Jet Measurements at DØ using a k_T Algorithm

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on behalf of the DØ collaboration

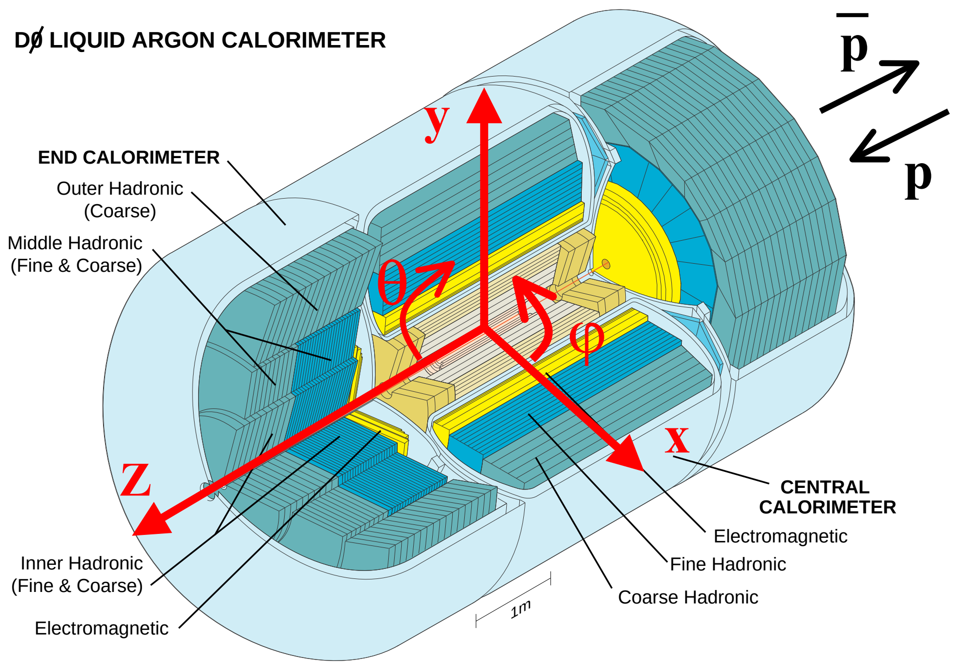
Outline

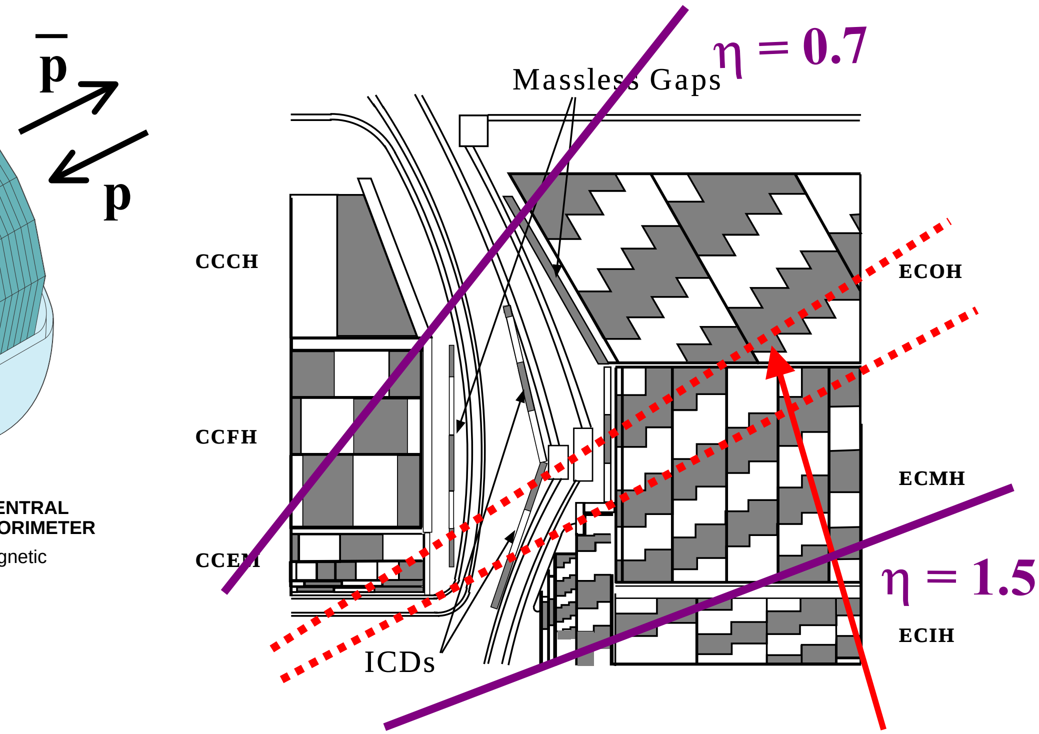
- Introduction: k_T jet algorithm @ DØ
- ABS 350: **Inclusive Jet Cross Section**
  Phys. Lett. B525 211, 2002 (hep-ex/0109041)
- ABS 407: **Sub-jet Multiplicities**
  Phys. Rev. D65 052008, 2002 (hep-ex/0108054)
- ABS 421: **Thrust Cross Sections**
  Preliminary

DØ Run 1 $p\bar{p}$ Data at $\sqrt{s}$ = 1800 GeV & 630 GeV

Run 1B (94-95)	Run 1C (95)
~90 pb^{-1}	~0.6 pb^{-1}

DØ - Calorimeter





- **Ur/liq. Ar calorimeter: high granularity, good hermeticity, hermeticity, quasi-compensated**

$\eta = -\ln[\tan(\theta/2)]$

$|\eta| < 4.2 \qquad \lambda_{int} > 7.2$ (total)

- **Transverse segmentation (towers)**

$\Delta\eta \times \Delta\varphi = 0.1 \times 0.1$

Electrons: $\sigma_E / E = 15\% / \sqrt{E} + 0.3\%$

Pions: $\sigma_E / E = 45\% / \sqrt{E} + 4\%$

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Run 1 k_T Algorithm

Jet Algorithms:

- Fixed cone: most DØ Run 1 results, all CDF results
- k_T -algorithm: New DØ Run 1 results:
  - **fewer split-merge ambiguities,**
  - **infrared safe to all orders in perturbation theory.**

Ellis, Soper Phys. Rev. D48 3160, 1993
Catani, Dokshitzer, Seymour, Webber Nucl. Phys B406 187, 1993

For each object and pair of objects:

$$d_{ii} = k^2_{T,i}$$

$$d_{ij} = \underbrace{\min(k^2_{T,i}, k^2_{T,j})}_{\text{Soft}} \frac{\Delta R^2_{ij}}{D^2}$$

Collinear (if $\Delta R << 1$)

Resolution parameter (D=1)

order all d_{ii} and d_{ij}:

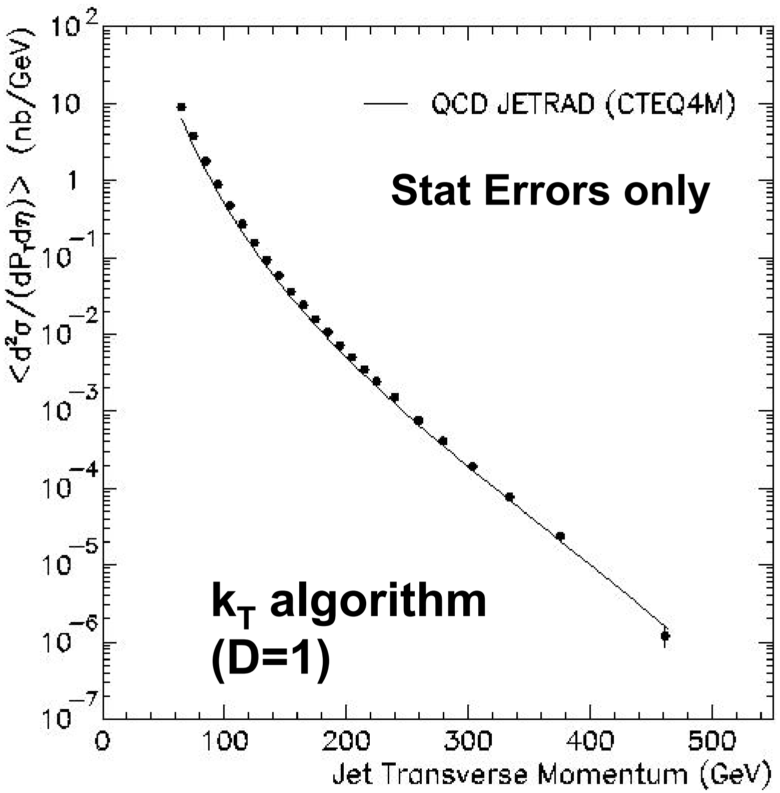
If $d_{min}=d_{ij}$
⇒ merge particles

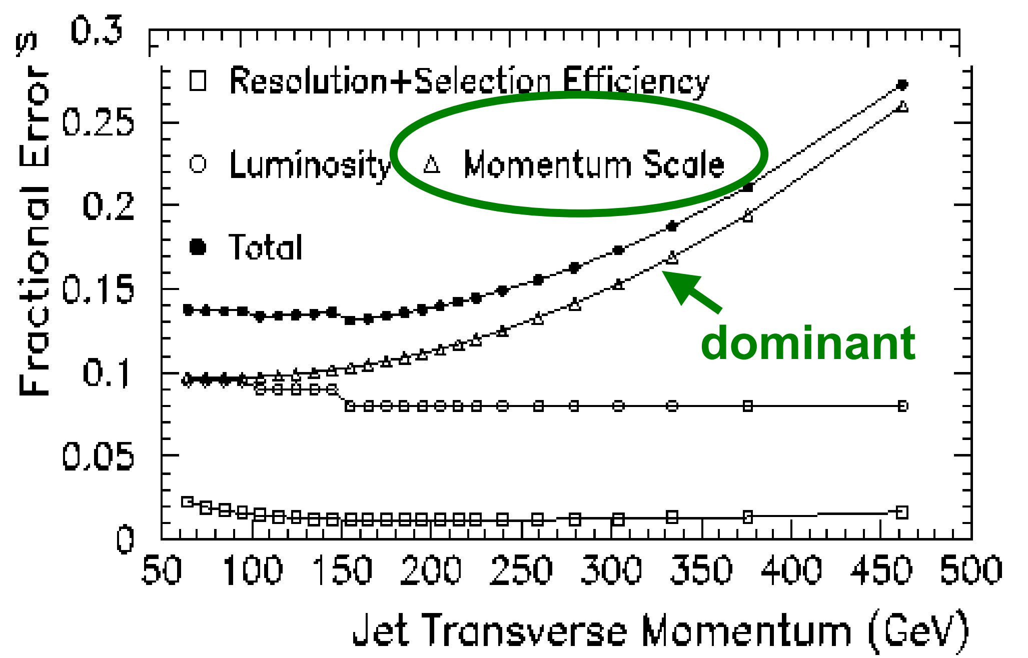
If $d_{min}=d_{ii}$
⇒ jet

Inclusive Jet Cross Section

⇒ pQCD predictions, proton structure, quark compositeness

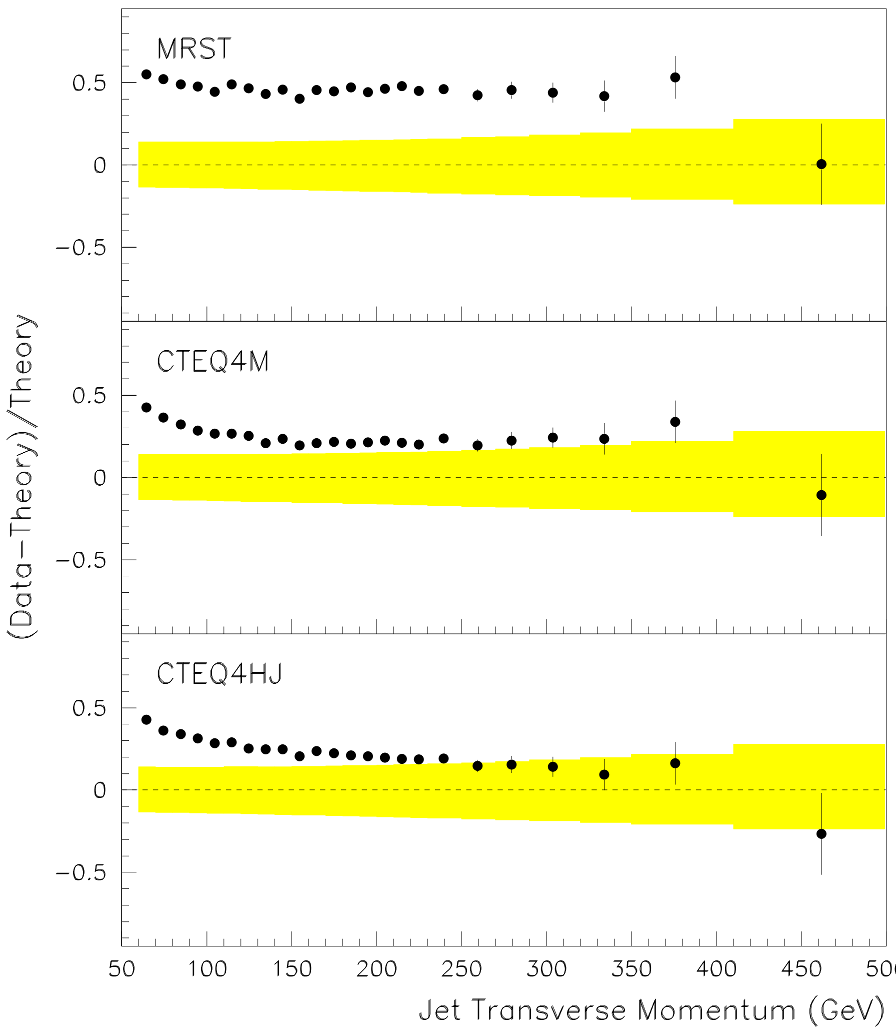
$$\left\langle \frac{d^2\sigma}{dP_T d\eta} \right\rangle (p\bar{p} \to jet + X) = \frac{N}{\Delta p_T \cdot \Delta\eta \cdot L} \cdot \frac{C_{JES} C_{Resol}}{\varepsilon_{ff}} \quad \text{versus} \quad P_T$$





Tot. Err = 14 (27)% at 60 (450) GeV

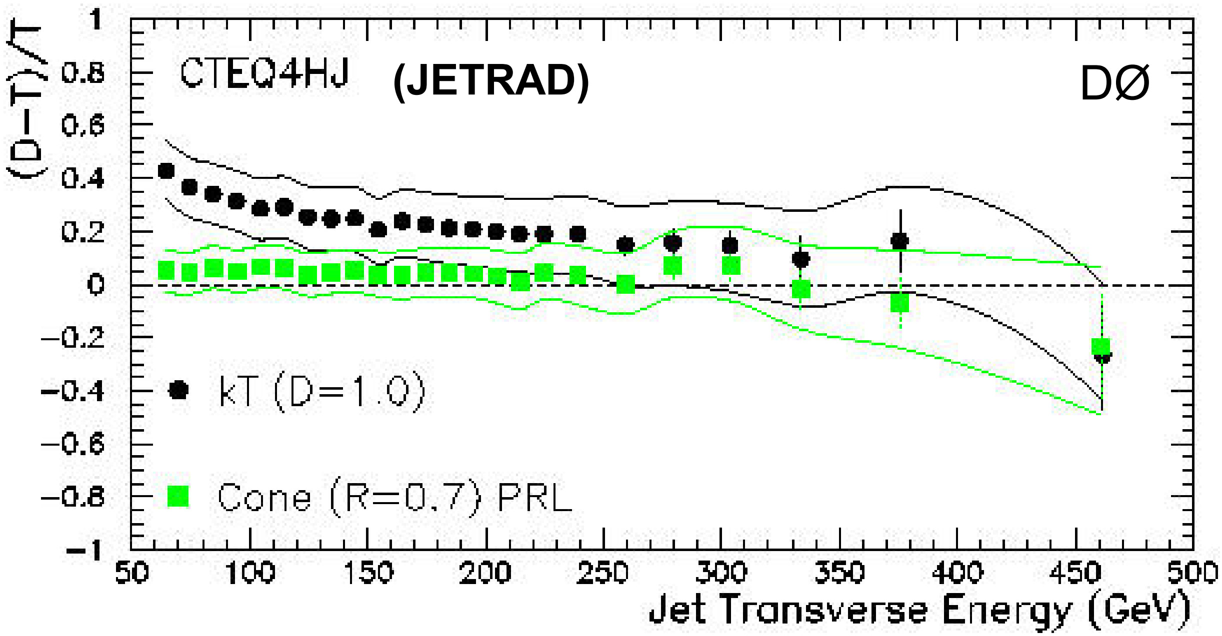
Comparisons with pdf's



- MRST: nearly constant offset
- CTEQ4M: improved description at high p_T
- CTEQ4HJ: better χ^2, especially at high p_T

all data points		
pdf	χ^2(ndf=24)	prob(%)
CTEQ3M	37.6	3.8
CTEQ4M	31.2	15
CTEQ4HJ	27.2	29
p_T> 100 GeV only		
pdf	χ^2(ndf=20)	prob(%)
CTEQ3M	17.4	62.7
CTEQ4M	15.8	72.7
CTEQ4HJ	15.1	77.3

Comparison with Cone Result



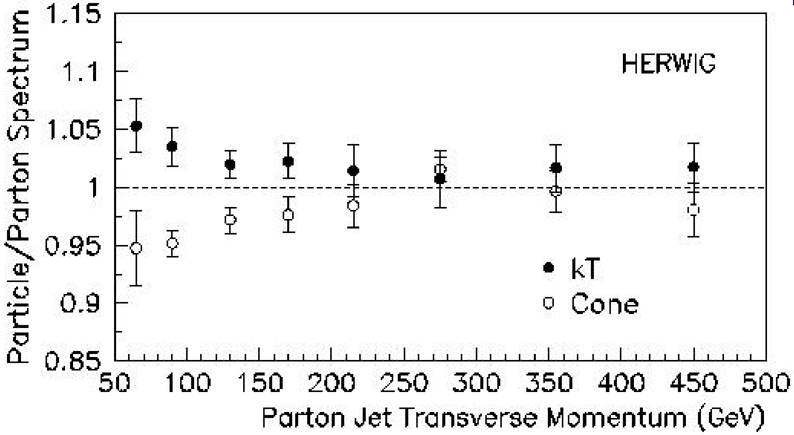
Each result is compared to its own NLO prediction

- **k_T vs. cone agreement is reasonable; marginal at low P_T**
- **NLO predictions: $\sigma(k_T, D=1) = \sigma(\text{cone}, R=0.7)$ within 1%**

→ the data is corrected back to particle level

→ error correlations are large point-to-point in p_T, but largely uncorrelated between the two measurements.

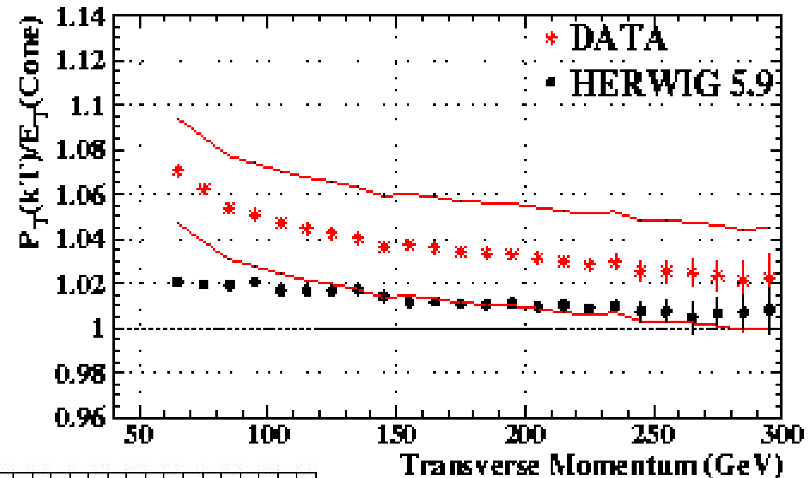
Hadronization effects



- particle jets are more (less) energetic than parton jets with k_T (cone)

→ k_T collects more energy

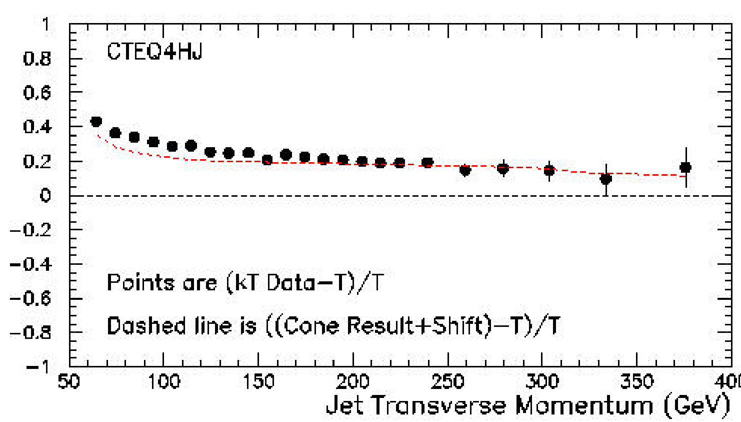
→ cone looses energy



→ k_T jets are 7 (3)% more energetic at at 60 (200) GeV than cone jets:

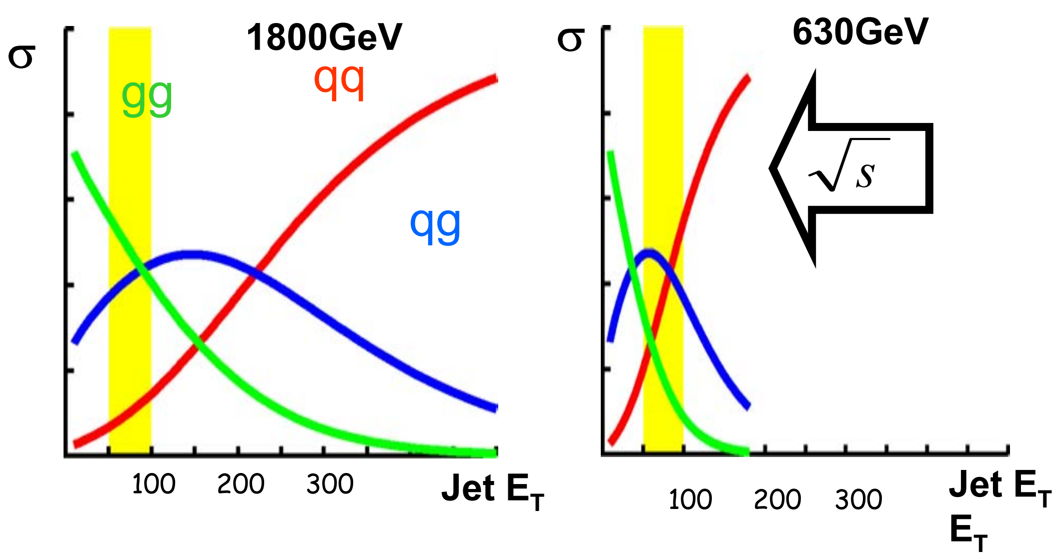
- consistent with HERWIG at high p_T, p_T, at 2σ at low p_T

applying correction to to cone-jets improves improves agreement between the two algorithms



Multiplicity in Quark & Gluon Jets

- **Test of QCD: difference between quark & gluon jets**
  - **→ ratio of color factors of gluons radiated from gluons/quarks = 9/4**
  - **~ multiplicity of objects in gluon/quark jets at asymptotic limit**
  - **→ particles in a gluon jet are softer than in a quark jet**
- **Separate quark from gluon jets: top, Higgs, W+Jets events**



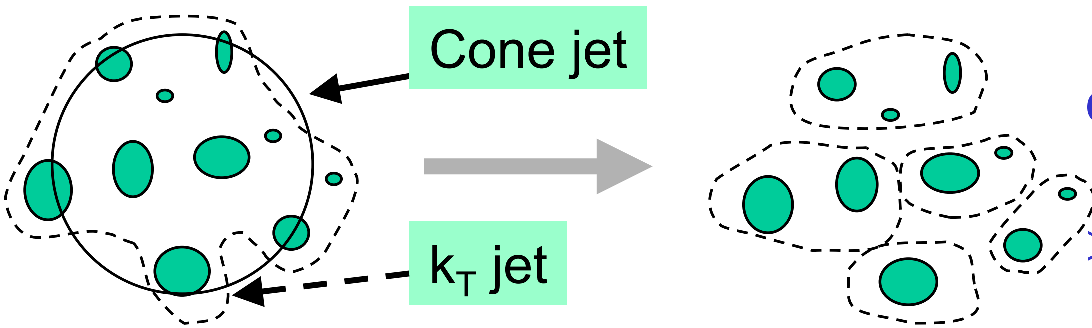
at fixed Jet E_T quark/gluon jet contribution to the total x-section vary with $\sqrt{s}$

⇒ measure the sub-jet multiplicity in quark and gluon jets

Sub-jets with the k_T algorithm algorithm

Merge criteria adjusted to study jet structure:

- re-run k_T algorithm on all particles already assigned to a jet



$$d_{i,j} = \min(k_{T,i}^2, k_{T,j}^2)\frac{\Delta R_{ij}^2}{D^2} > y_{cut} E_{T,Jet}^2$$

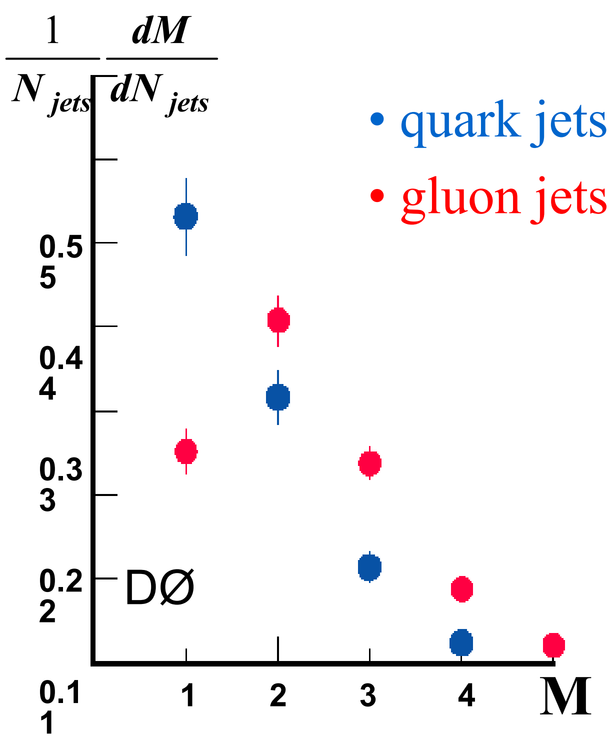
D= 0.5

$y_{cut}=10^{-3}$
$y_{cut}=1$: no splitting
$y_{cut}=0$: no merging

- determine gluon jet fraction f_g from MC: $f_{1800}=0.59$ $f_{630}= 0.33$ *($55<E_T<100$ GeV)*
- sub-jet multiplicity defined as: $M = f_g M_g + (1-f_g) M_q$
- assuming sub-jet multiplicity independent of $\sqrt{s}$

$\Rightarrow$ extract gluon (M_g)/quark (M_q) sub-jet multiplicities from data at 1800 and 630 GeV

Sub-jets in Quark & Gluon Jets



- gluon jets have a higher sub-jet multiplicity as expected
- good description by HERWIG
- dominant uncertainties:
  - → quark/gluon jet fraction, dependent on pdf
  - → jet energy scale
- result qualitatively in agreement with resummation resummation calculation from Forshaw & Seymour Seymour

$$R \equiv \frac{\langle M_g \rangle - 1}{\langle M_q \rangle - 1}$$

$$R = 1.84 \pm 0.15\,(\text{stat}) \pm {}^{0.22}_{0.18}\,(\text{sys})$$

HERWIG:1.91

ALEPH (e^+e^-): 1.7 ±0.1

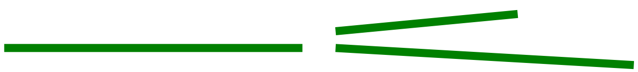
Event Shape Variable: Thrust

Event shape variables allow to:

- **study spatial distribution of hadronic final states**
- **test perturbative QCD, verify resummation calculations**
- **extract α_s**

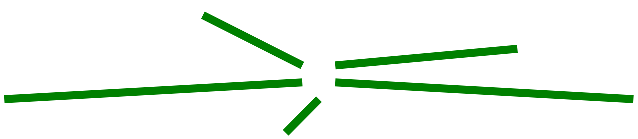
2 partons in final state

T=1



3 partons in final state

T=[2/3,1] (LO)



N partons in final state

T=[1/2,1] (N...NLO)

$$T = \max_{\hat{n}} \frac{\sum_i |\vec{p}_i \cdot \hat{n}|}{\sum_i |\vec{p}_i|}$$

$\hat{n}$: direction which maximizes T

i : number of partons/particles/jets in an event

Thrust characterizes sphericity of an event

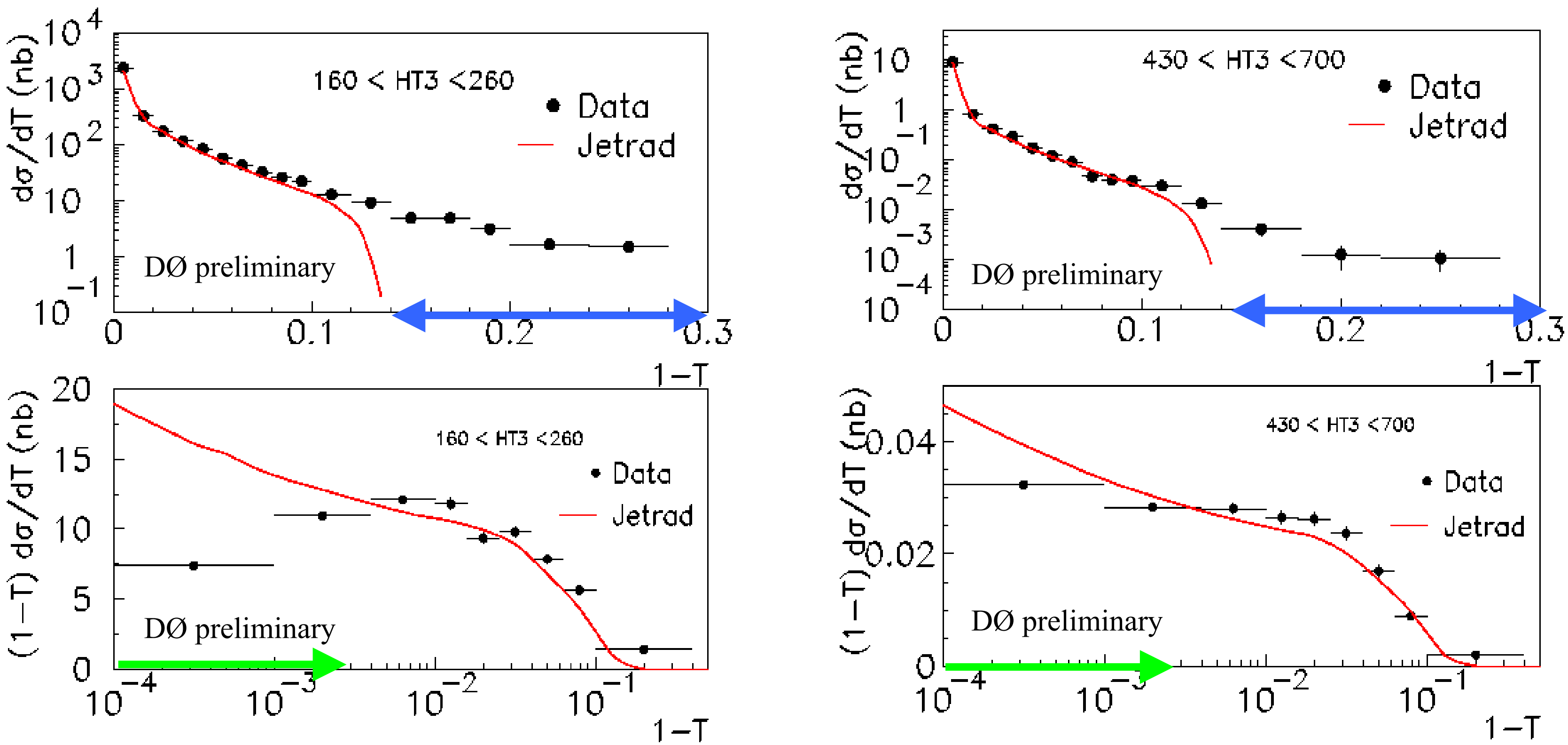
Thrust at hadron colliders

- **difficulties: underlying event, pile-up, multiple interactions**
  - ⇒ **define thrust from 2 leading jets in thrust T_2**
- **thrust is not Lorentz invariant**
  - ⇒ **introduce Transverse Thrust T_2^T computed from p_t**

$$T_2^T = \max_{\hat{n}} \frac{\sum_i \left|\vec{p}_{ti} \cdot \hat{n}\right|}{\sum_i \left|\vec{p}_{ti}\right|} \qquad \sqrt{2}/2 \le T_2^T \le 1$$

- **x-sect in bins of** $H_{3T} = \sum_{i\le 3} \left|\vec{p}_{ti}\right| \propto$ **Q^2 on parton level**

Dijet Transverse Thrust x-section



- **Disagreement with JETRAD calculation in 2 regions:**

⇒ **$\sqrt{2}/2 \leq T_2^T \leq \sqrt{3}/2$:** LO calculation is $O(\alpha_s^4) \rightarrow$ NLO calculation?

⇒ **limit (1-T) « 1** → emission of soft and collinear gluons → logarithmic terms terms in ln(1-T) → resummation?

Summary

- DØ has successfully implemented and calibrated a k_T k_T jet algorithm in a hadron collider

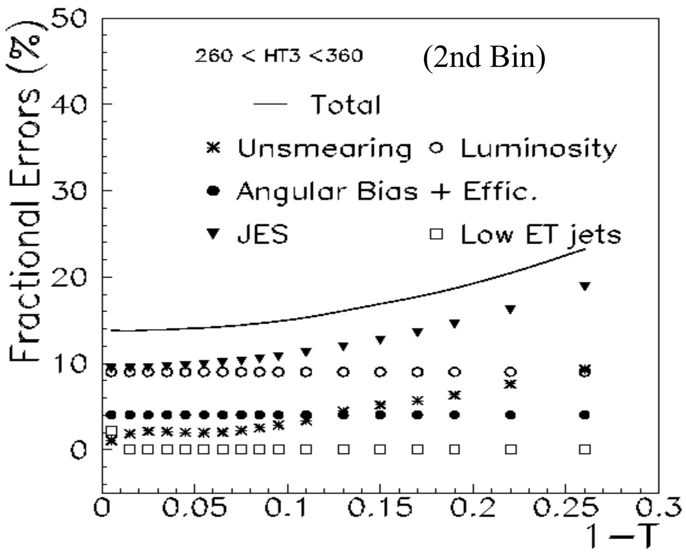
⇒ comparison of the k_T x-section, cone x-section and NLO calculations at low p_t opened a discussion on matters such us hadronization, underlying event and and algorithm definition

⇒ quark & gluon jets have a different structure, consistent with HERWIG predictions

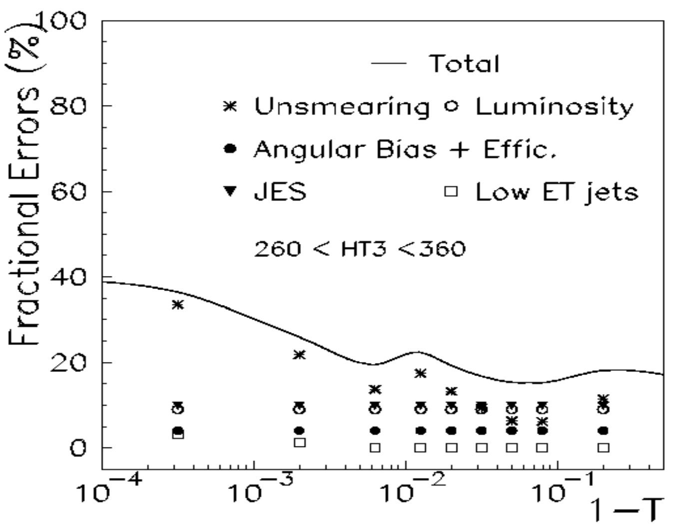
⇒ thrust distributions offer an excellent opportunity to test the recently developed NLO 3-jet generators

- Further measurements to come using Run 2 data

Systematic Uncertainties
Uncertainties



Error Source	1st HT3 Bin Order of Magnitude (%)	2nd Bin Order of Magnitude (%)	3rd Bin Order of Magnitude (%)	4th Bin Order of Magnitude (%)
Luminosity	8	8	8	8
Unfolding	1 – 8	1 – 9	1 – 12	1 – 12
Pos Biases + Effic	4	4	4	4
Low energy jets	0 – 4	0 – 2	0 – 2	0 – 2
Mom Scale	10 – 15	10 – 18	10 – 20	10 – 20



Error Source	1st HT3 Bin Order of Magnitude (%)	2nd Bin Order of Magnitude (%)	3rd Bin Order of Magnitude (%)	4th Bin Order of Magnitude (%)
Luminosity	8	8	8	8
Unfolding	10 – 85	10 – 30	5 – 20	5 – 20
Pos Biases + Effic	4	4	4	4
Low energy jets	0 – 5	0 – 3	0 – 2	0 – 2
Mom Scale	10	10	10	10