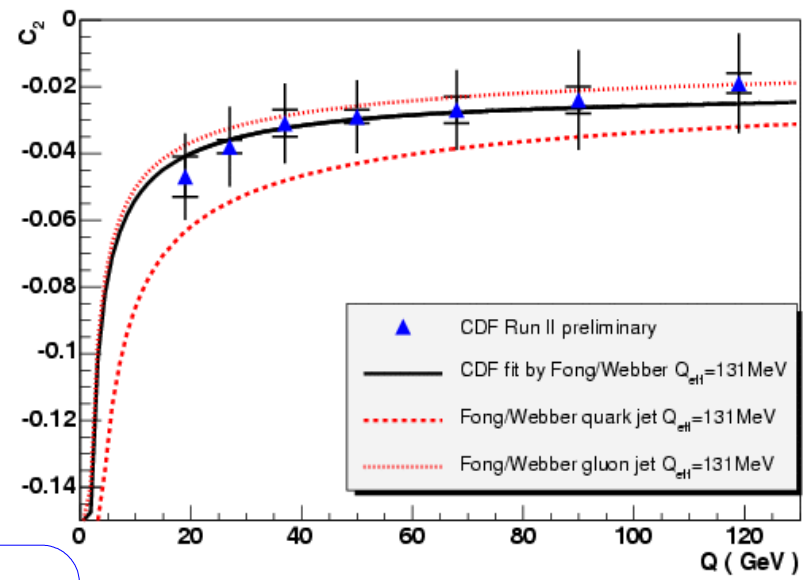




Momentum Correlations: Data (4)

Plotting the energy dependence of the coefficients we are able to extract Q_{eff}





$$C_1(E_{jet}) = +\frac{a_1}{Y^{1.5}} + \cdots$$

$$Y = \ln\left(\frac{E_{jet}\theta_{cone}}{Q_{eff}}\right)$$

$$C_2(E_{jet}) = -\frac{a_2}{Y^2} + \cdots$$

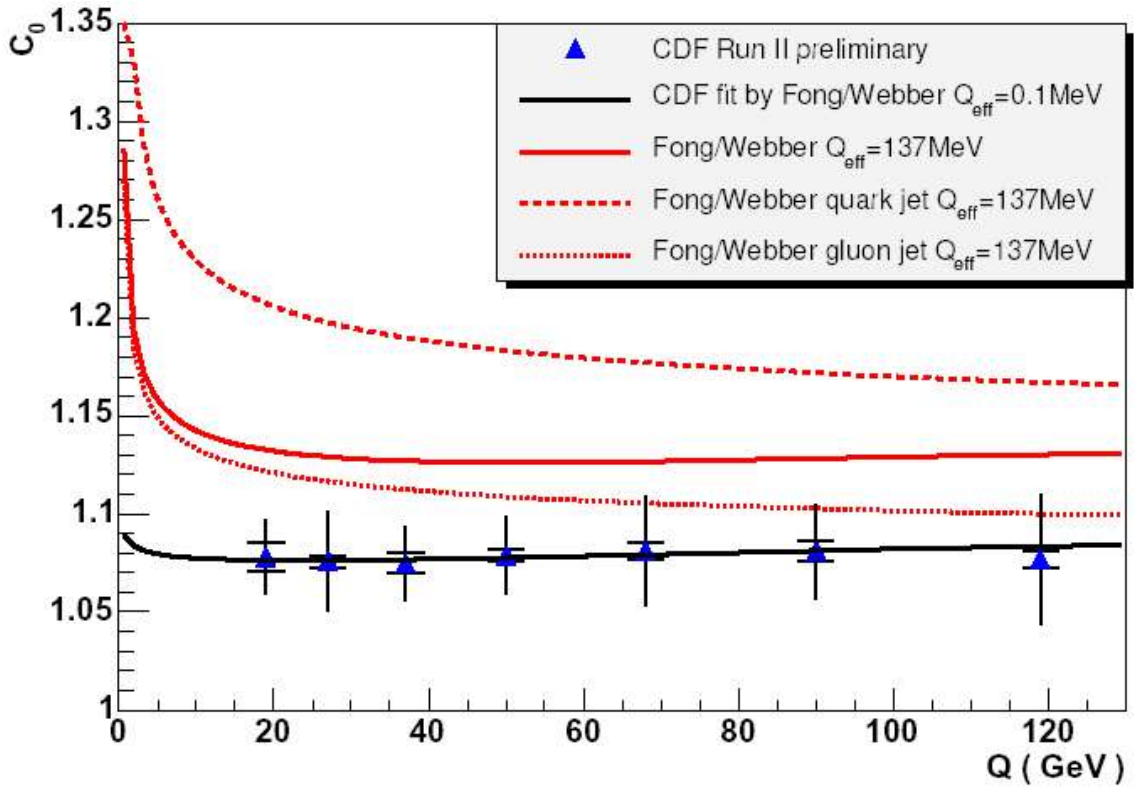
$Q_{eff} = 150 \pm 80$ MeV

$Q_{eff} = 130 \pm 80$ MeV

Theory reproduces trends seen in data

Momentum Correlations: Data (5)

- C_0 smaller than theory predicts
- However, it's independent of energy (as predicted)
- Theoretically this parameter is Sensitive to expansion point

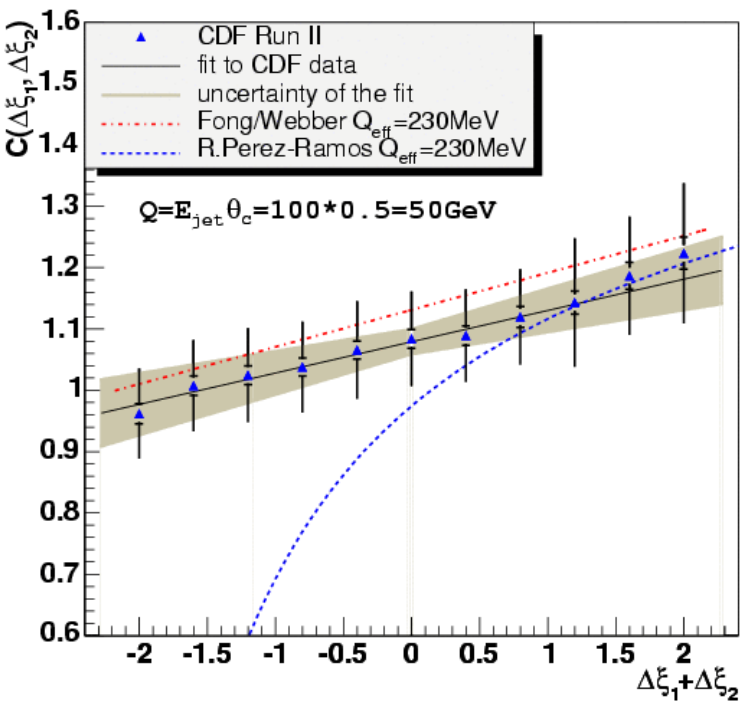


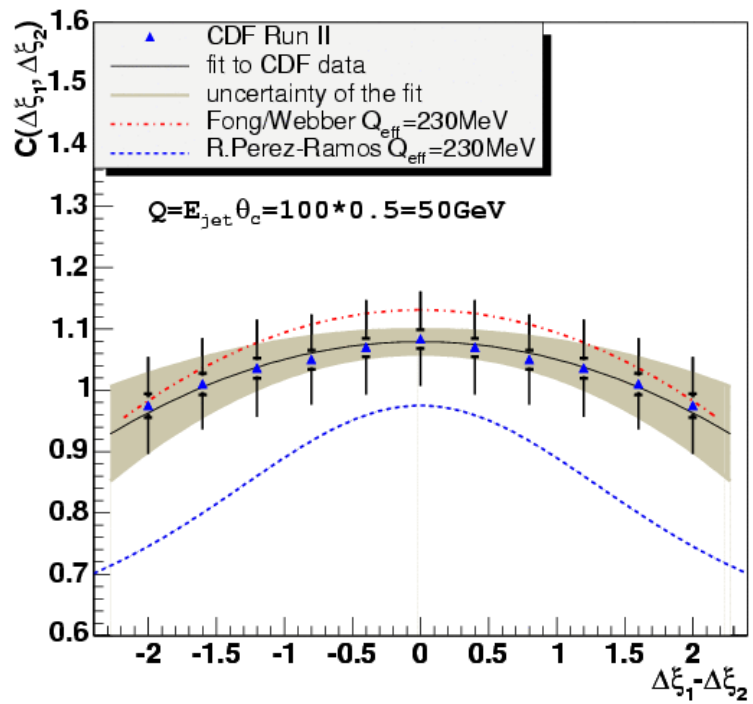
Momentum Correlations: Data (6)

Correlations have recently been revisited within MLLA framework:

R. Perez-Ramos
JHEP 0606:019 & 0609:014, 2006

Qualitatively they show the same trends, but disagreement obviously larger than Fong & Webber



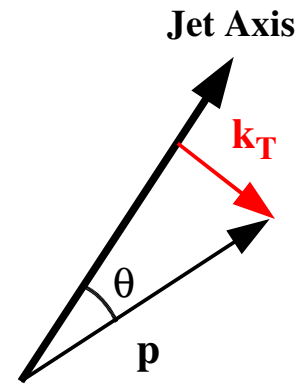


k_T Distribution of Particles in Jets

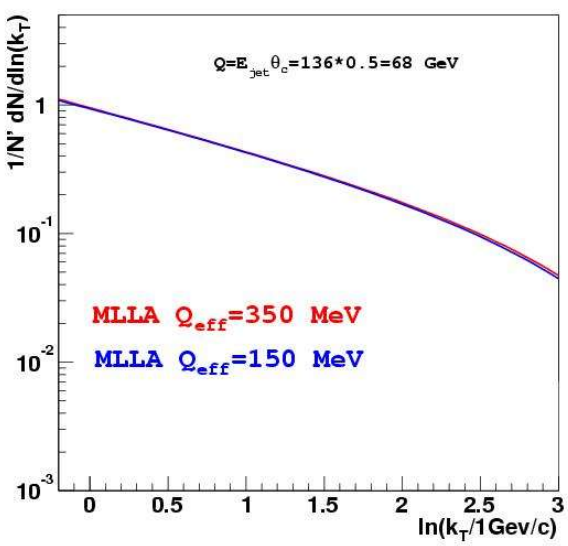
Theory: R. Perez-Ramos & B. Machet

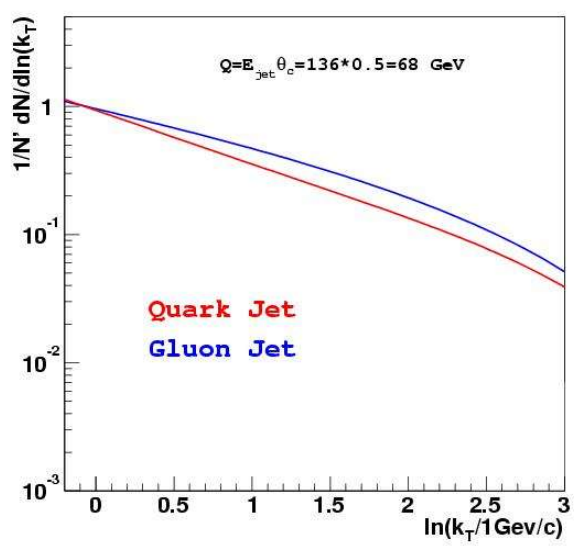
JHEP04 (2006) 043

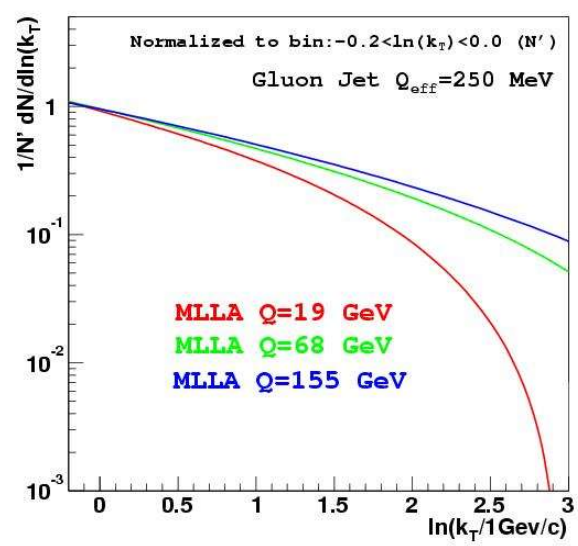
- Nearly no dependence on Q_{eff}
- Weakly dependent on jet origin (q or g)
- Energy scale $Q = E_{jet}\theta$ defines k_T cutoff



$k_T = |p| \cdot \sin(\theta)$

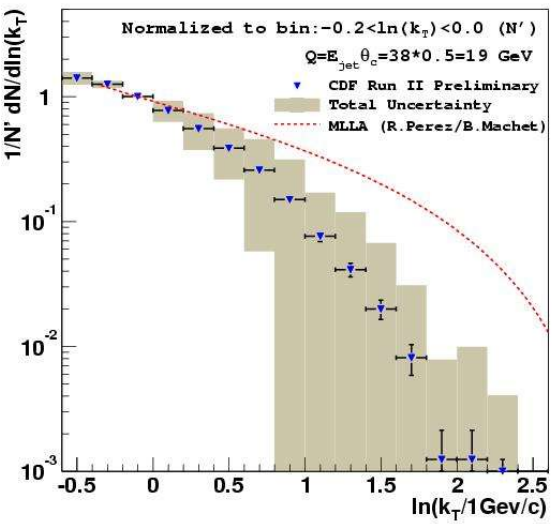


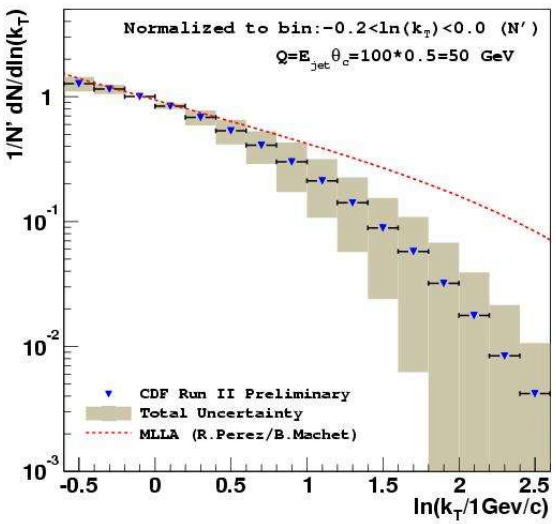


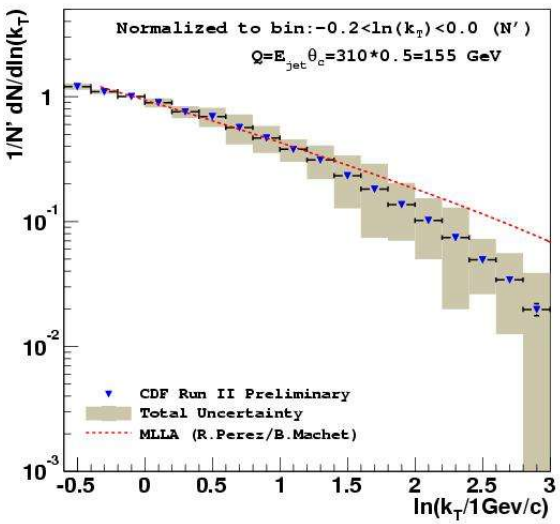


k_T Distribution: Data vs. Theory

- Data indicates fewer particles with large k_T
- Better agreement with increasing Energy scale Q



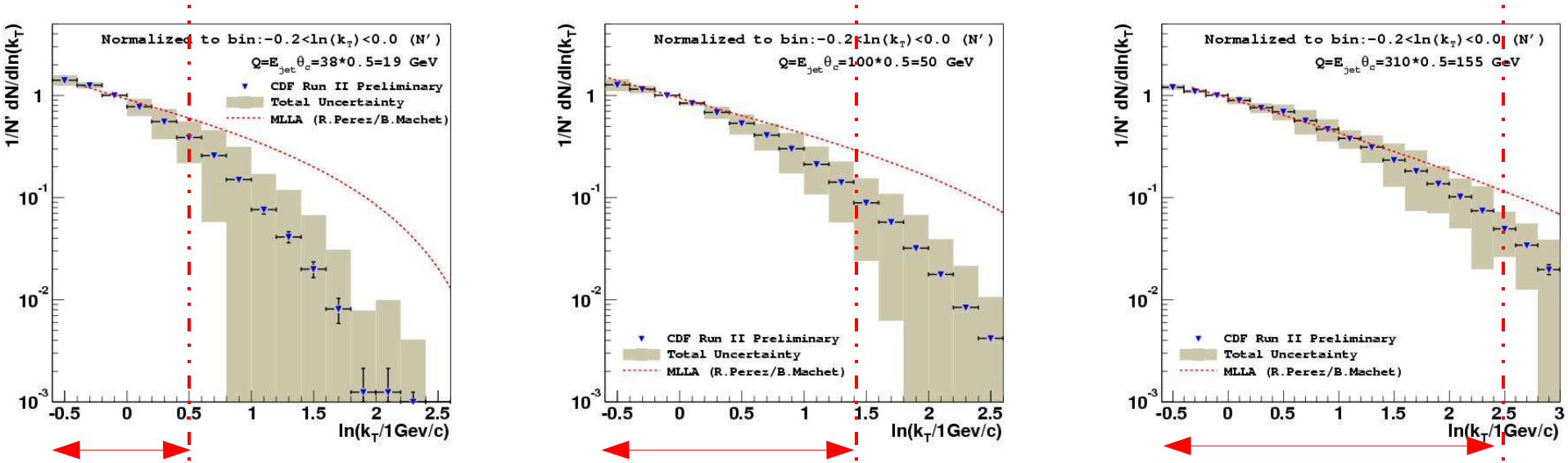




k_T Distribution: Data vs. Theory

→ Data indicates fewer particles with large k_T

→ Better agreement with increasing Energy scale Q



Theory makes soft approximation: $p/E_{jet} \sim 0.1$

→ Valid in the region $\ln(k_T/Q_{eff}) < \ln(Q/Q_{eff})-2.5$

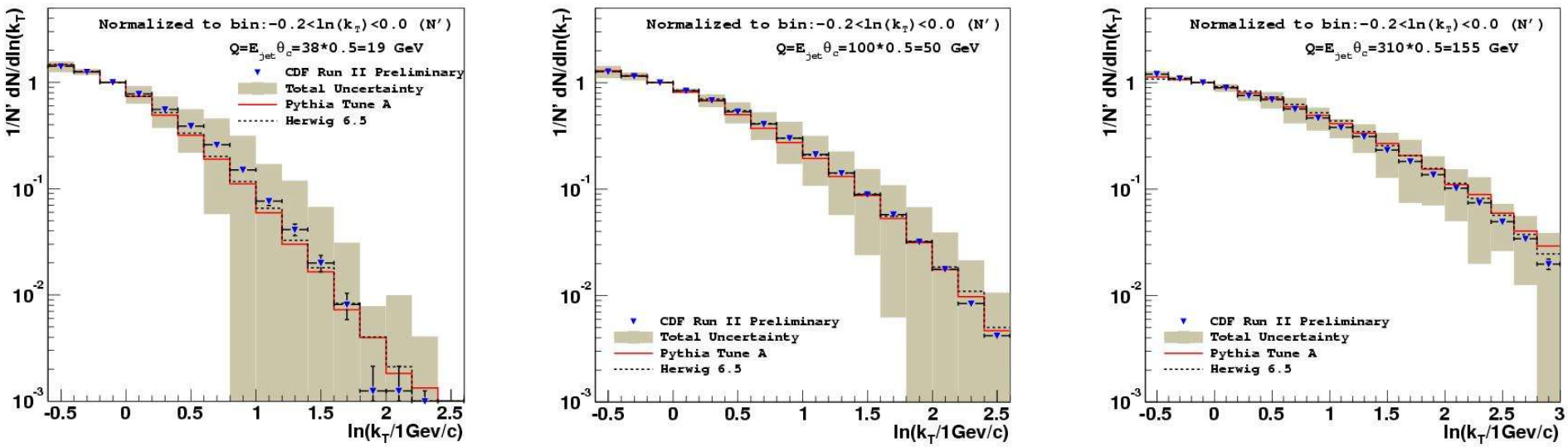
k_T Distribution: Data vs. MC

→ Pythia and Herwig (Hadron level) in agreement with Data over the full range of k_T

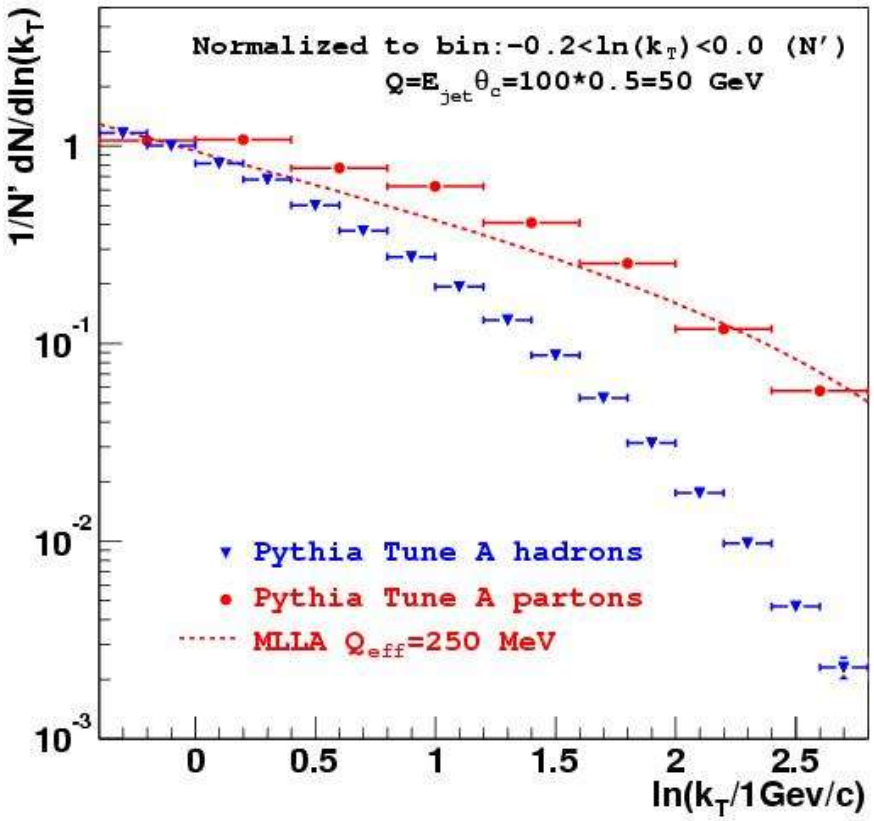
Where is the discrepancy coming from?

MLLA → Next-to-Leading Log

Pythia → Leading Log + Energy conservation



k_T Distribution: Pythia Partons



- Pythia partons follow MLLA predictions.
- Doesn't look like it's energy conservation
- Hadronization (?)

Is this really an effect of hadronization, or just an incomplete picture of pQCD?

Dedicated theoretical predictions in the region of large k_T would be nice!

Summary

Our studies are aimed at understanding the relative roles of perturbative and non-perturbative QCD in the development of jets.

Momentum Distributions & Multiplicity of Charged Particles in Jets

- pQCD within MLLA framework consistent with data
- Parton Shower cutoff $Q_{eff} \sim \Lambda_{QCD}$
- Lent support to Local Parton Hadron Duality ($N_{hadrons} = K_{LPHD}\, N_{partons}$) $K_{LPHD} \sim 1$
- N^{gluon} / N^{quark} consistent with NNLLA prediction

Momentum correlations of particles in jets

- follow pQCD predictions for partons
- $Q_{eff} \approx 140 \pm 80$ MeV for parabolic and linear terms
- the constant (momentum-independent) term is much smaller than predicted

k_T-distribution of particles

- data at low k_T agrees with theory, but deviates at large k_T
- discrepancy gets smaller for larger Q
- theory predictions in the region of large k_T necessary

Backups