Fragmentation, Underlying Event and Jet Shapes at the Tevatron (CDF)

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On behalf of the CDF collaboration

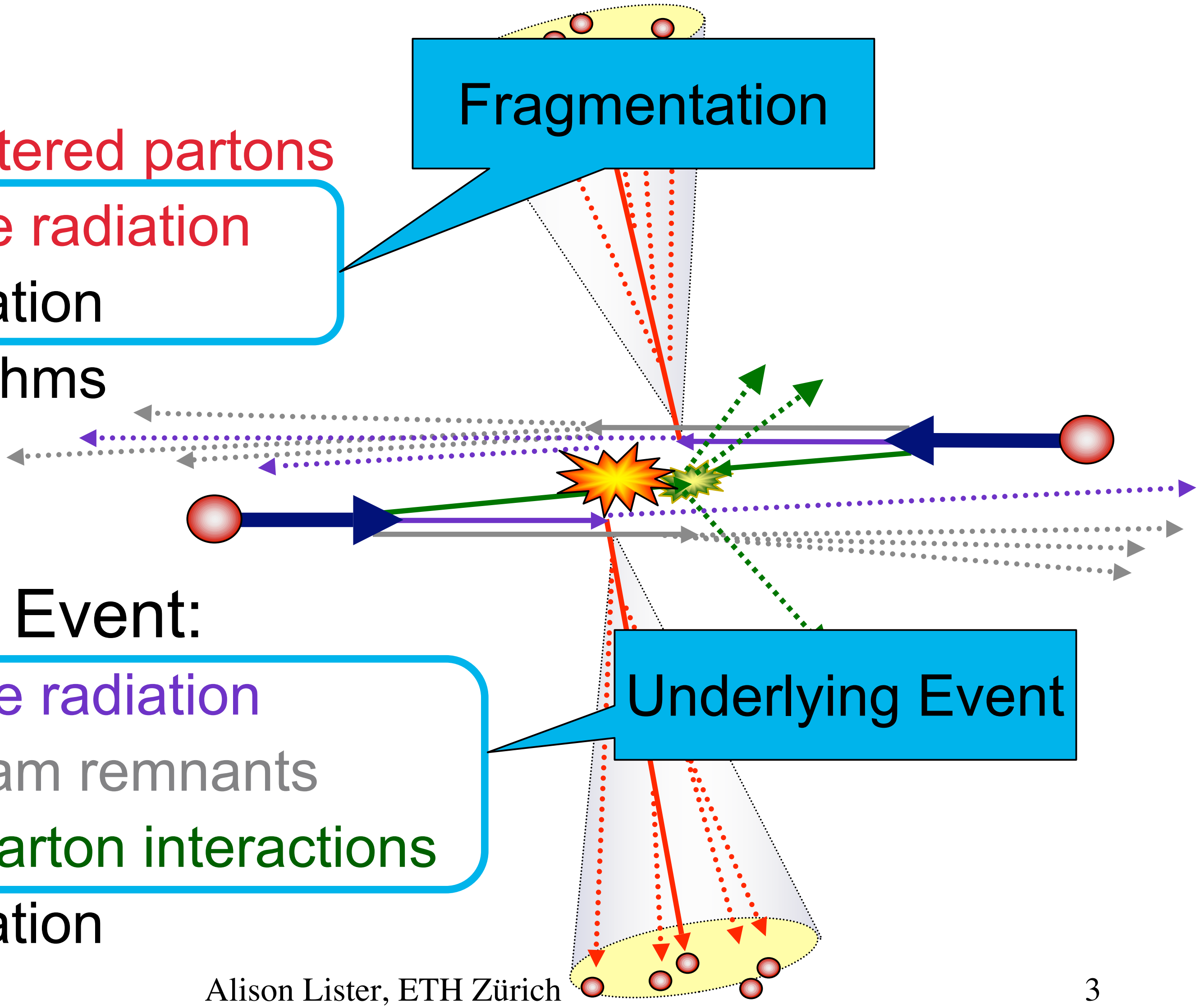
Outline:

- Fragmentation
  - Particle momentum spectra
  - Charge multiplicity
- Underlying Event
  - Definitions
  - Transverse charge density distributions
- Jet Shapes
  - Definitions
  - Inclusive shapes

Hadron collider event

- Jets:
  - Hard scattered partons
  - Final state radiation
  - Hadronisation
  - Jet algorithms

- Underlying Event:
  - Initial state radiation
  - Beam-beam remnants
  - Multiple parton interactions
  - Hadronisation



Fragmentation

Fragmentation

- Why study fragmentation?
  - Driven by soft QCD (k_T<<1 GeV)
  - Theoretical challenge (QCD at $k_T \sim \Lambda_{QCD}$)
  - Hadronisation stage still poorly understood
- Why at the Tevatron?
  - Push energy scale up
  - Study different sub-processes
  - Much more “noisy” than lepton colliders

Particle momentum spectra

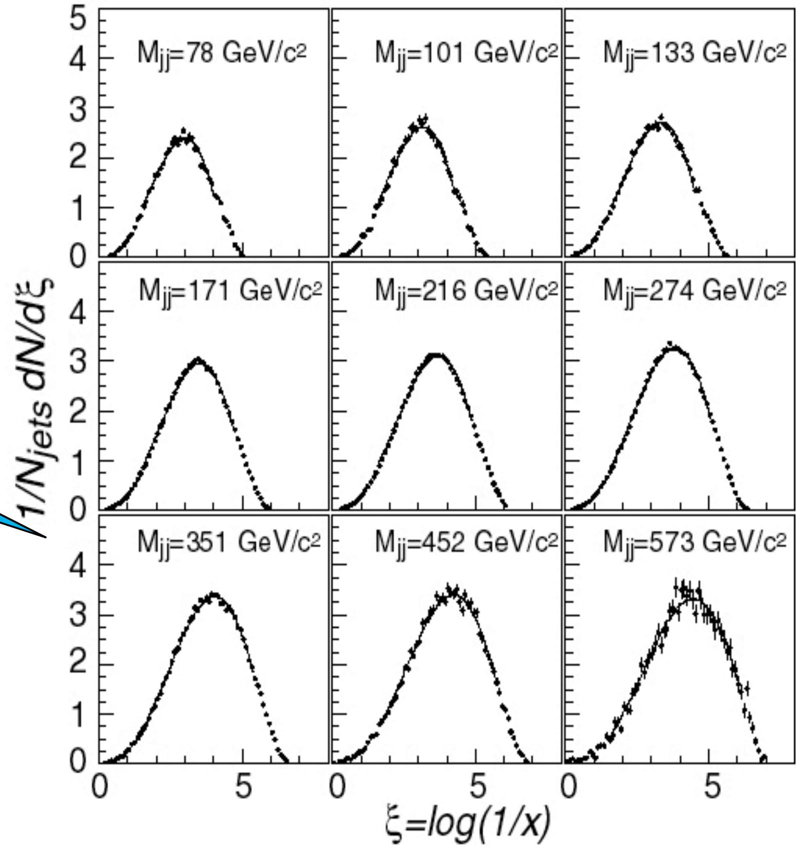
- Measurement:
  - central dijet events with M_{jj} ~ 80
  - dijet ce E_{jet} = ½
  - charged ΔR ~0.3
  - energy $E_{jet}q$

Works surprisingly well over a wide range of dijet masses

- Results:

  Phys. Rev. D 68, 012003 (2003)
  - Qeff = 240 ± 40 MeV
    - kT-cutoff can be set as low as Λ_{QCD}
  - $K_{LPHD(\pm)}$ = 0.56 ± 0.10
    - $N_{hadrons} \approx N_{partons}$

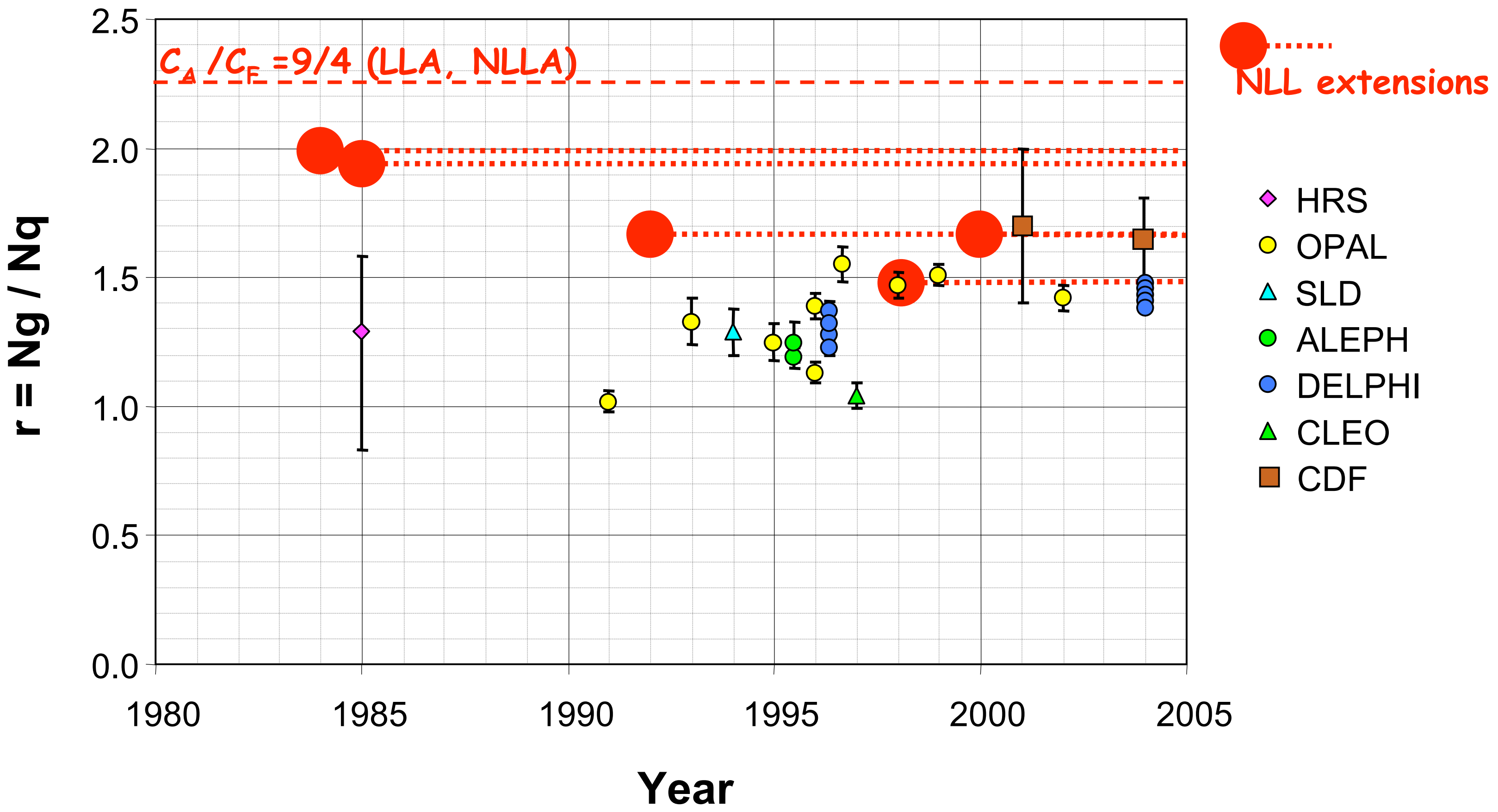
CDF
Charged particle momentum spectra (θ_{cone}=0.47)
and MLLA+LPHD fit



$$x = \frac{p_{particle}}{E_{jet}}$$

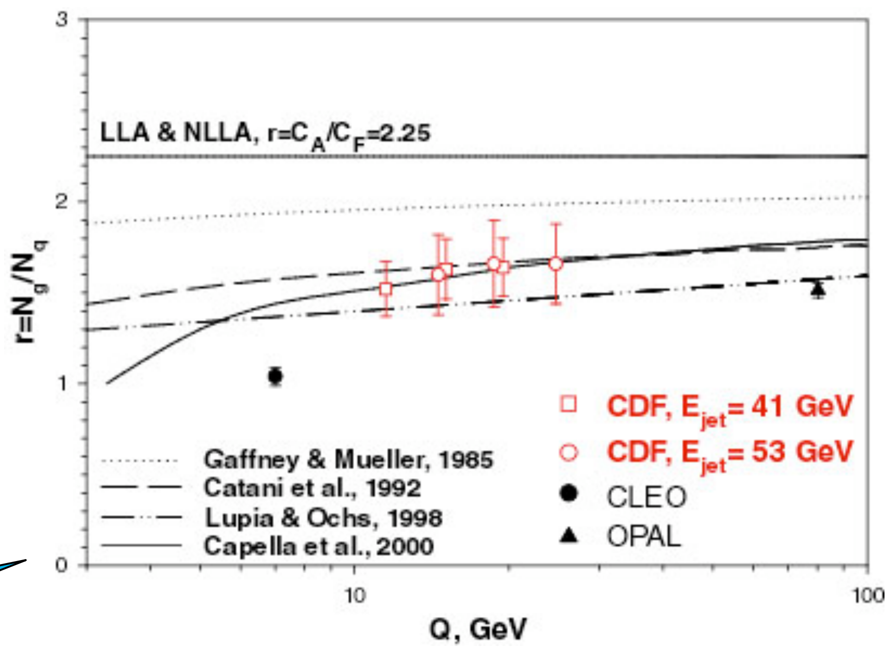
Multiplicities in q- and g-jets

Ratio r = N_{ch}(gluon jet) / N_{ch}(quark jet)



Multiplicities in q- and g-jets

- dijet events with M_{jj}~100 GeV
  gluon jet fraction ~60%
- γ-jet events with $M_{\gamma j}$~100 GeV
  gluon fraction ~20%
- measure N_{jj} and $N_{\gamma j}$ inside
  15-30° cone around jet axis



Tevatron and recent OPAL "unbiased" data (r=1.51± 0.04 at Q=80 GeV) agree and follow trends obtained in the recent NLL extensions

RESULT: r = 1.6±0.2

Ongoing analyses (RunII):

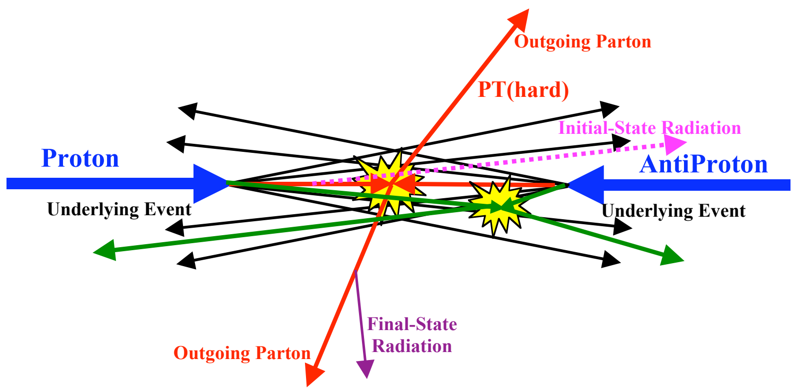
- Two particle momentum correlations in jets
  - $R(\xi_1,\xi_2)=C_0 + C_1 (d\xi_1 + d\xi_2) + C_2 (d\xi_1 - d\xi_2)^2$
    - Where $d\xi = \xi - \langle\xi\rangle$
  - LEP correlation data cannot be fitted with current QCD calculations
  - Higher order contributions might be important
  - What does the Tevatron have to say?

- Event shapes:
  - Beam-beam remnants models
  - Hadronisation "power corrections"

Fragmentation summary

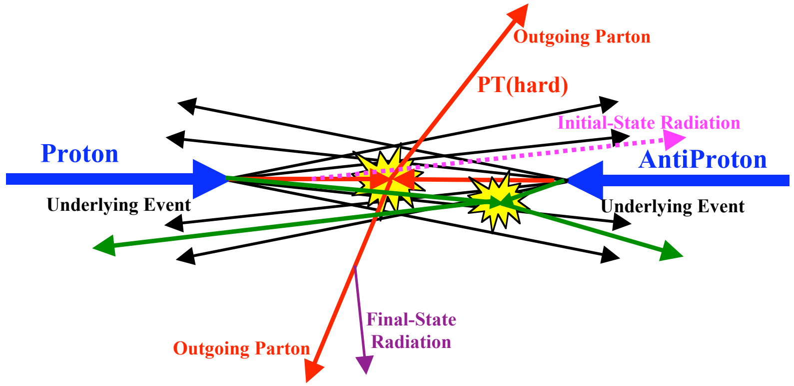
- Momenta of charged particles in jets
  - well described by theory
  - k_T-cutoff can be set as low as $\sim\Lambda_{QCD}$
  - number of hadrons ~ number of partons
- Ratio of charged particle multiplicities in gluon/quark jets $r = 1.6 \pm 0.2$
  - multiplicities and their ratio agree with NLLA extensions and recent LEP data
- Many promising ongoing analyses

Underlying Event



Underlying Event

- The underlying event consists of:
  - initial- and final-state radiation
  - beam-beam remnants
  - possible multiple parton interactions



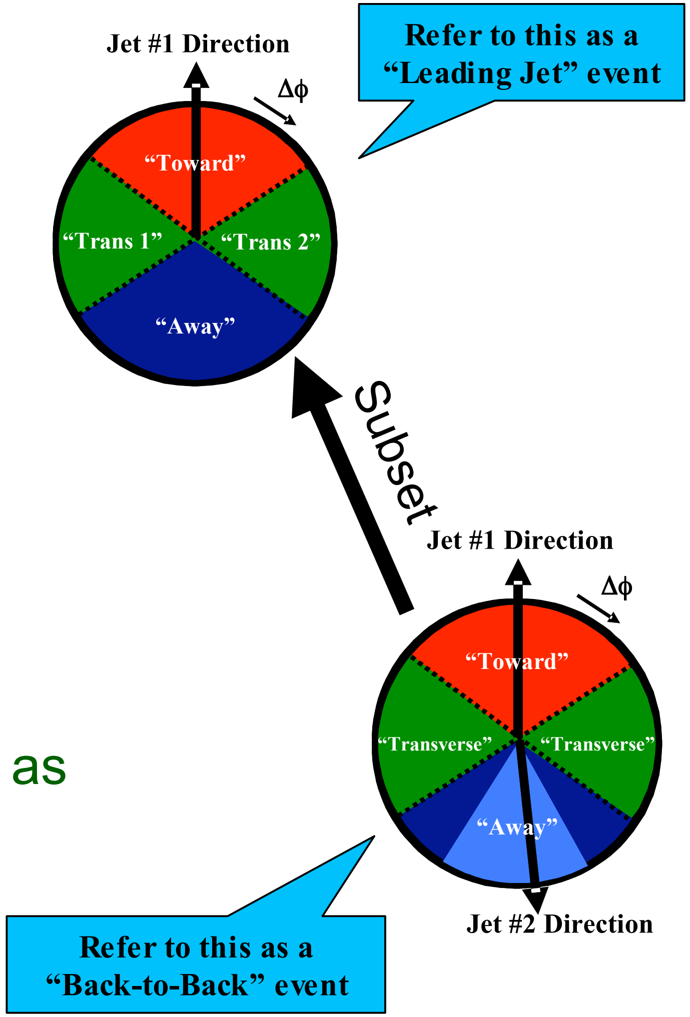
- Study the charged particle correlations

- Many different variables to look at. e.g.
  - Charged particle density, $dN_{chg}/d\eta d\phi$, as a function of $\Delta\phi$ or E_T
  - Charged scalar p_T sum density *(not presented here, see public CDF web-pages for more plots)*
  - …

Event Topologies

Define the following event topologies:

- "Leading jet": the highest p_T jet in the event (JetClu cone 0.7, $|\eta| < 2$)
- "Back-to-Back": at least two jets with:
  - $\Delta\phi_{12} > 150^o$
  - E_T(jet 2)/E_T(jet 1) > 0.8
  - E_T(jet 3) < 15 GeV



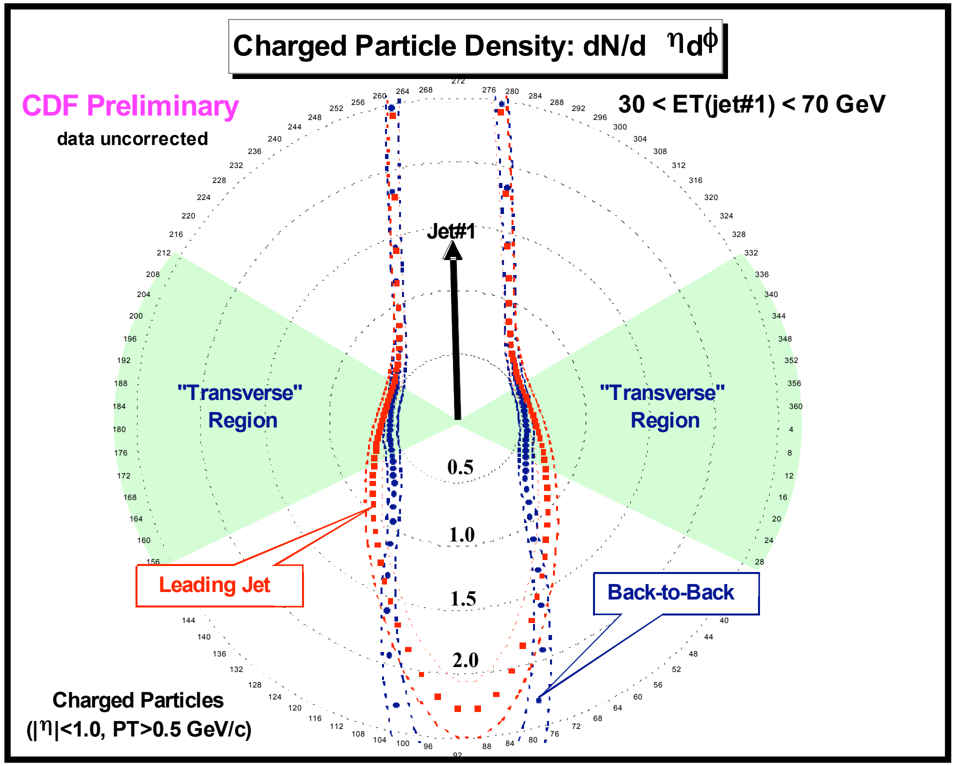
Define spatial regions around jet axis:

- $|\Delta\phi| < \pi/3$ as "Toward"
- $\pi/3 < -\Delta\phi < 2\pi/3$ and $\pi/3 < \Delta\phi < 2\pi/3$ as "Transverse 1" and "Transverse 2"
- $|\Delta\phi| > 2\pi/3$ as "Away"

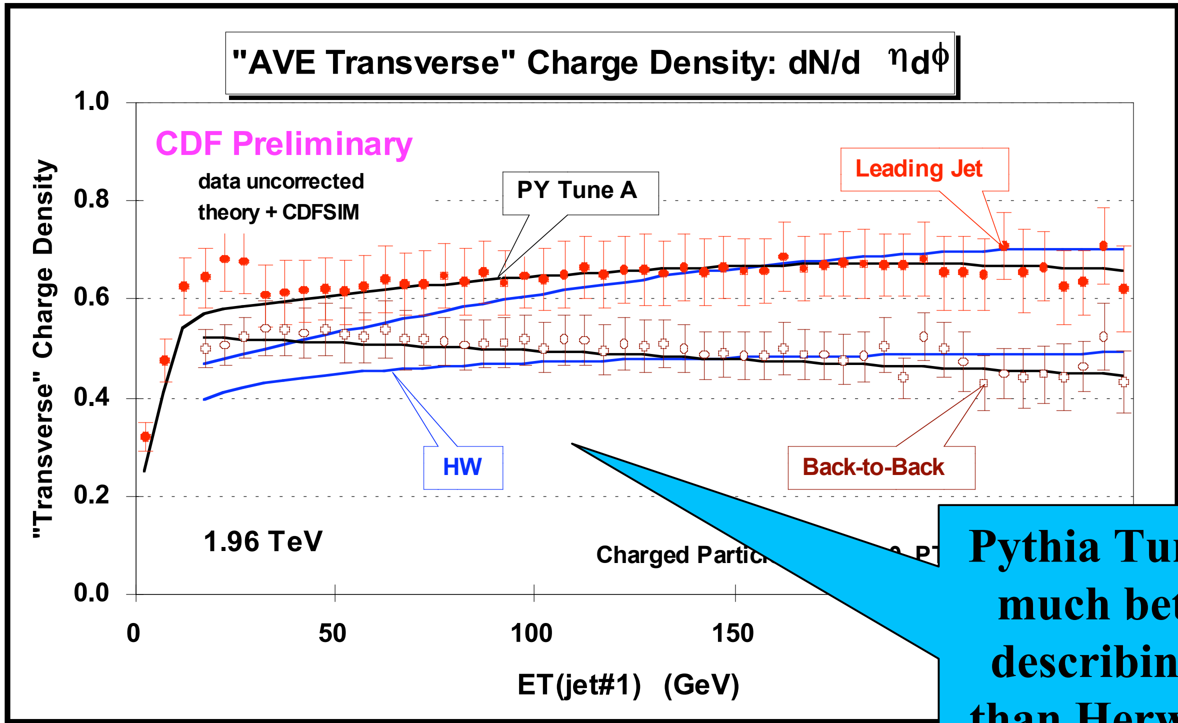
Charged particle density $\Delta\phi$ dependence

- $\Delta\phi$ dependence of the charged particle density in the "Leading Jet" and "Back-to-Back" events.

- Cuts:
  - $p_T > 0.5$ GeV/c
  - $|\eta| < 1$ relative to jet1
  - $30 < E_T(\text{jet1}) < 70$ GeV



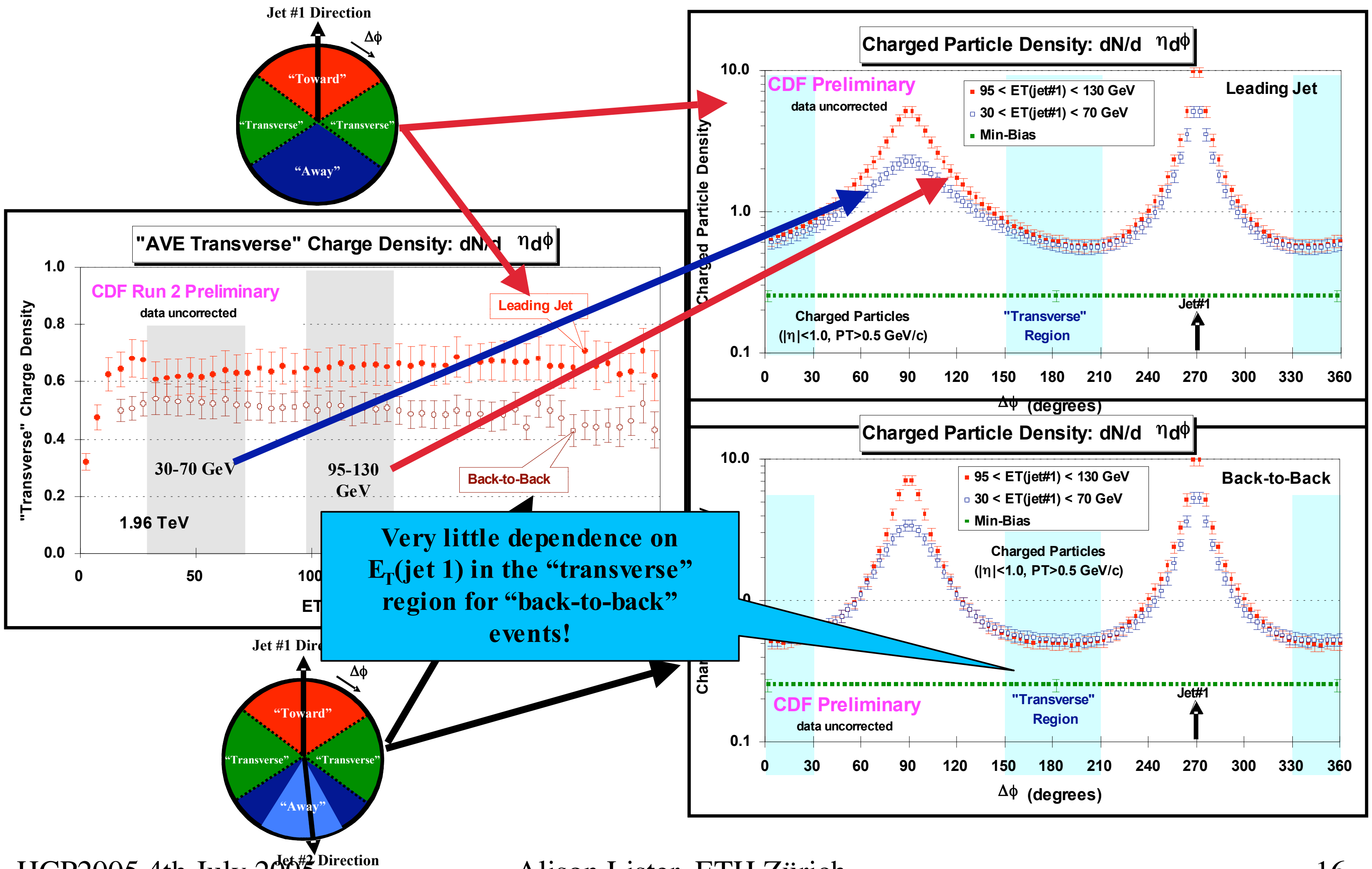
"Transverse" charged particle density vs. E_T leading jet



Pythia Tune A does a much better job at describing the data than Herwig *(without multiple parton interactions)*

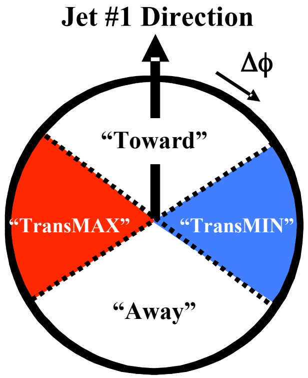
- Compares the (*uncorrected*) data with PYTHIA HERWIG Monte Carlos after detector simulatio

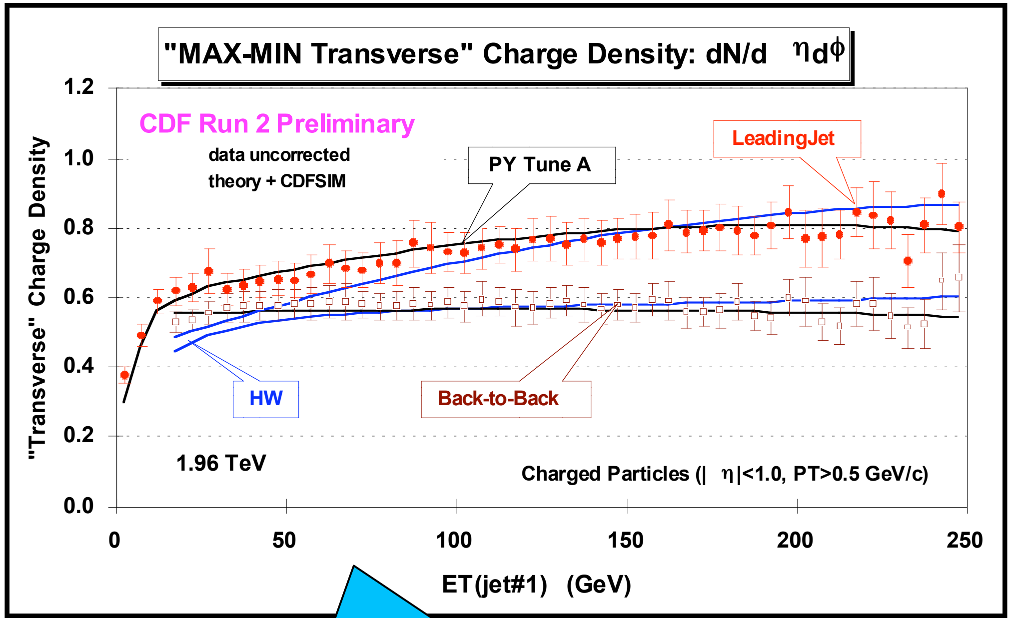
"Transverse" charged particle density vs. E_T leading jet



Very little dependence on E_T(jet 1) in the "transverse" region for "back-to-back" events!

“Transverse difference” charge density vs. E_T(jet 1)

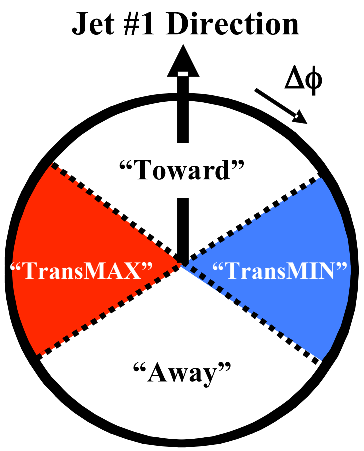


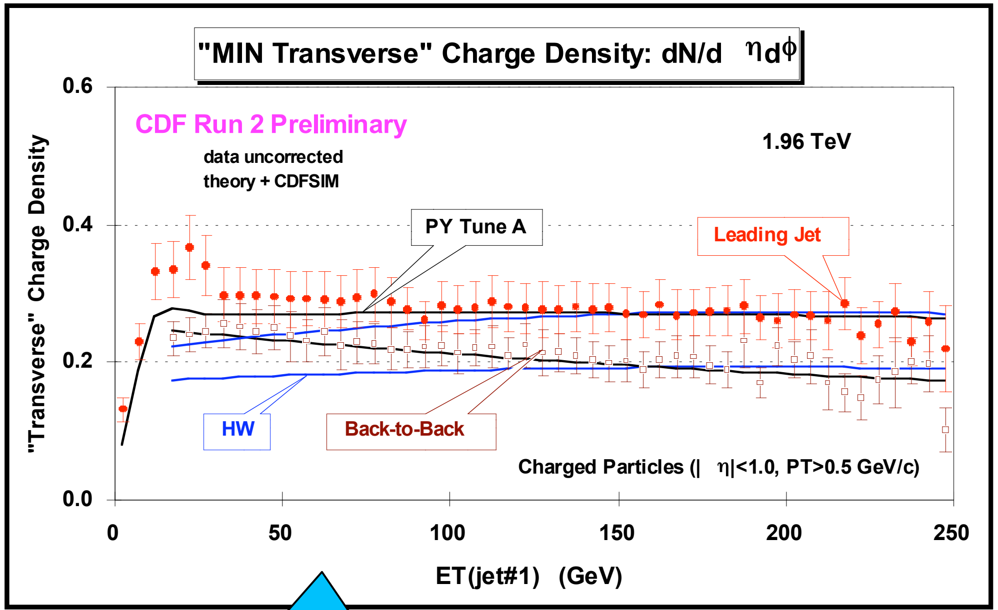


- Look at the difference in the charge particle density between two transverse regions (MAX-MIN)

“MAX-MIN” is very sensitive to the initial and final state radiation component of the underlying event

"Transverse minimum" charge density vs. E_T(jet 1)

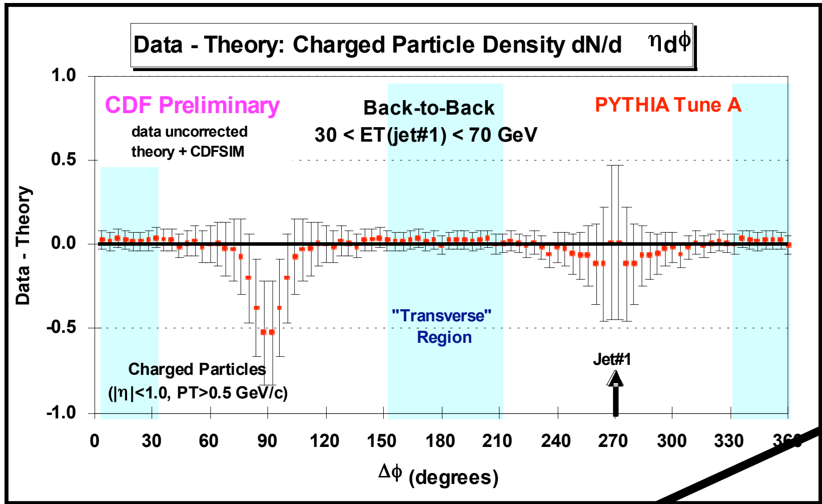


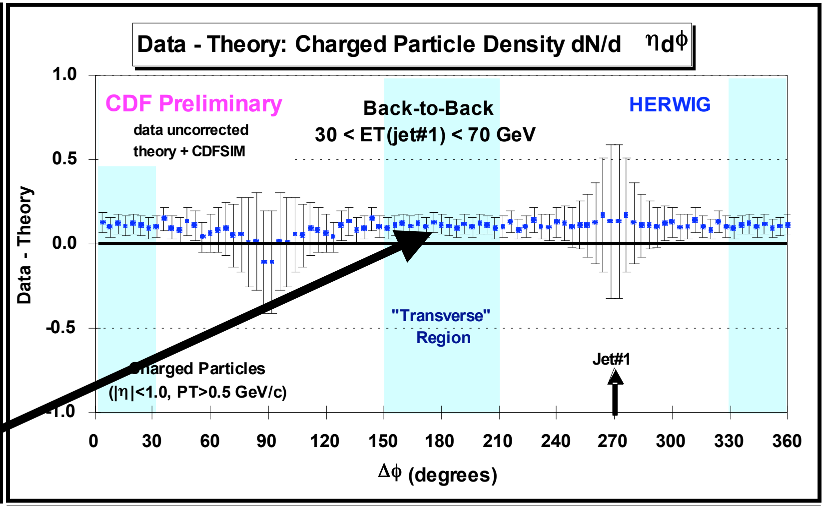


- Look at charge density distribution of the transverse region with the lowest charge density (MIN)

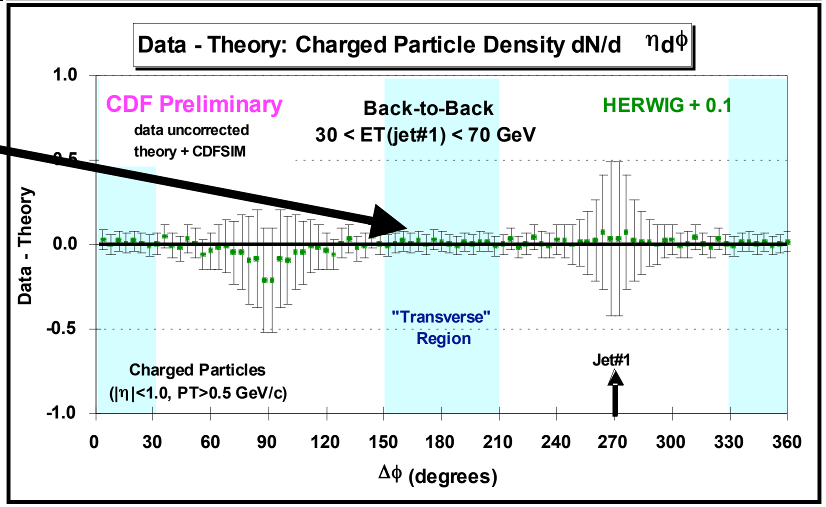
"MIN Transverse" is very sensitive to the "beam-beam remnance" component of the underlying event!

Charged Particle Density
PYTHIA Tune A vs HERWIG





dN/dηdφ + 0.1



- Look at 30<pt<70 GeV
- Difference data - theory
- Add 0.1 charged particles per unit η-φ to HERWIG density (i.e. adding 0.1 x 4π = 1.3 particles for the entire range)

Summary: underlying event

- Interesting correlations between the two transverse regions

- "Back-to-Back" less initial and final state radiation in transverse region than "Leading-Jet"
  → closer look at beam-beam remnants and multiple parton interactions

- PYTHIA Tune A *(with multiple parton scattering)* describes these correlations better than HERWIG (*without multiple parton scattering*)

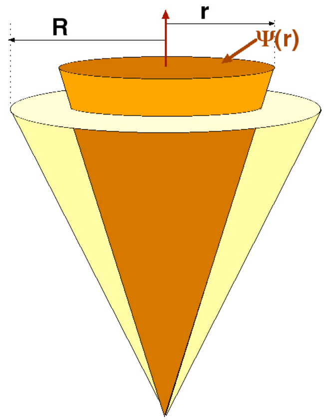
- Ongoing analysis to make results usable by other experiments:
  - unfold distributions to particle level
  - MidPoint algorithm
  - HERWIG + JIMMY

Jet Shapes

Jet Shapes: definitions

- Integrated shape:

  Fractional p_T of jet inside cone r around jet axis



$$\Psi(r) = \int_0^r \frac{p_T(r')}{p_T^{jet}} dr' = \frac{1}{N_{jets}} \sum_{jets} \frac{p_T(0,r)}{p_T(0,R)}$$

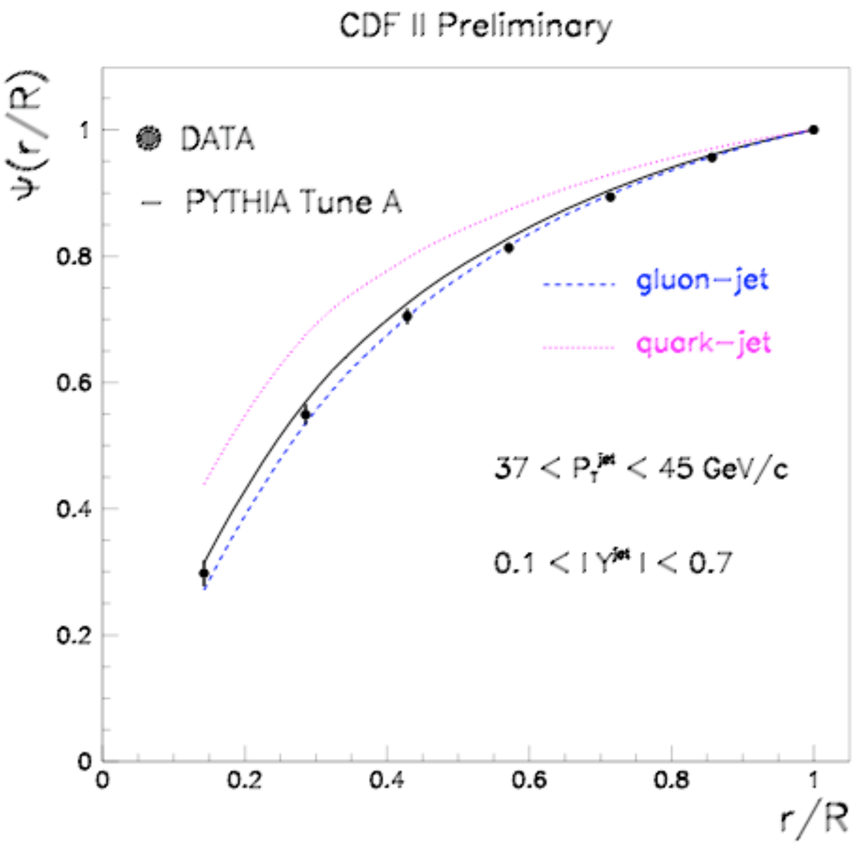
$$\Delta R = \sqrt{(\Delta\phi)^2 + (\Delta Y)^2}$$

- Measurement:
  - ~170 pb^{-1} CDF Run II data
  - MidPoint jet algorithm (cone 0.7, f_{merge} 75%)
  - Jet rapidity: $0.1 < |Y| < 0.7$
  - Shapes corrected back to hadron level
  - Binned in jet p_T

Jet Shapes: Results

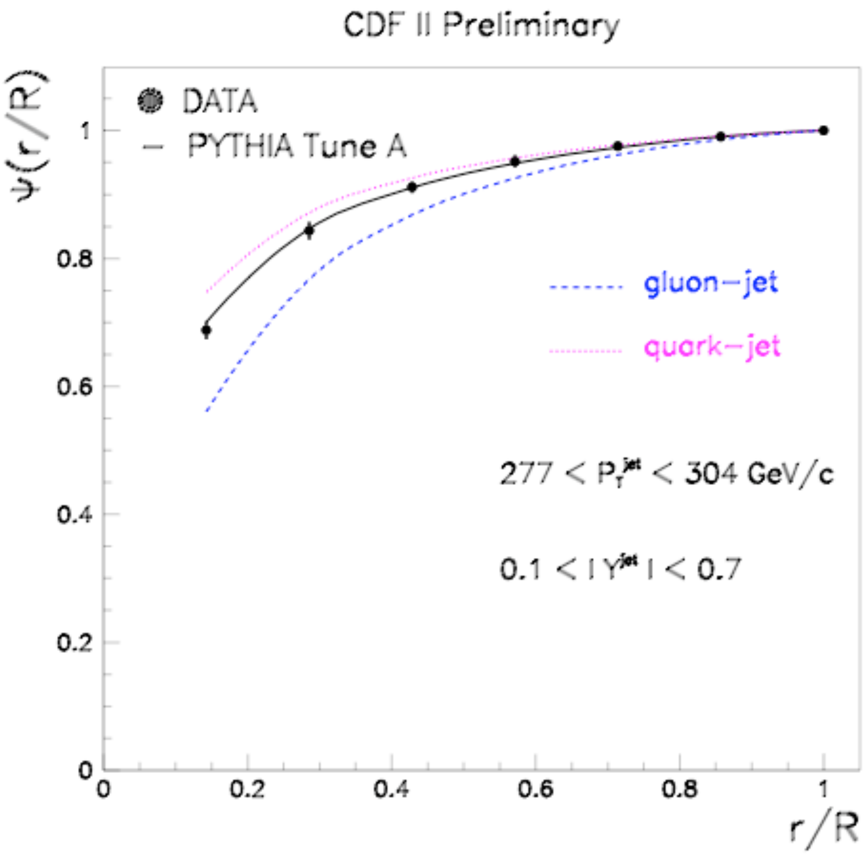
- Low p_T:

  dominated by gluon jets



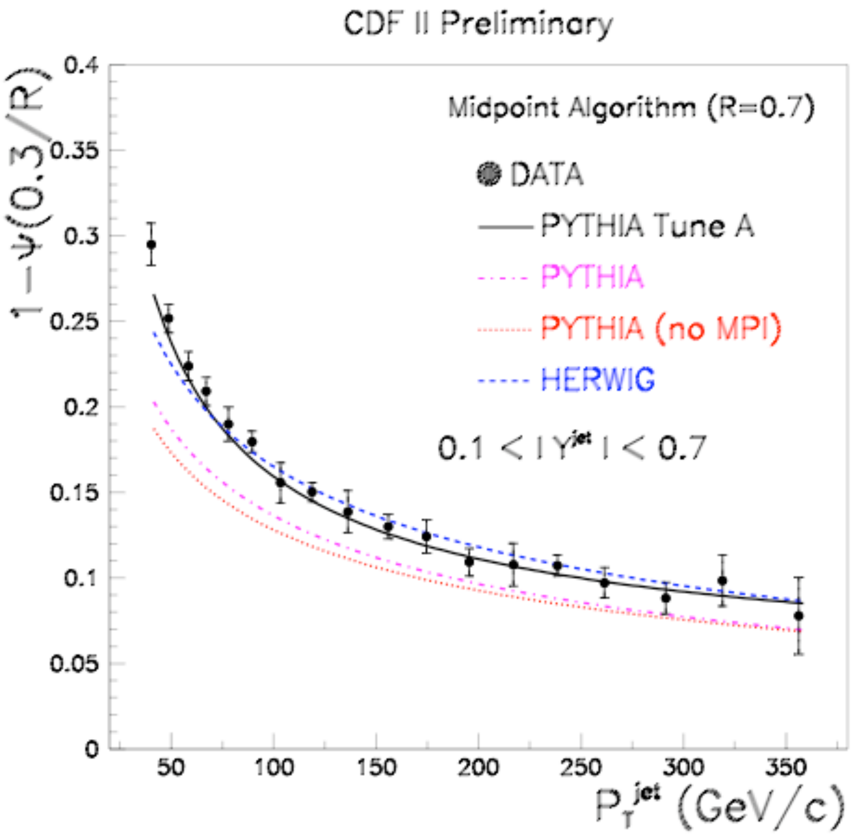
- High p_T:

  dominated by quark jets



Jet Shapes: Results

- Pythia Tune A Monte Carlo *(tuned to Run I underlying event)* describes data very well
- Multiple parton interaction (MPI) important in the description of jet shape



Jet Shapes: Summary

- First RunII analysis on Jet Shapes
- Pythia Tune A describes data well
- Ongoing analysis to measure the shapes of b-jets

Backup slides

Jet Shapes: Results