New Jet Fragmentation Results at CDF

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for CDF collaboration

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Jet fragmentation vs analytical pQCD

- Momentum distribution of particles in jets;

- Multiplicity of charged particles in jets;
  including g/q jet differences

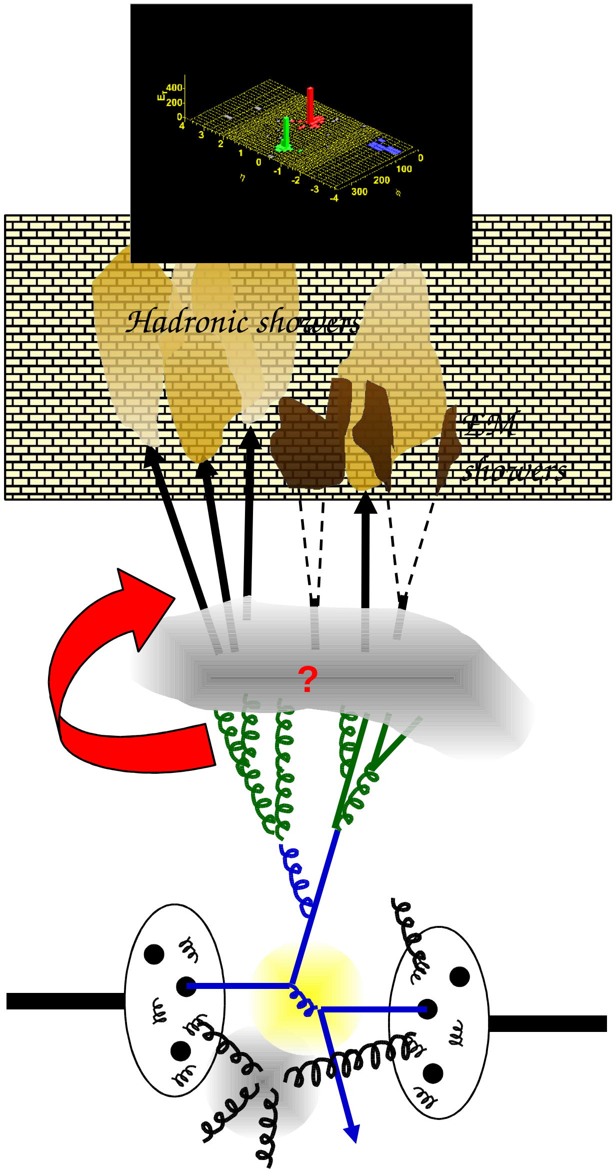
- Momentum correlation of particles in jets;

- k_T-distributions of particles in jets;
  (k_T-transverse momentum with respect to jet axis)

Forthcoming results: (not public yet)

- Global Event Shapes;

Partons, Hadrons, Jets



Pick two partons and their momenta:
-phenomenological parton density functions, PDF

Hard Scattering:
-pQCD exact matrix element at LO, some at NLO,...

Soft final state radiation:
-pQCD approximate resummation in all orders: LLA (leading log approximation), NLLA

Underlying event:
-phenomenological models

Hadronization:
-phenomenological models

Calorimeter response:
-electromagnetic shower for photons

-hadronic shower for "stable" hadrons

Jet identification:
-jet finding algorithms

Particle momenta and average multiplicity

Partons: NLLA resummation

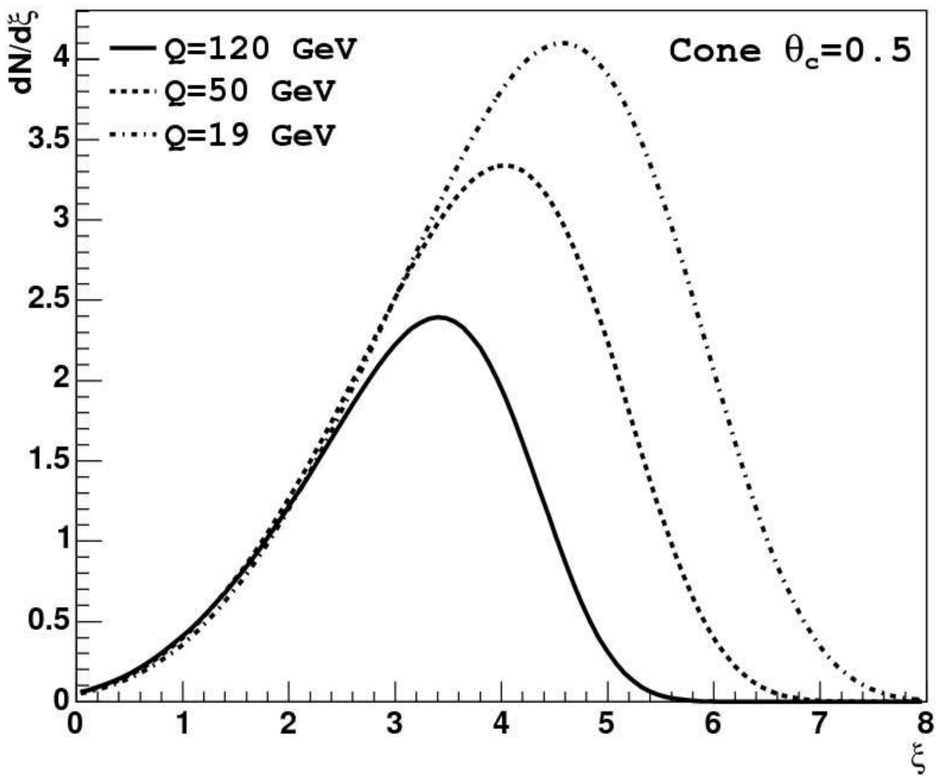
- Mueller (1983)
- Dokshitzer, Troyan (1984)
- Malaza, Webber (1984)
- plus subsequent corrections

$dN/d\xi = D(Y, \xi)$

$\xi = \ln(1/x) = \ln(E_{jet}/p_{parton})$

$Y = \ln(Q/Q_{eff})$, $Q = E_{jet}\theta_{cone}$

$Q_{eff} = Q_{cutoff} = \Lambda_{QCD}$



From partons to hadrons: Local Parton-Hadron Duality

- Azimov, Dokshitzer, Khoze, Troyan (1985)

Hadron observables follow patterns predicted for partons

- $N_{hadrons} \sim N_{partons}$?
- Momentum distributions?
- Momentum correlations?
- ...

Particle momenta and average multiplicity

Momentum distribution of charged particles in jets:

- dijet events with well-balanced E_T
- 15-30° cone around dijet axis

Two parameter fit (MLLA+LPHD):

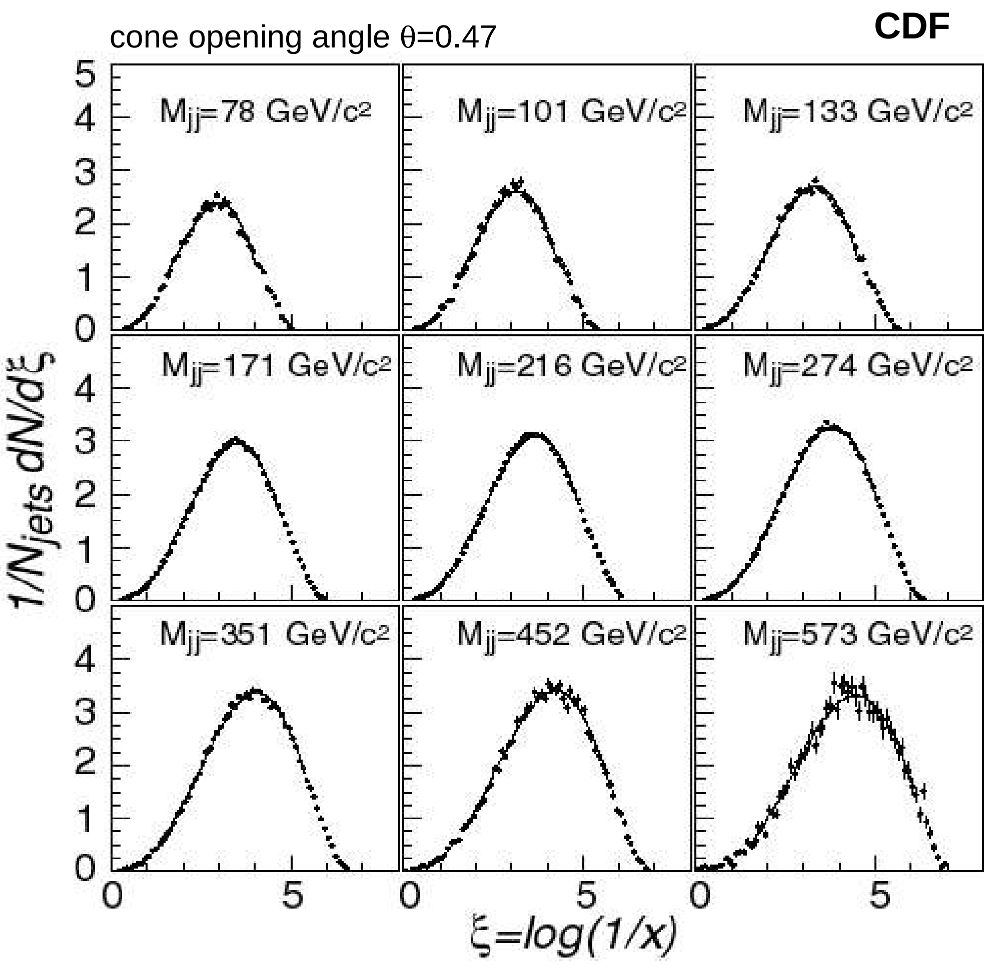
- works surprisingly well in wide range of dijet masses

- MLLA Q_{eff} = 230±40 MeV

k_T-cutoff can be set as low as Λ_{QCD}

- $K_{LPHD(\pm)}$ = 0.56 ± 0.10

$N_{hadrons} \approx N_{partons}$



$$x = \frac{p_{particle}}{E_{jet}} \qquad \xi = \ln(1/x) = \ln\left(\frac{E_{jet}}{p_{particle}}\right)$$

Gluon/Quark Jet Differences

Charged particle multiplicities in gluon and quark jets:

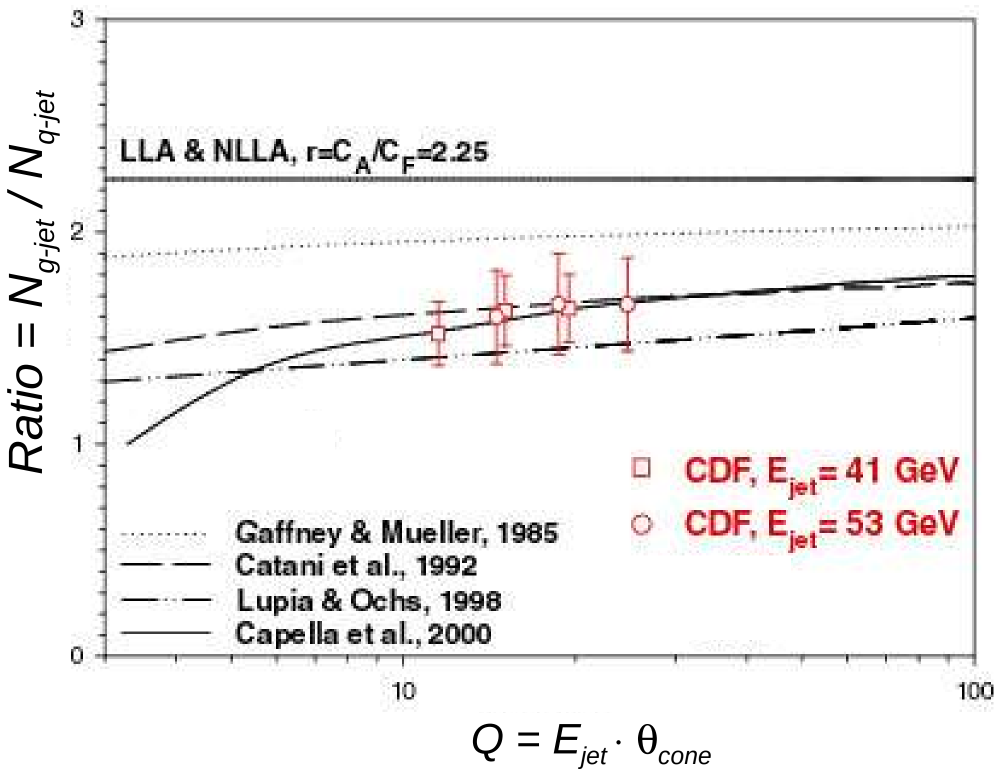
- Measured multiplicities in di-jet and γ-jet events can be resolved for multiplicities in quark and gluon jets;

Results agree with NNLLA:

r=1.64±0.17 at Q=20 GeV

Most recent LEP result (OPAL):

r=1.51±0.04 at Q=90 GeV



Momentum Correlations

Theory: C.Fong, B.Webber (1990)

- Momentum distributions normalized to # of partons N:

$$R(\xi_1,\xi_2)=\frac{\left(\frac{dN}{d\xi_1 d\xi_2}\right)}{\left(\frac{dN}{d\xi_1}\right)\left(\frac{dN}{\xi_2}\right)}$$

mixes together:
- momentum correlations
- multiplicity fluctuations

- To decouple momentum correlations and multiplicity fluctuations effects we used distributions normalized to unity:

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

where $F=\frac{\langle N(N-1)\rangle}{\langle N\rangle^2}$ - binomial moments taken from theory

Momentum Correlations

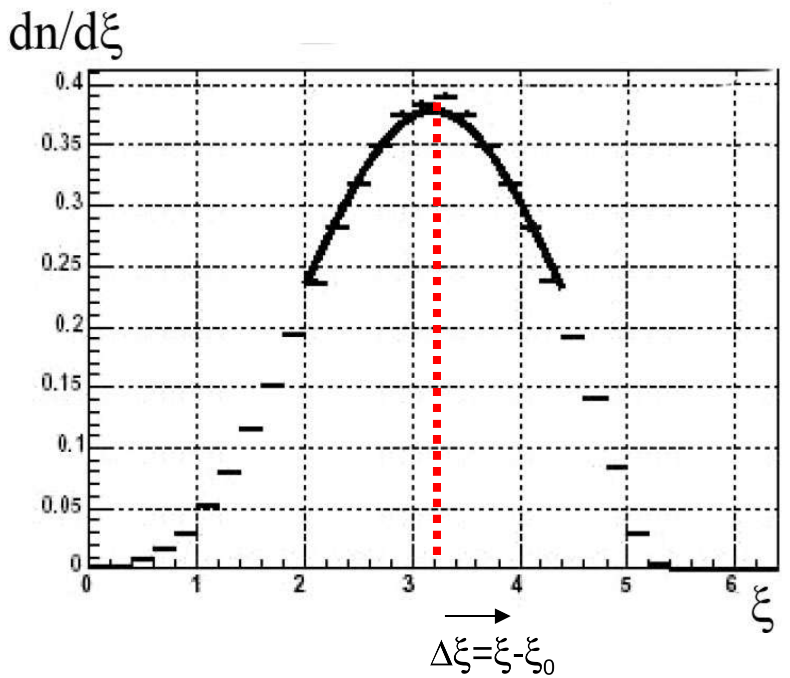
Theory: C.Fong, B.Webber (1990)

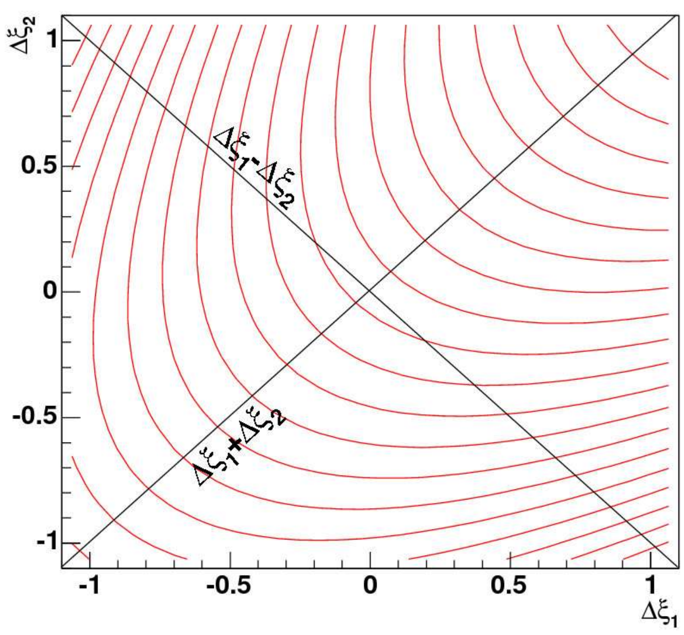
- All particles in the cone $\theta_c = 0.5$ around jet axis:

Around the peak of inclusive momentum distribution, $C(\xi_1,\xi_2)$ is predicted by NLLA:

$$C(\xi_1,\xi_2) = \frac{\left(\frac{dn}{d\xi_1 d\xi_2}\right)}{\left(\frac{dn}{d\xi_1}\right)\left(\frac{dn}{d\xi_2}\right)} = c_0(E_{jet}) + c_1(E_{jet})\cdot(\Delta\xi_1 + \Delta\xi_2) + c_2(E_{jet})\cdot(\Delta\xi_1 - \Delta\xi_2)^2$$

- C_0, C_1 and C_2 depend on $Y = \ln(E_{jet}\theta_c/Q_{eff})$





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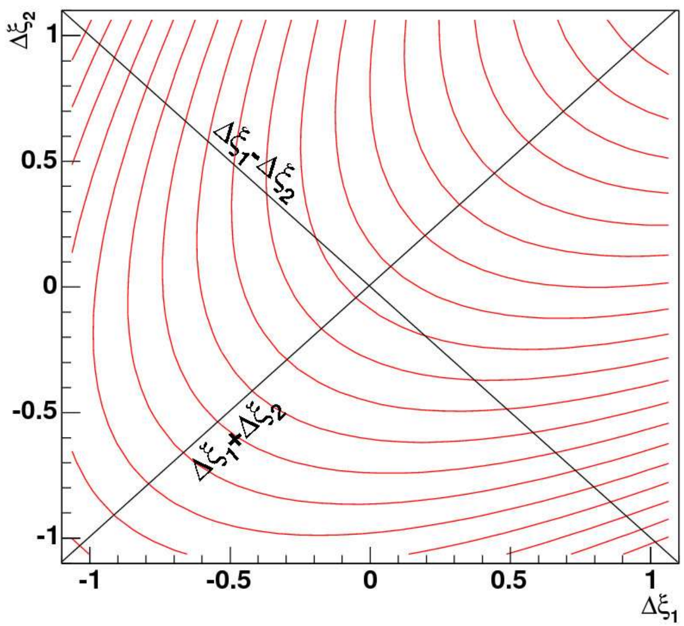
- C_0, C_1 and C_2 depend on $Y=\ln(E_{jet}\theta_c/Q_{eff})$

- C_0 is always >1 ;
  (depends on the point of the expansion)

- C_1 is always positive ;

- C_2 is always negative ;



Experimental Features

Measurement:

- Well balanced di-jet events with Mjj ranging 60-600 GeV;
- Jet axis in the central region $|\eta|<0.9$;
- Events with only one vertex;
- Measurement done in the dijet center-of-mass frame;
- Cone jet algorithm with R=1.0;

- Charged particles in the cone with $\theta_c=0.5$;
- Unfold the small underlying event contribution;
- Remove secondaries (conversions, ...)

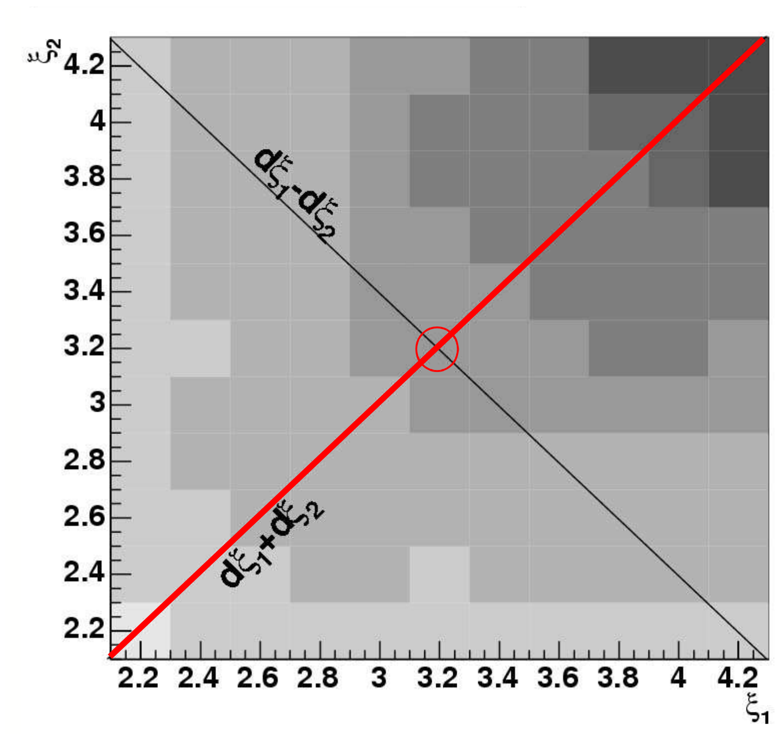
Theory(to make compare to data):

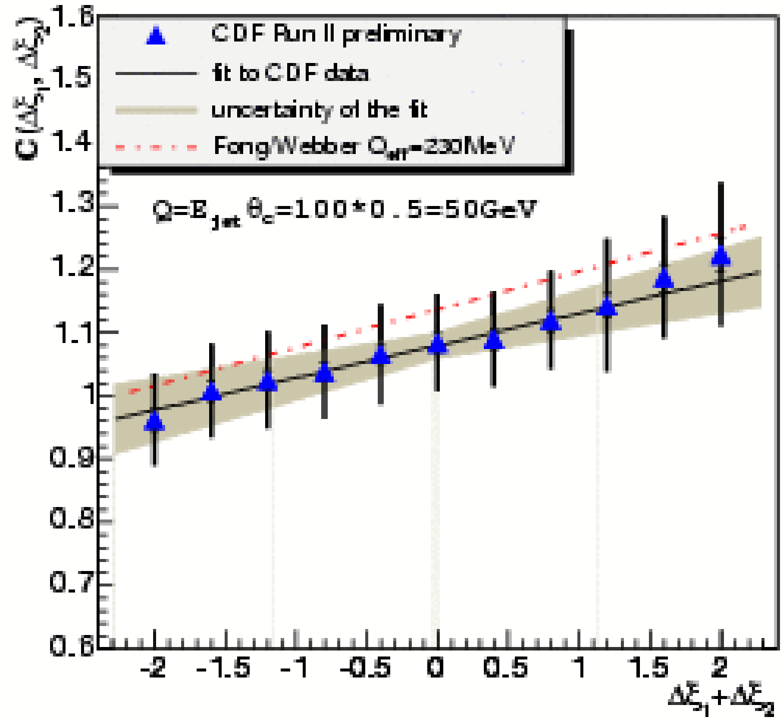
- produce correlation function for a mixture of quark and gluon jets;
- get fraction of gluon jets in the sample from Pythia Tune A Monte-Carlo;

Momentum Correlations

- Hadron correlations follow the pattern expected for partons;

$$C(\xi_1,\xi_2) = c_0(E_{jet}) + c_1(E_{jet})\cdot(\Delta\xi_1+\Delta\xi_2) + \cancel{c_2(E_{jet})\cdot(\Delta\xi_1-\Delta\xi_2)^2}$$





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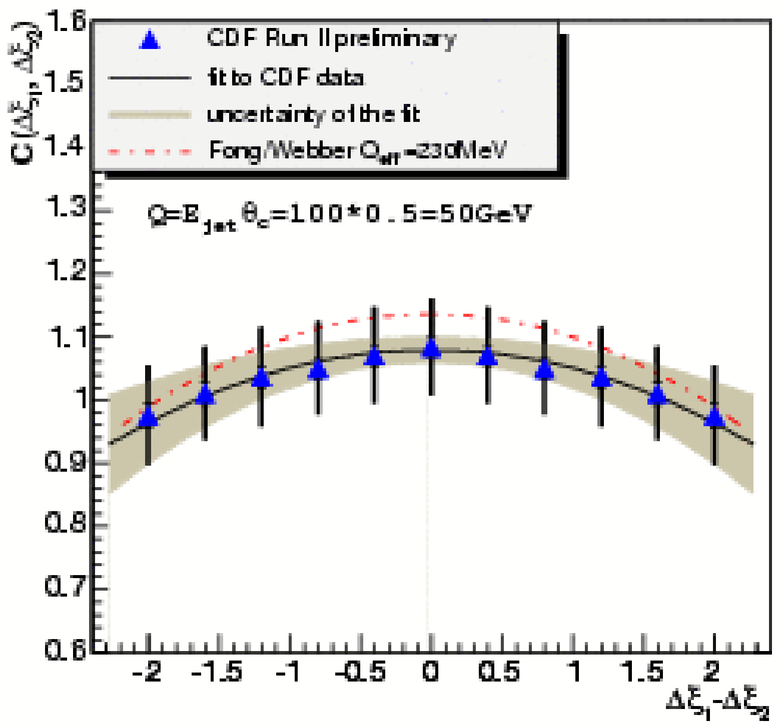
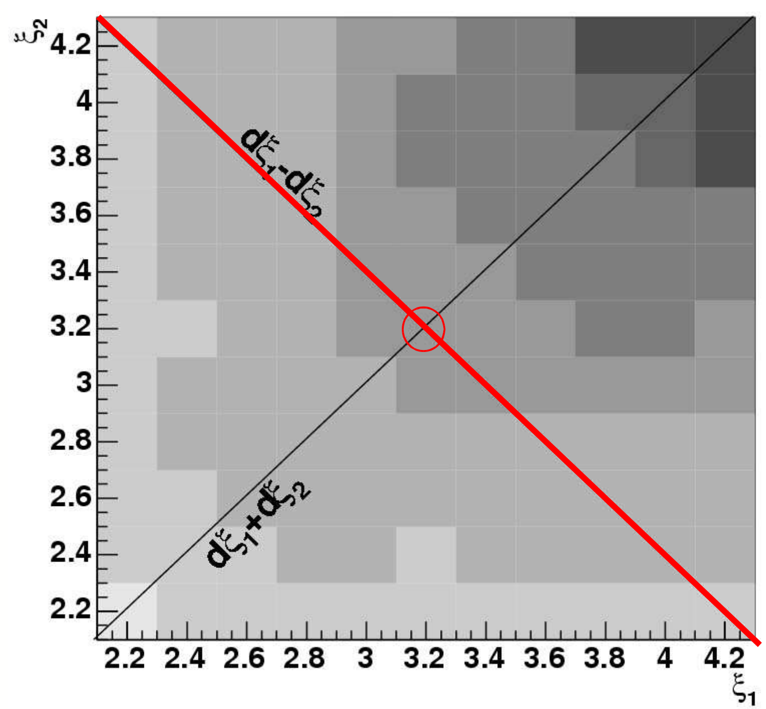
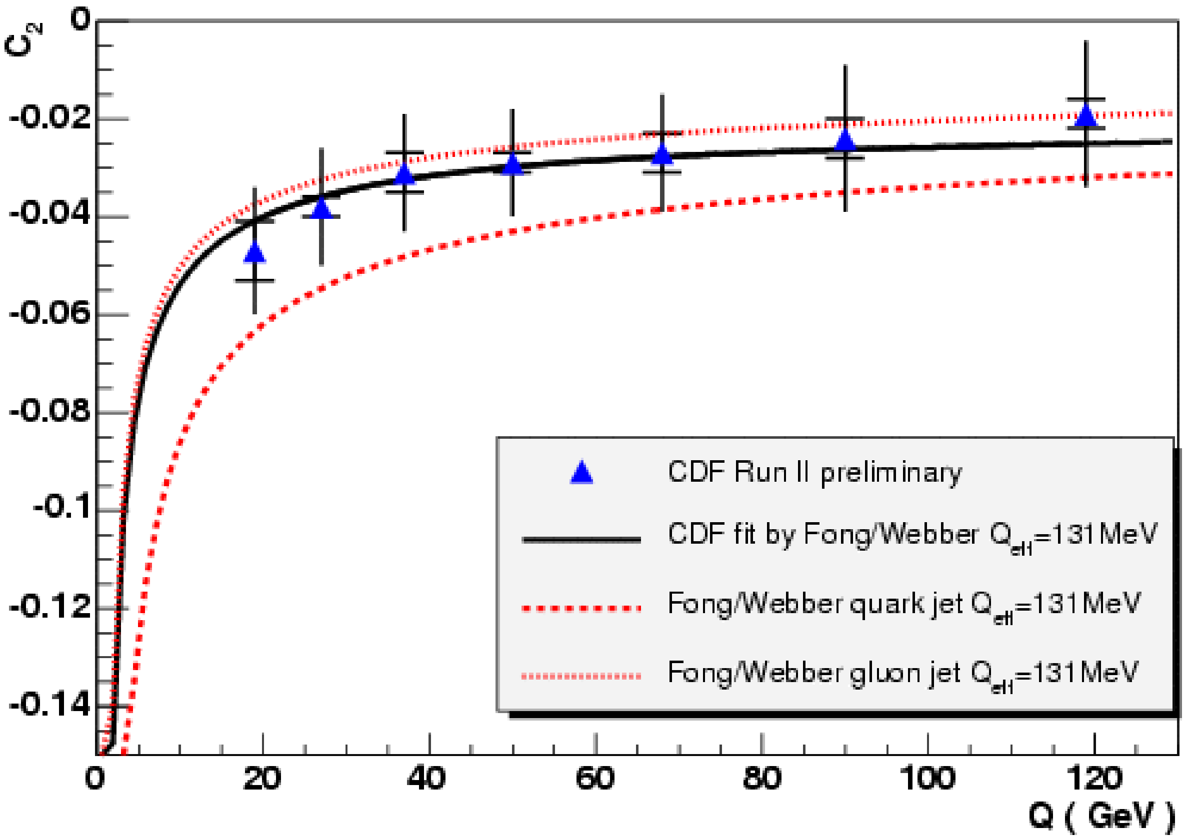




Momentum Correlations

- Fit C_2 vs. Q gives Q_{eff}~130±80 MeV;

- Data and theory show same trends;



mixed q/g jets

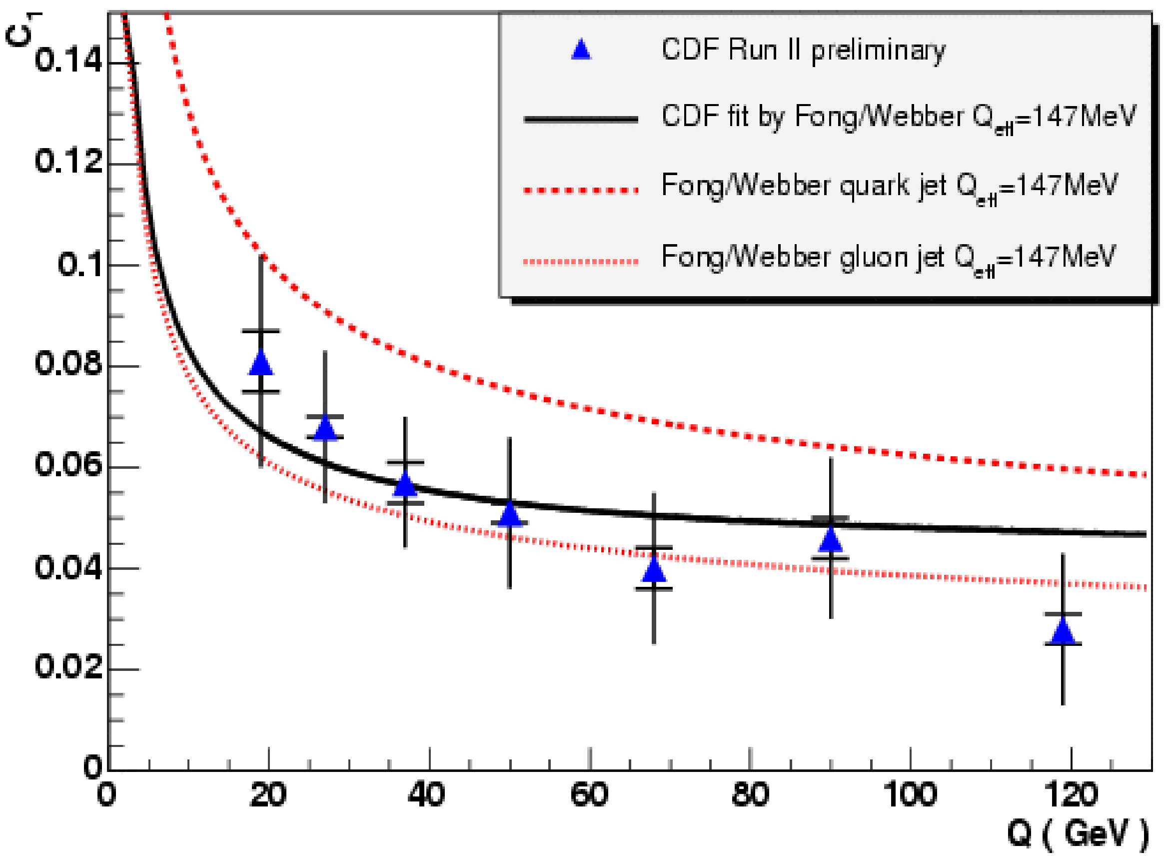
$$c_2 = -\frac{a_2}{Y^2} + \ldots$$

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

Momentum Correlations

- Fit C_1 vs. Q gives Q_{eff}~150±80 MeV;

- Data and theory show same trends;



mixed q/g jets

$$c_1 = \frac{a_1}{Y^{1.5}} + \ldots$$

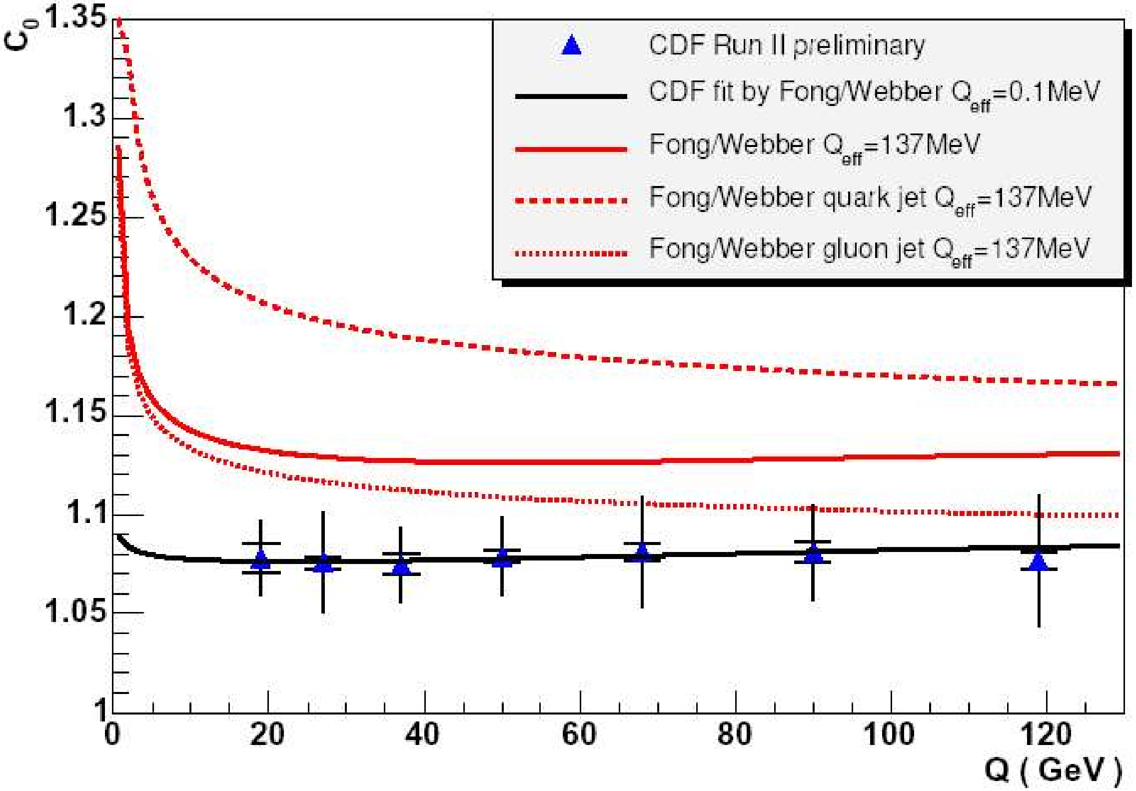
$$Y = \ln\left(\frac{E_{jet}\theta_{cone}}{Q_{eff}}\right)$$

Momentum Correlations

- C_0 is too small if compared to theory;

- However, it's almost independent of energy, as expected;

- Theoretically, this parameter has some issues...

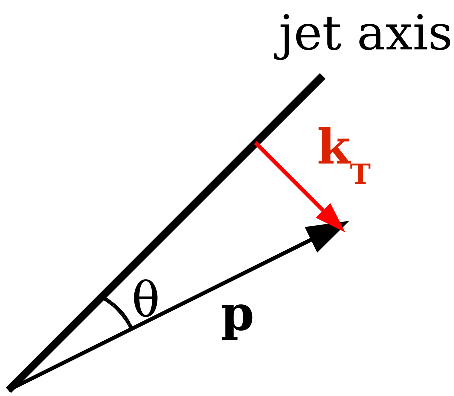


$$c_0 = 1 + \Delta - \frac{a_0}{\sqrt{Y}} + \ldots$$

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

Kt distributions

R.Perez-Ramoz & B.Machet (2006)
JHEP 04 (2006) 043

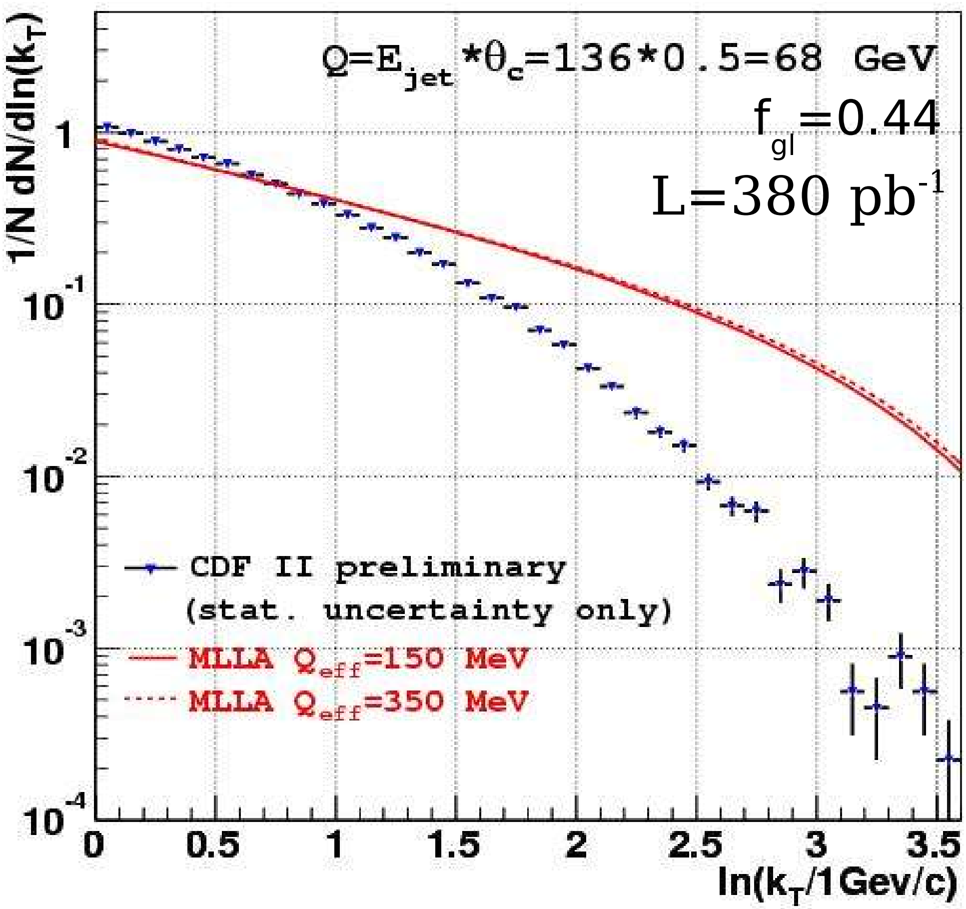


$$k_T = p \cdot \sin(\theta)$$

In theory $dN/d\ln(k_T)$ are produced.

- Theory predicts more particles with high Kt

Distributions are normalized to unity



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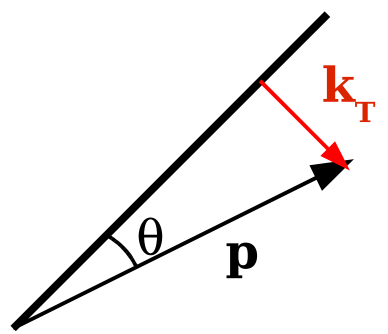

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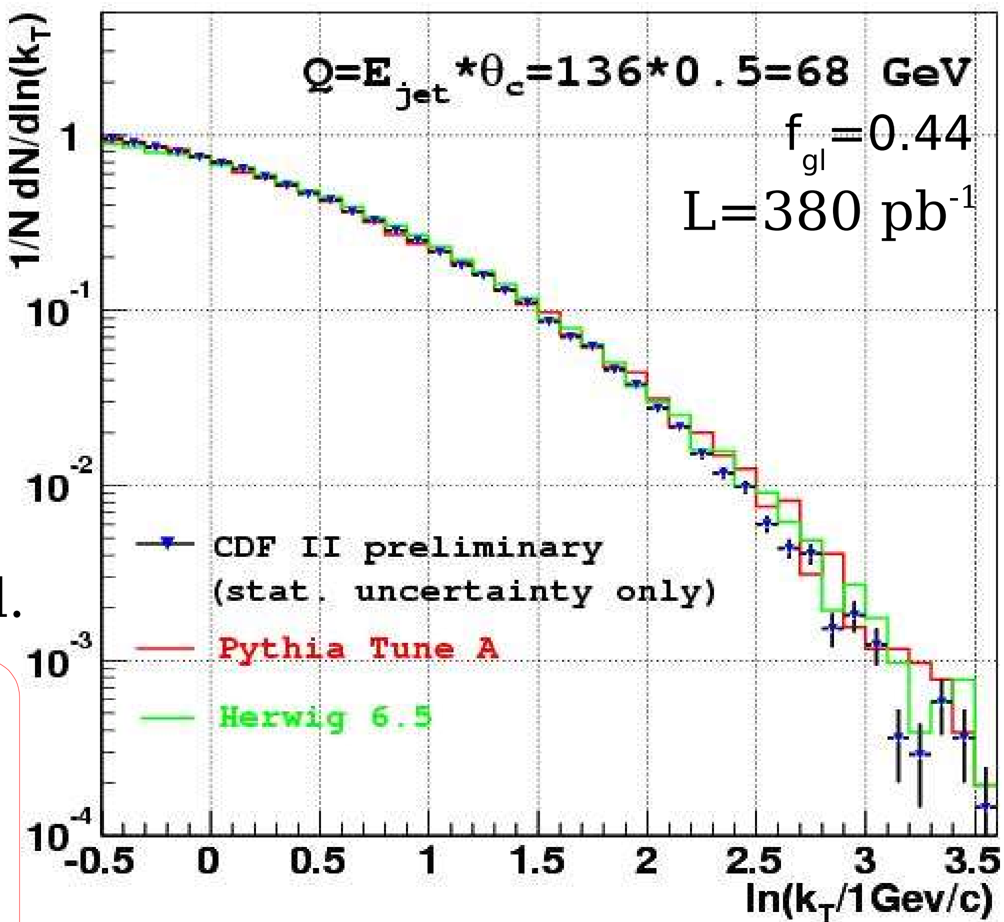

In theory $dN/d\ln(k_T)$ are produced.

- **Theory predicts more particles with high Kt**
- **Data and MC are in agreement**

Summary

Momentum distributions of particles in jets:

- Consistent with parton distribution predicted by MLLA;
- Q_{eff}=240±40 MeV over the entire range of dijet masses;

Multiplicity of particles in jets:

- $N_{hadrons}=K_{LPHD}\cdot N_{partons}$
- K_{LPHD}=0.56±0.10 for charged particles;
- Ratio of multiplicities in g/q jets r=1.6±0.2;

Momentum correlations:

- Hadron correlations follow the pattern expected for partons;
- The constant term is much smaller than predicted by pQCD...;
- Q_{eff}=140±80 MeV from linear and parabolic terms;

Kt distributions:

- Less hard particles than predicted by MLLA;
- Very good agreement between data and Monte-Carlo ;

Forthcoming results:

- Event shapes;

Backup

CDF results

Pythia Tune A and Herwig 6.5

- Both MC generators reproduce correlation in data fairly well;