UNIVERSITY OF FLORIDA

Fragmentation differences of quark and gluon jets at Tevatron

Alexandre Pronko

for CDF collaboration

Introduction & Motivation

- **Jets as a subject of studies:**

  → **jet fragmentation/structure is driven by very soft QCD**

  * borderline between pQCD and non-pQCD

- **Jets as a tool in high P_T physics:**

  → **better understanding of jet fragmentation is important for many analyses**

  * *t tbar* → *all jets* (signal: q-jets, background: lots of g-jets)

- **Jets in Monte Carlo event generators:**

  → **many analyses rely on simulation of jet fragmentation**

  * test of fragmentation models of Monte Carlo event generators

- **Jets in different collider environments:**

  → **data from Tevatron complement e^+e^- and *ep* measurements:**

  * test of universality of jets

Jet Fragmentation: analytical approach

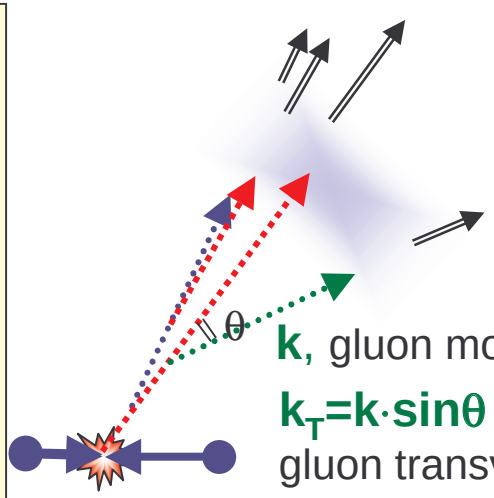
Parton shower development

- **Modified Leading Log Approximation (MLLA or NLLA) and its extensions:**
  - → two jets from color singlet
  - → k_T-cutoff on gluon emission: $k_T > Q_{cutoff} = Q_{eff} \sim \Lambda_{QCD}$
  - → small opening angle θ_c around jet direction
  - → energy scale $Q \approx E_{jet}\theta_c$
  - → LLA & NLLA precision: $r = N_g/N_q = C_A/C_F = 9/4$
  - → corrections beyond NLLA: $r = N_g/N_q = 1.4\text{-}1.8$ at $Q = 10\text{-}100$ GeV

Hadronization stage

- **Local Parton Hadron Duality hypothesis:**
  - → believed to be local, independent of jet origin:

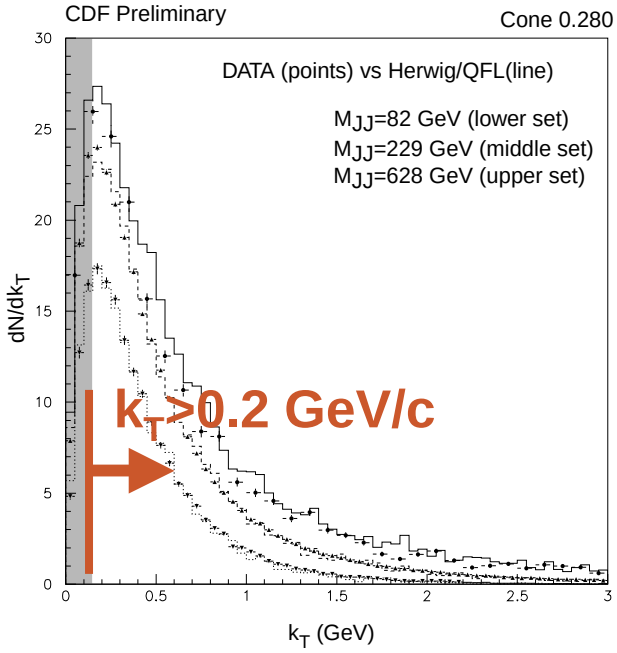
$$N_{hadrons} = K_{LPHD}\, N_{part}$$



k, gluon momentum

$k_T = k \cdot \sin\theta$

gluon transverse momentum



Ratio of multiplicities in quark & gluon jets:
History of measurements

Theory:

- $r=N_{ch}^{G\ jet}/N_{ch}^{Q\ jet}=1.4\text{-}1.8$, Q=10-100 GeV

e^+e^- colliders:

- Challenging measurement
- ~15 papers in last 10 years
- Results range from 1.0 to 1.5
- Diversity of results:

  → non-trivial 3-jet event topology:

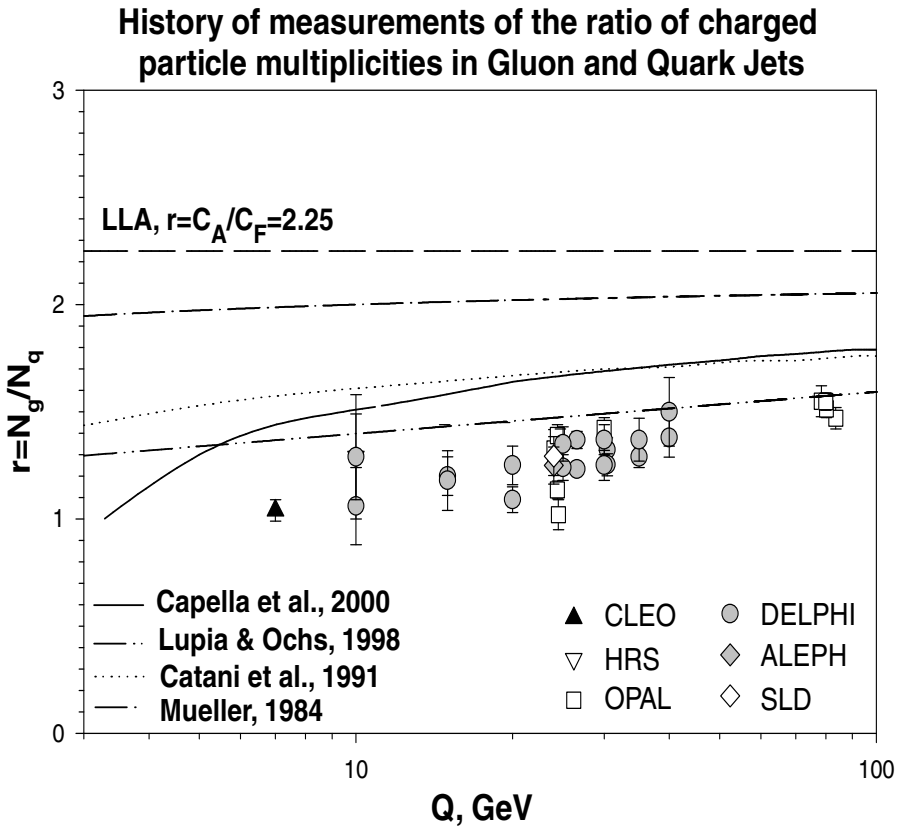
  → *energy scale confusion*

  → *model-dependent analyses*

  → 2 unbiased/model-independent results

Tevatron:

- D0 → ratio of sub-jet multiplicities $r=1.84^{+0.27}_{-0.23}$
- CDF → two model-dependent studies $r=1.7\pm0.3$

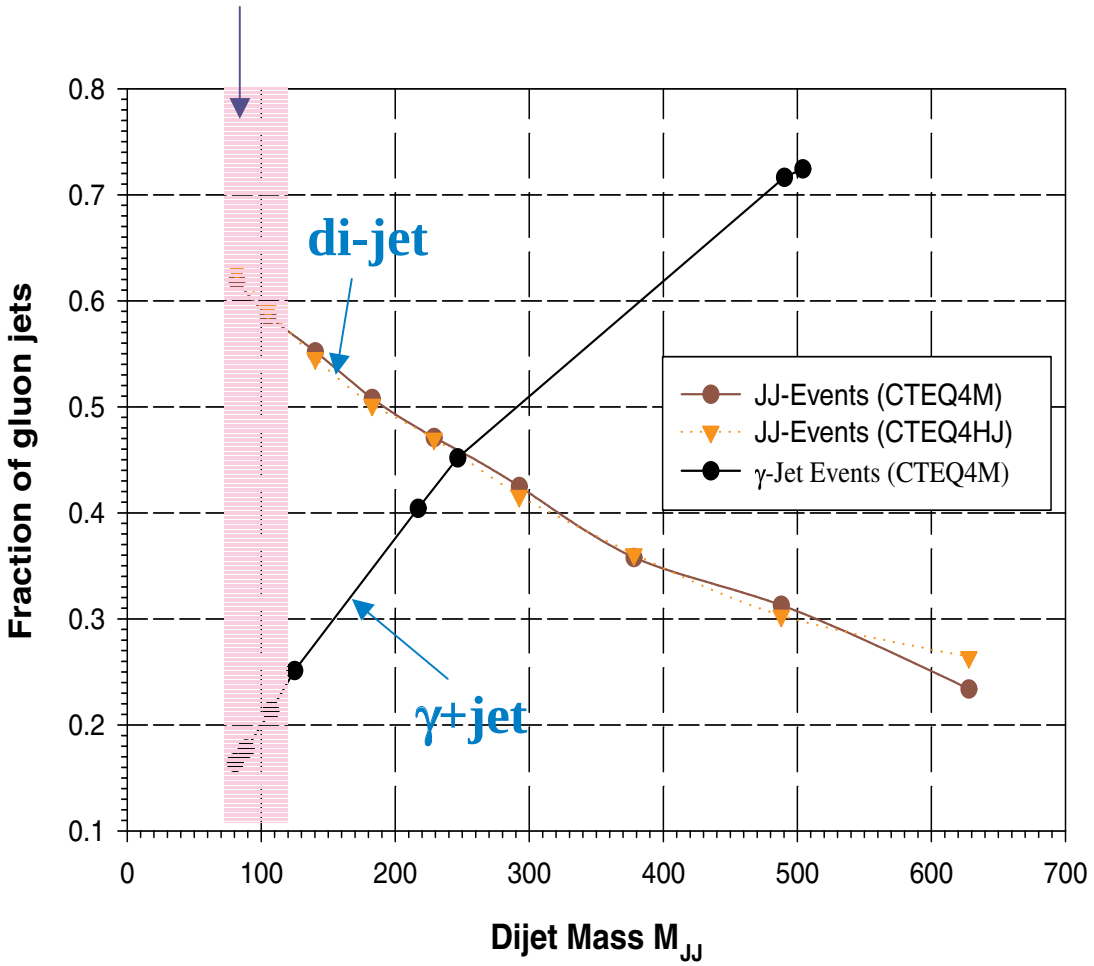


How can one study quark & gluon jets at Tevatron?

di-jet and γ+jet events:

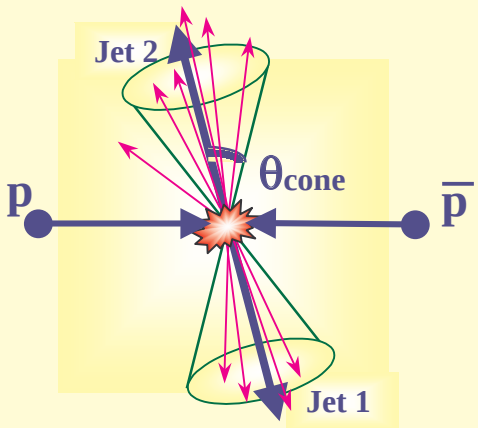
- different fractions of gluon jets
- trivial event topology
- use central jets and count particles in small cones around jet axis

Shaded area: *range of M_{jj} in CDF analysis*



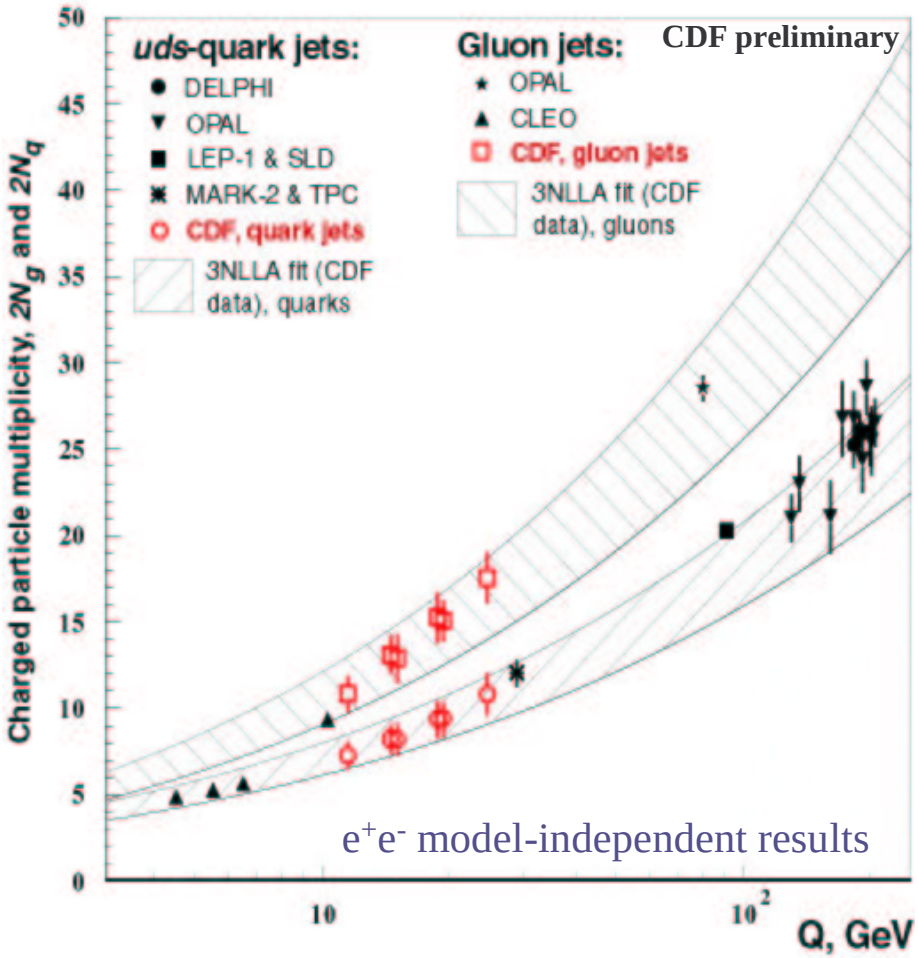
Quark & Gluon jets: Analysis at CDF

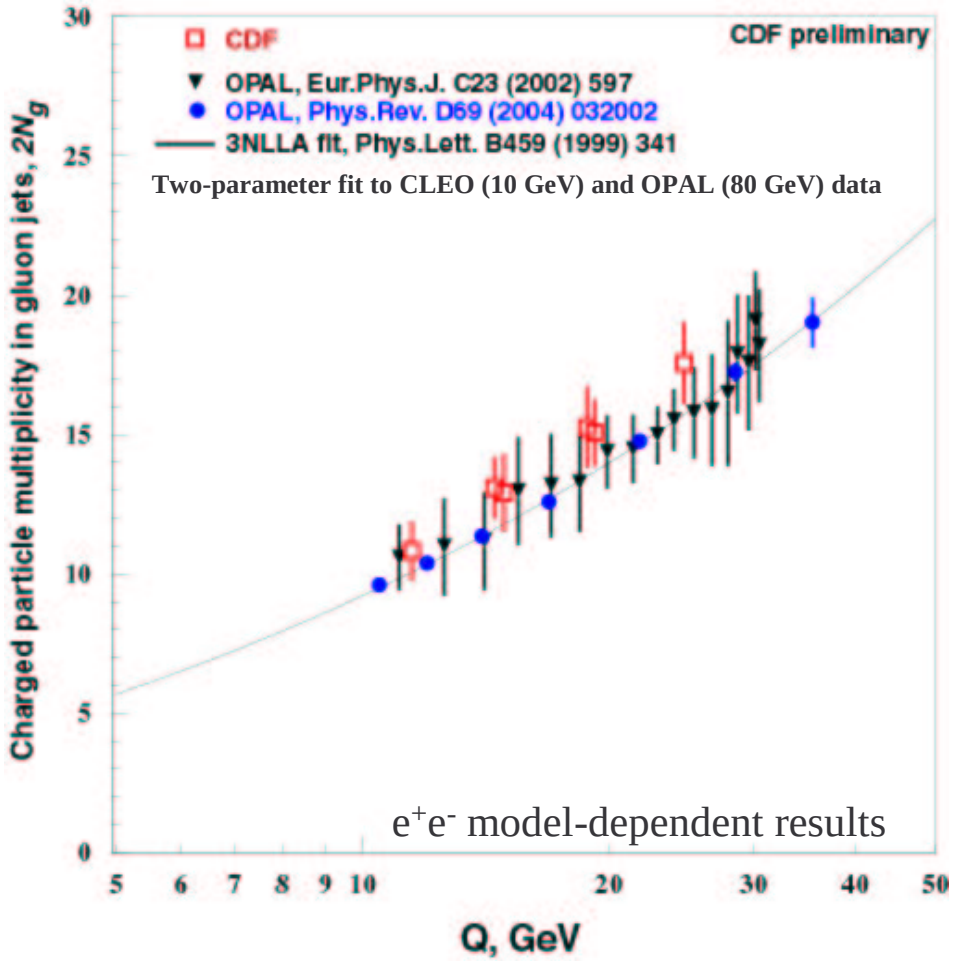
- **Cone jet finder (R=0.7), energy corrected to parton level**
  → systematics check using R=0.4 & R=1.0
- **Central di-jet & γ+jet events with M_{jj} or $M_{\gamma j}$ ~72-120 GeV**
- **Fraction of gluon jets: di-jet events — ~60%, γ+jet events — ~20%**
- **di-jet or γ+jet center of mass frame: $E_{jet}=M/2$ ($\langle E_{jet}\rangle$=41 and 53 GeV)**
- **Multiplicity in cones with opening angle θ_C=0.28, 0.36, and 0.47 rad**
- **subtract contributions of underlying event & secondary interactions**
- **Energy scale $Q = 2E_{jet}\tan(\theta/2) \approx E_{jet}\theta_C$ (~10-25 GeV)**



Multiplicity in quark and gluon jets

- ✓ CDF and e^+e^- data (Q>10 GeV) agree
- ✓ CDF and e^+e^- data (Q>10 GeV) follow 3NLLA trends
- ✓ CDF data confirm $Q \approx E_{jet}\theta_C$ scaling





Ratio of multiplicities in quark & gluon jets

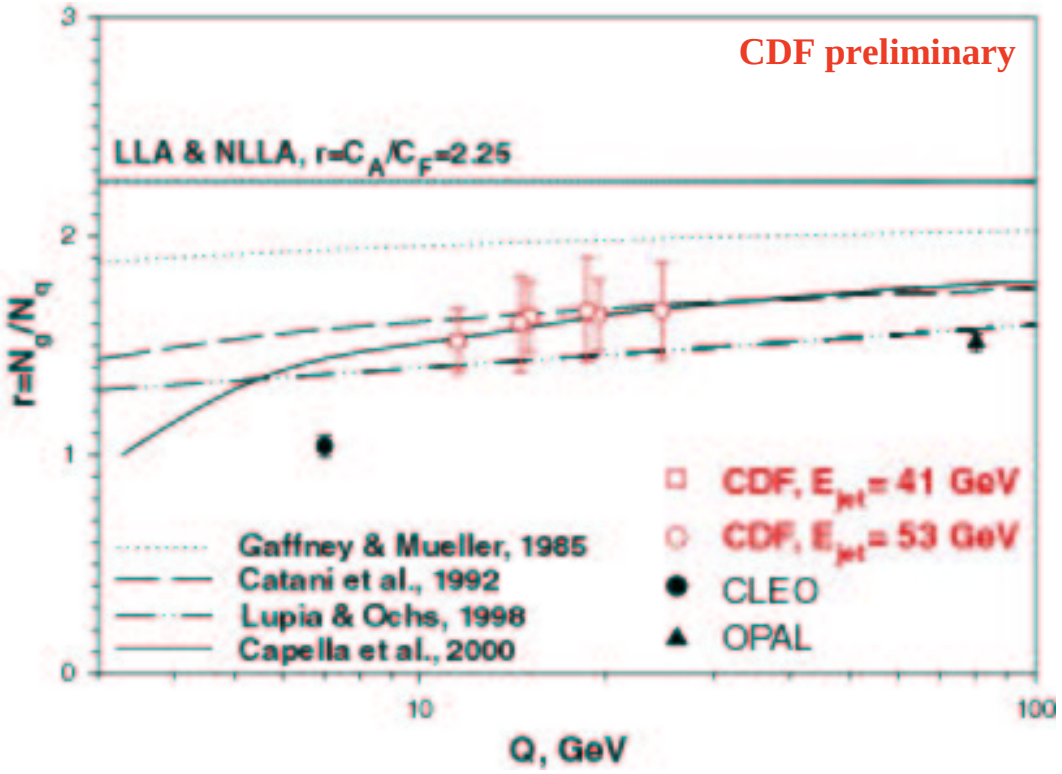
CDF results:

- ✓ **ratio measured in range of Q=11-25 GeV**
- ✓ **r=1.64±0.17 at Q=19 GeV**
- ✓ **$Q \approx E_{jet}\theta_C$ scaling observed**
- ✓ **CDF data follow trends of the recent NLLA extensions:**

→ Q_1=41 GeV * 0.47 rad =19.2 GeV

→ Q_2=41 GeV * 0.28 rad =11.5 GeV

→ **$\Delta r = r(Q_1) - r(Q_2) = 0.12 \pm 0.02 \pm 0.05$**



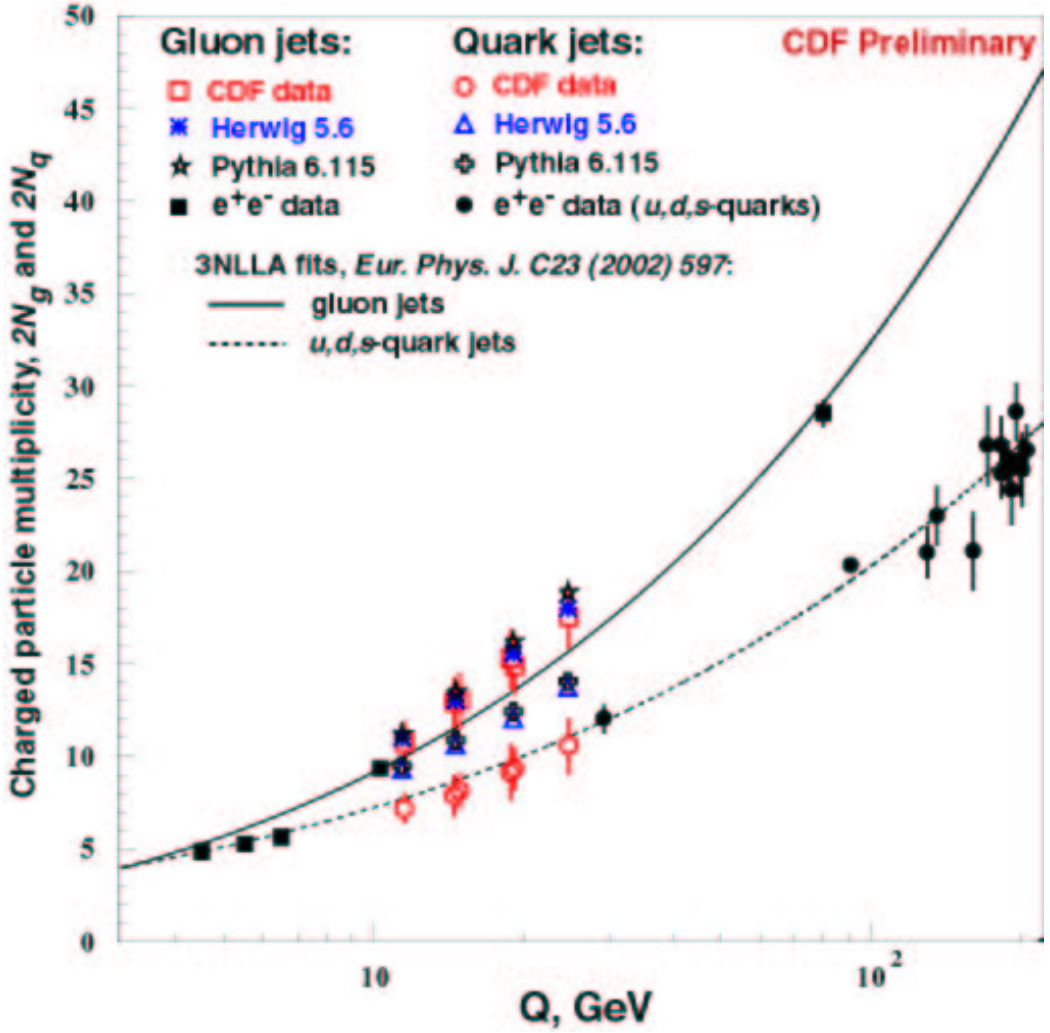
e^+e^- data: only unbiased/model-independent results are presented on the plot

Comparison with Monte Carlo

Herwig 5.6 & Pythia 6.115:

- reproduce gluon jets fairly well
- <u>over-estimate multiplicity in quark jets by ~30%</u>

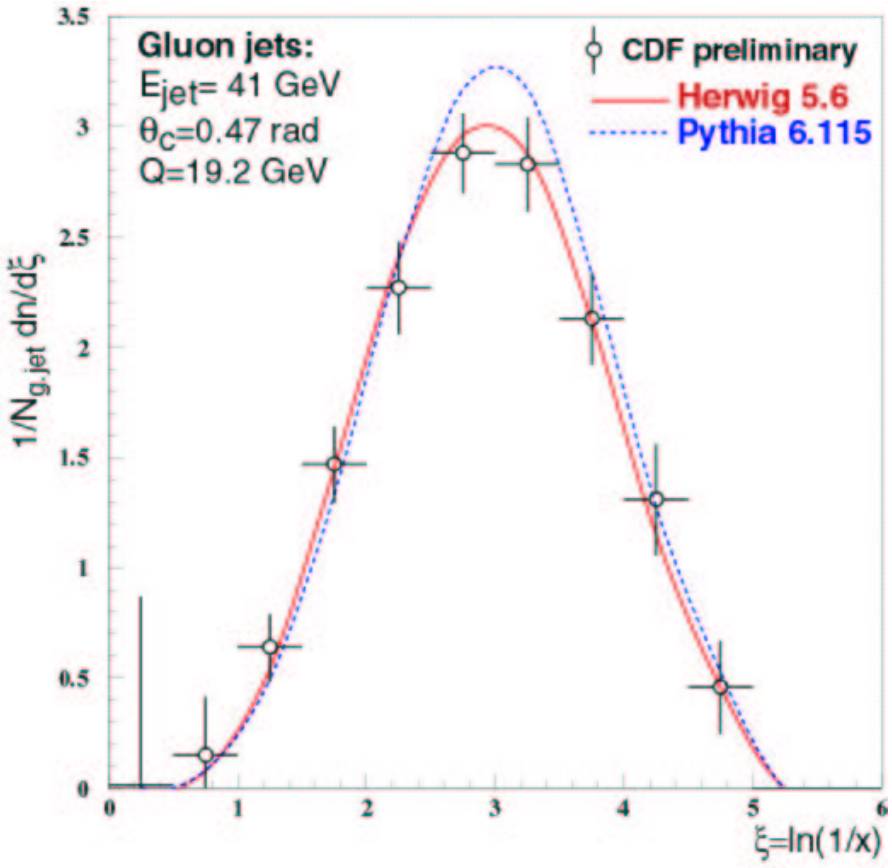
  $\rightarrow r_{MC} \approx 1.3$ ($r_{exp} = 1.6 \pm 0.2$)
- Pythia gives ~3-4% higher multiplicity than Herwig

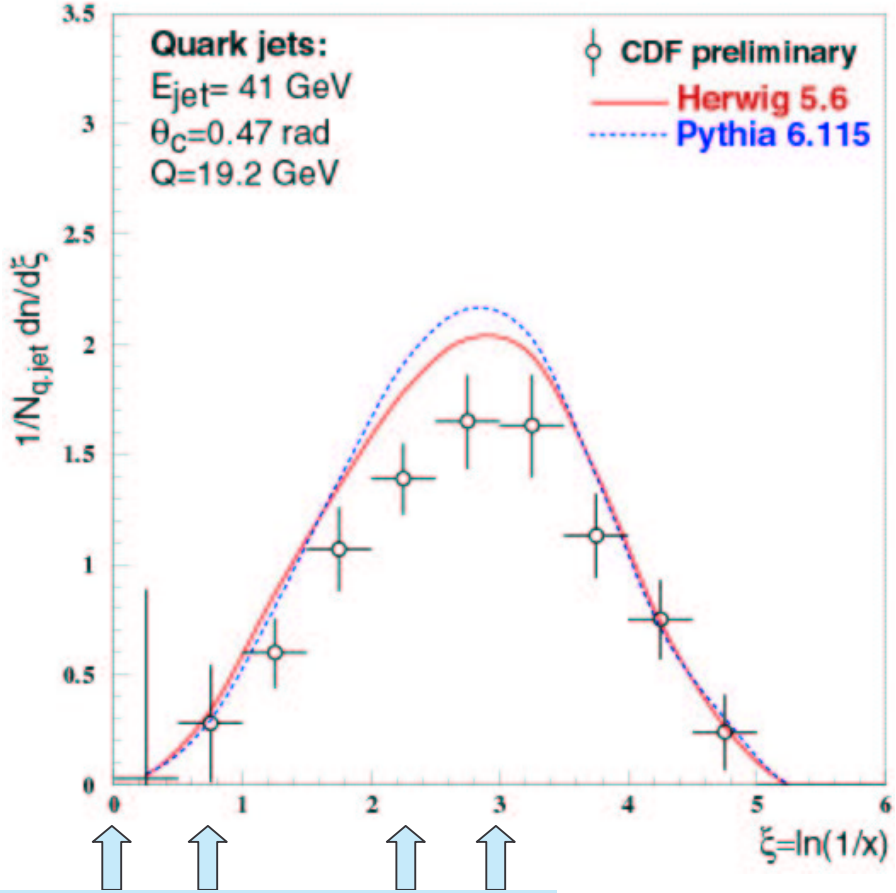


Momentum distribution of charged particles in quark & gluon jets

Gluon jets: Herwig and Pythia are in reasonable agreement with data

Quark jets: Herwig and Pythia <u>disagree</u> with data

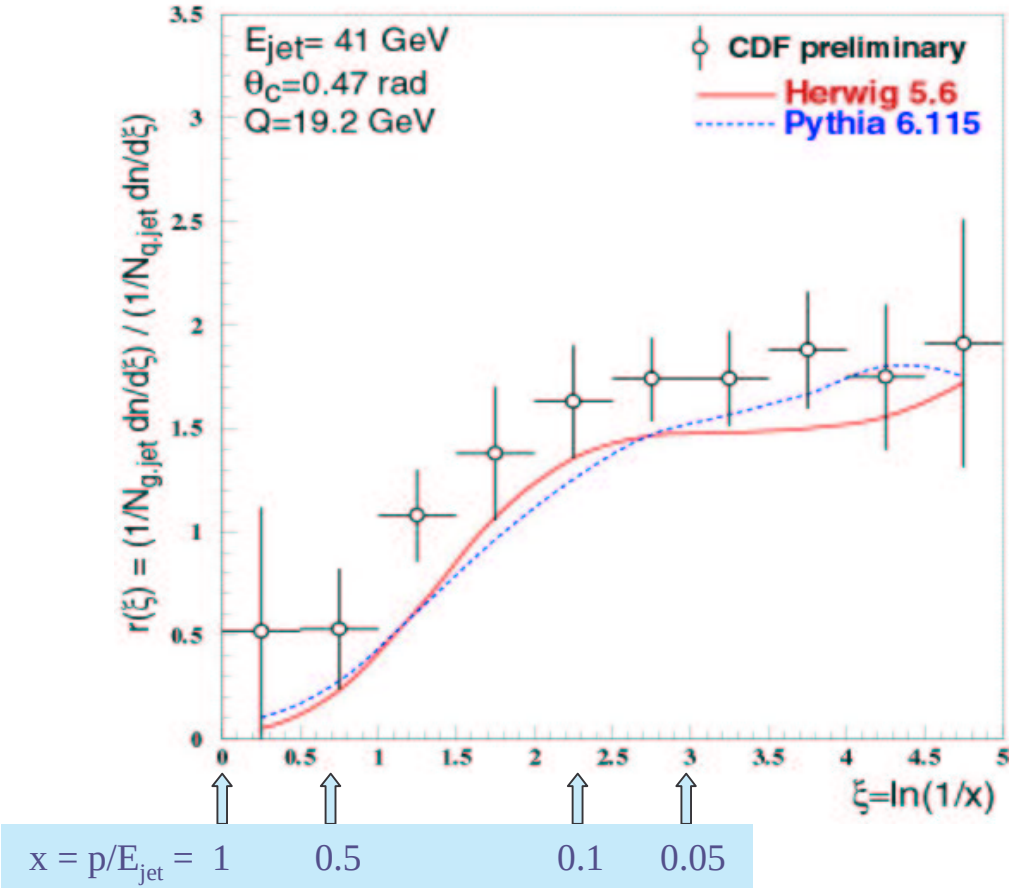


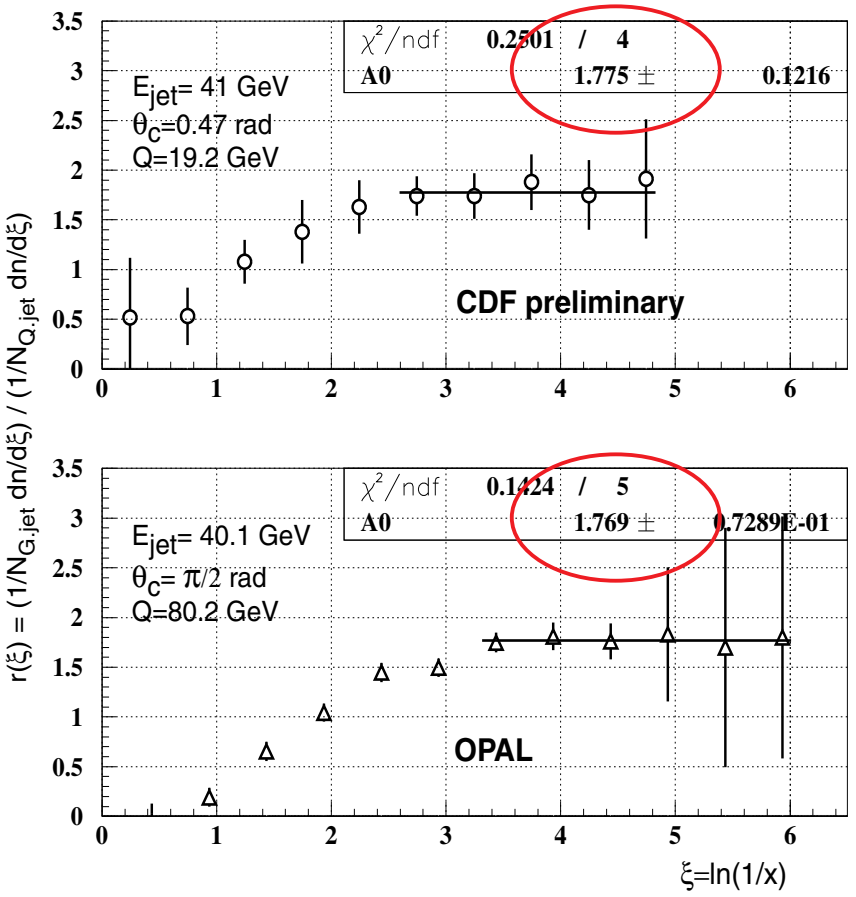


$x = p/E_{jet}$ = 1 0.5 0.1 0.05

Ratio of momentum distribution of charged particles in quark & gluon jets

- ✓ ratio "saturates" in soft part of spectrum at $r(\xi_{soft}) \approx 1.8$
- ✓ same pattern was observed at LEP
- ✓ MC qualitatively reproduces shape of $r(\xi)$





Summary

- ✓ First model-independent analysis of quark and gluon jet differences using charged particles at hadron colliders
- ✓ Multiplicities in gluon and quark jets and their ratio are measured for energy scales Q=11-25 GeV
- ✓ $r=N_g/N_q=1.64\pm0.17$ at Q=19 GeV
- ✓ Multiplicities and ratio follow predictions of recent extensions to Next-to-Leading Log Approximation
- ✓ Good agreement with e^+e^- results
- ✓ Herwig 5.6 and Pythia 6.115 reproduce gluon jets fairly well, but systematically over-estimate multiplicity in quark jets by ~30%