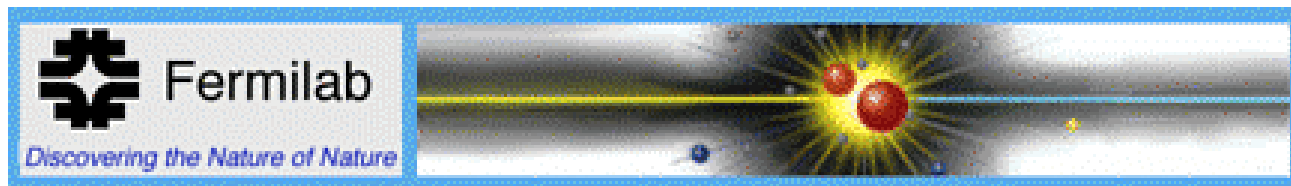


K_T Jets in Run I: Comparisons with QCD-NLO

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Jets Workshop, Fermilab,
December 16th 2002



Outline

- Introduction to the K_T jet algorithm, the D0 definition

- Physics Results

- Subjet Multiplicities

Phys. Rev. D65 052008, 2002 (hep-ex/0108054)

- Thrust Cross Sections

Preliminary

- The Inclusive Jet Cross Section

Phys. Lett. B525 211, 2002 (hep-ex/0109041)

D0 Run I pp Data at $\sqrt{s} = 1.8$ TeV & 630 GeV

Run I B (94-95)

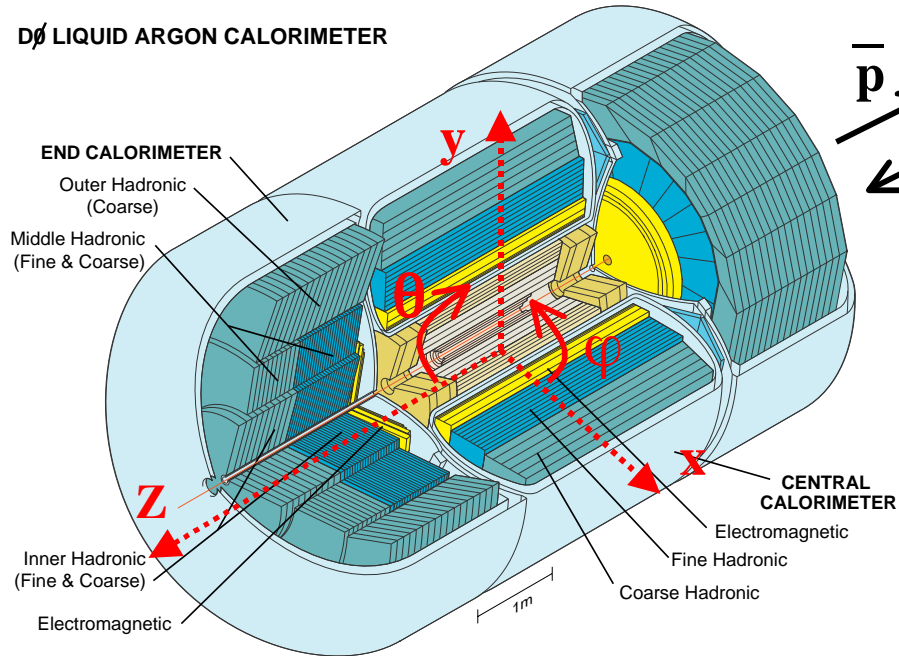
Run 1C (95-96)

~ 90 pb⁻¹

~ 600 nb⁻¹

The D0 Calorimeters

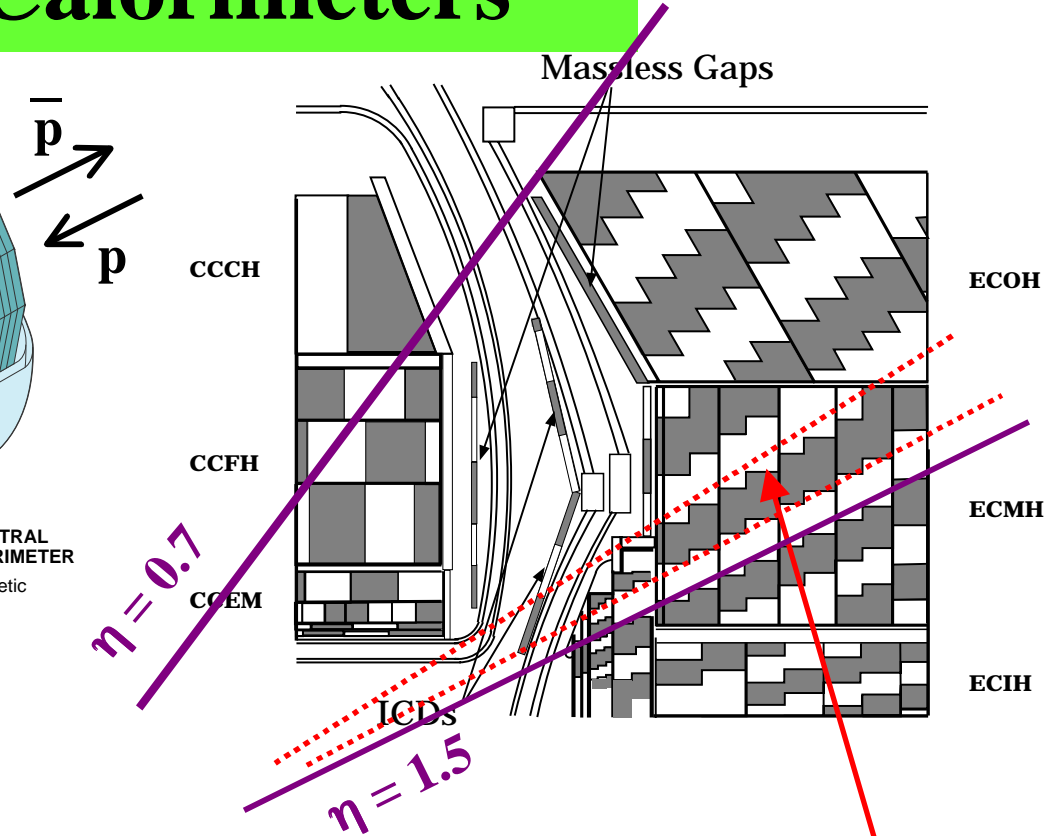
DØ LIQUID ARGON CALORIMETER



- Liquid argon sampling and uranium absorber
- Hermetic with full coverage

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

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

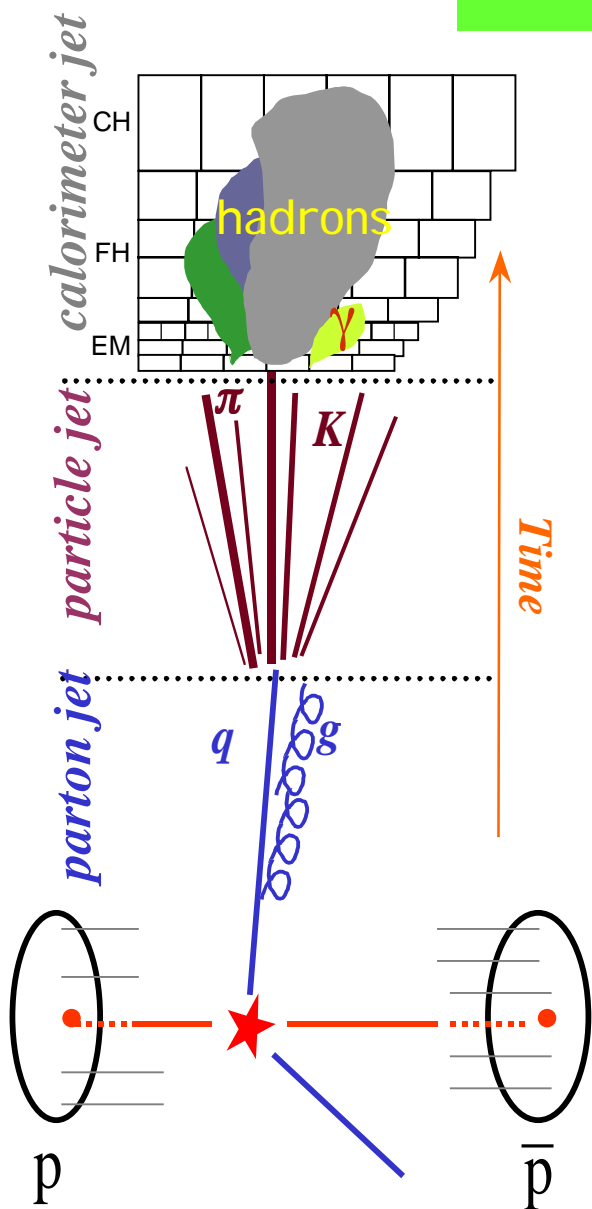


- Transverse segmentation (towers)
 $\Delta\eta \times \Delta\varphi = 0.1 \times 0.1$

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

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

Jet Definition



- Hard Scattering ($q\bar{q}$, qg , ... , gg)
- Parton shower (higher orders)
- Fragment./Hadroniz. (colorless particles)

- Parton jet: q and g (before hadroniz.)
- Particle jet: final state (after hadroniz.)
- Calorimeter jet: measured object (after calorimeter shower)

Jet Algorithm

- **Fixed cone** (D0 Run I results published before 2002, all CDF measurements)
- **Clustering** (New 2002 D0 Run I K_T results)

Run I KT Algorithm at D0

Ellis, Soper Phys. Rev. D48 3160, 1993

Catani, Dokshitzer, Seymour, Webber

Nucl. Phys B406 187, 1993

$$d_{ij} = \min(\overbrace{K_{T,ij}^2}^{\text{Soft}}, \overbrace{K_{T,ij}^2}^{\text{Collinear}}) \overbrace{\Delta R_{ij}^2}$$

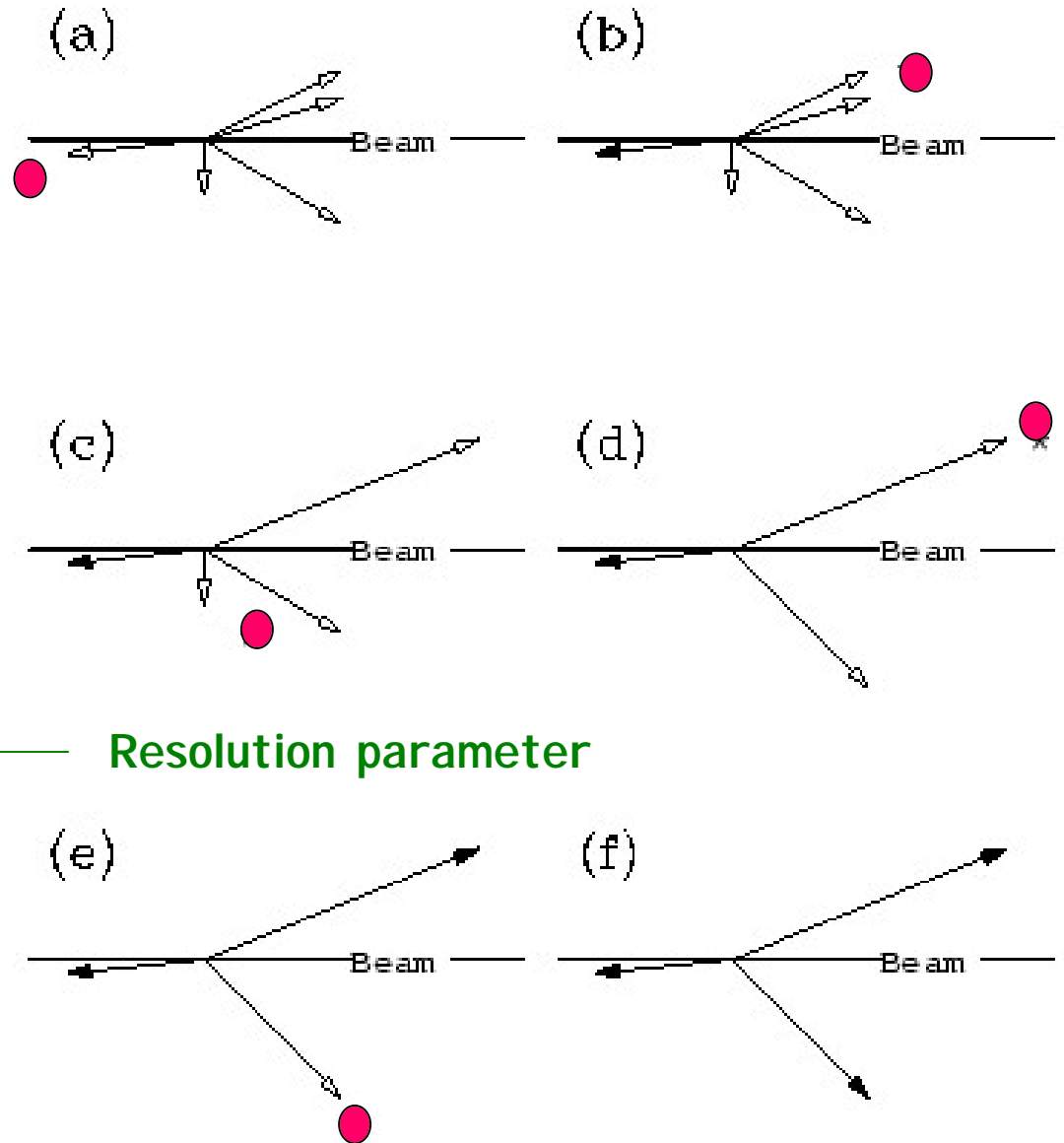
↓ (if $\Delta R \ll 1$)

$$d_{ij} = \min(P_{T,i}^2, P_{T,j}^2) \frac{\Delta R_{ij}^2}{D^2}$$

$$d_i = P_{T,i}^2$$

For each pair of particles
and for each particle

Successively associate pairs of Jets



Resolution parameter

Run I KT Algorithm at D0

Find the minimum of d_i & d_{ij} :

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

If $d_{\min} = d_i$ make it a jet

Iterate over the list of particles until I have only jets

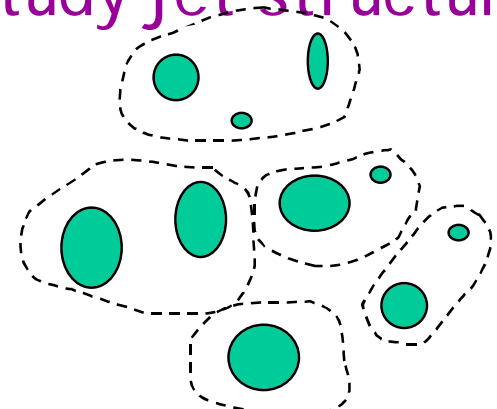
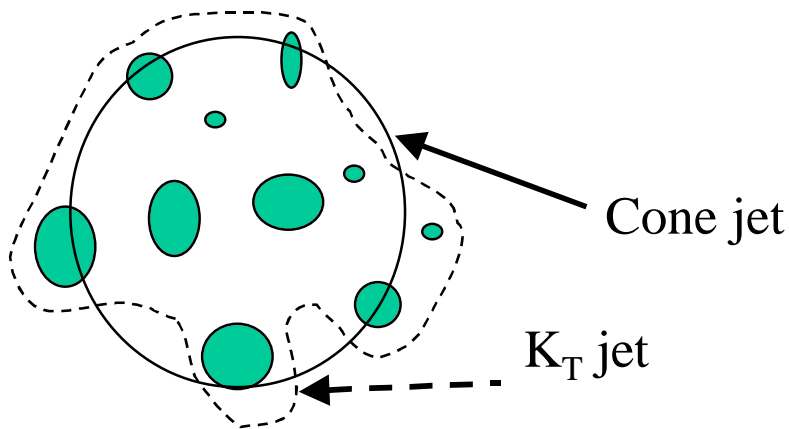
$$p_{ij} = p_i + p_j$$

$$E_{ij} = E_i + E_j$$

$$R_{ij} = \sqrt{\Delta\eta_{ij}^2 + \Delta\phi_{ij}^2}$$

Subjects:

Merge criteria adjusted to study jet structure.



$$d_{i,j} = \min(P_{T,i}^2, P_{T,j}^2) \frac{\Delta R_{ij}^2}{D^2}$$

$$> y_{\text{cut}} E_{T,\text{Jet}}^2$$

resolution parameter

Jet E_T

Re-run K_T algorithm on all particles already assigned to a jet

Subjet Multiplicity in Quark & Gluon Jets

R. Snihur's thesis

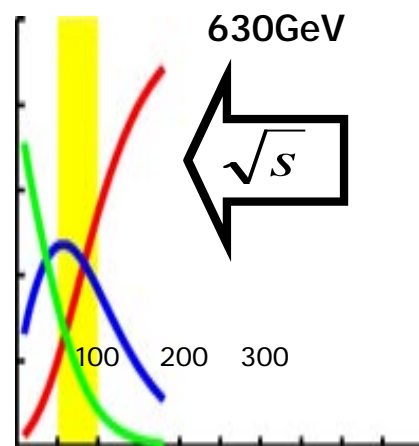
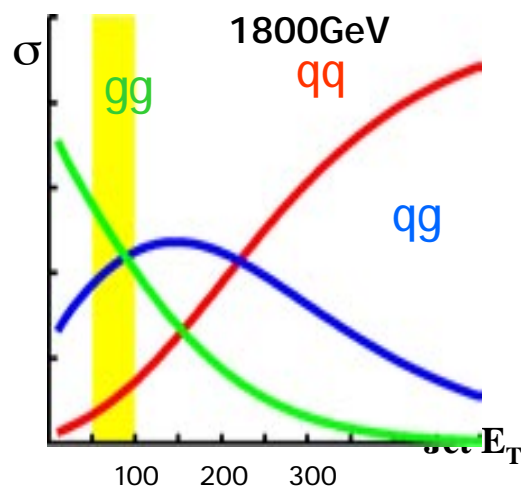
Motivation:

- Test of QCD (Q & G jets are different)
- Separate Q jets from G jets (top, Higgs, W+Jets events)

Measure the subjet multiplicity in quark and gluon jets^σ

Method:

- Select quark enriched & gluon enriched jet sample (K_T with $D=0.5$)
- Compare jets at same $(E_{T,S}, \eta)$ produced at different \sqrt{s} and assume relative q/g content is known



Contributions of different initial states to the cross section for fixed Jet E_T vary with \sqrt{s}

Subjet Multiplicity in Quark & Gluon Jets

Subjet Multiplicity:

$$M = f_g M_g + (1 - f_g) M_q$$

(g jet fractions f_g obtained from HERWIG prediction)

$$f^{630} = 33\% \quad f^{1800} = 59\% \quad (55 < ET < 100 \text{ GeV})$$

- Assuming that the subjet multiplicity is independent of

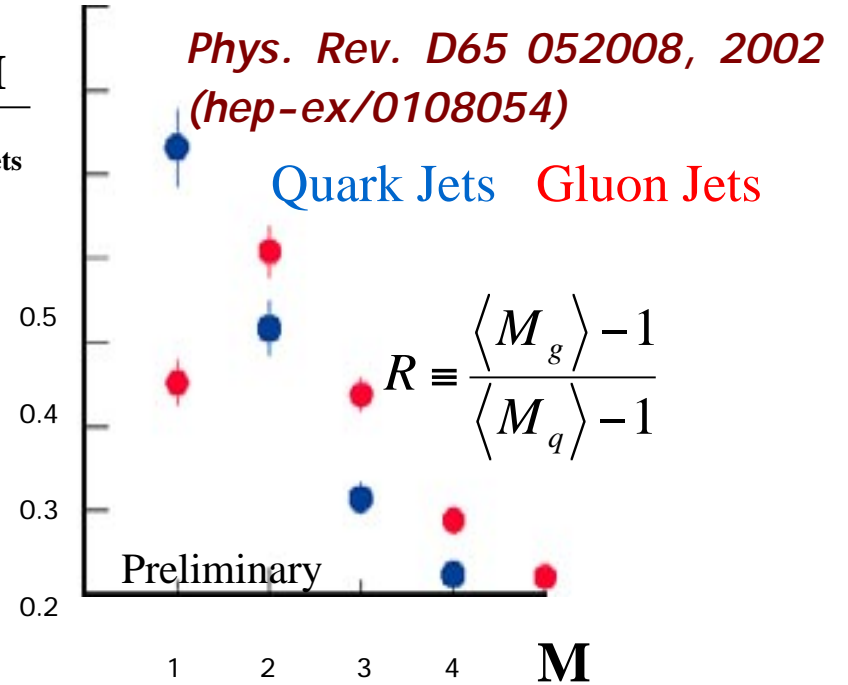
$$M_q = \frac{f^{1800} M^{630} - f^{630} M^{1800}}{f^{1800} - f^{630}}$$

$$M_g = \frac{(1 - f^{630}) M^{1800} - (1 - f^{1800}) M^{630}}{f^{1800} - f^{630}}$$

- Use k_T algorithm; unravel jets until all subjets are separated by $y_{\text{cut}} = .001$
- Measure number of subjets for events with jets with $55 < E_T < 100 \text{ GeV}$

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$$\frac{1}{N_{\text{jets}}} \frac{dM}{dN_{\text{jets}}}$$



$$R = 1.84 \pm 0.15 \text{ (stat)} \pm \begin{matrix} 0.22 \\ 0.18 \end{matrix} \text{ (sys)}$$

HEWIG prediction = 1.91

Forshaw & Seymour fully resummed calculation = 2.12

Dominant uncertainties come from g jet fraction and energy calibration

V. Daniel Elvira

Event Shapes: Dijet Transverse Thrust

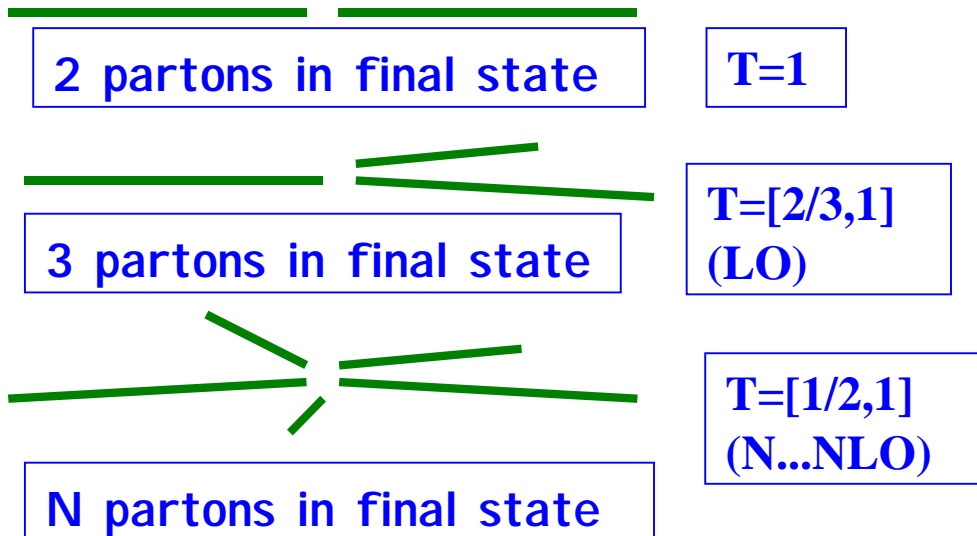
V. Sorin's thesis

Test QCD predictions (new NLO-three jet calculations), study significance of resummation calculations

$$T_2^T = \max_{\hat{n}} \frac{\sum_i |p_{ti} \cdot \hat{n}|}{\sum_i |p_{ti}|}$$

- Sum done over jets (K_T with $D=1$)
 - Only the two leading jets in thrust
 - Bin thrust in H_{T3} (3 lead jets)
 - Use transverse p_T (Lorenz invariance)
- } Reduce "noise"

T : Pencil-likeness of the event



Jet production rate:

α_s^2 is LO

α_s^3 is NLO

Event shape: (thrust)

α_s^3 is LO

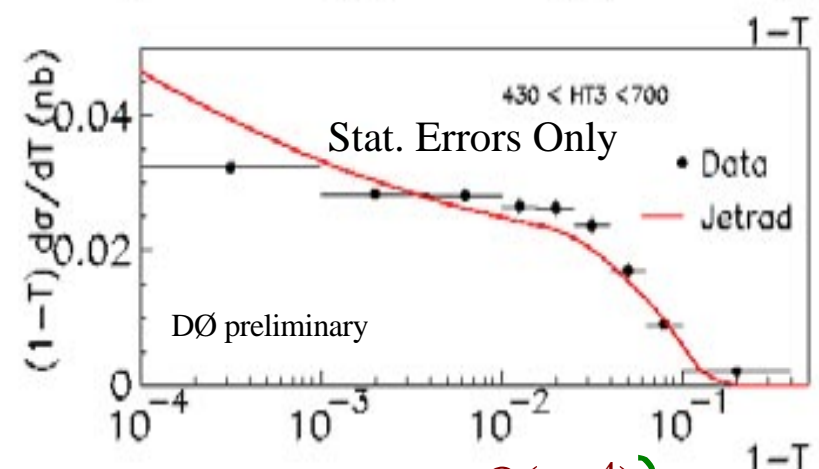
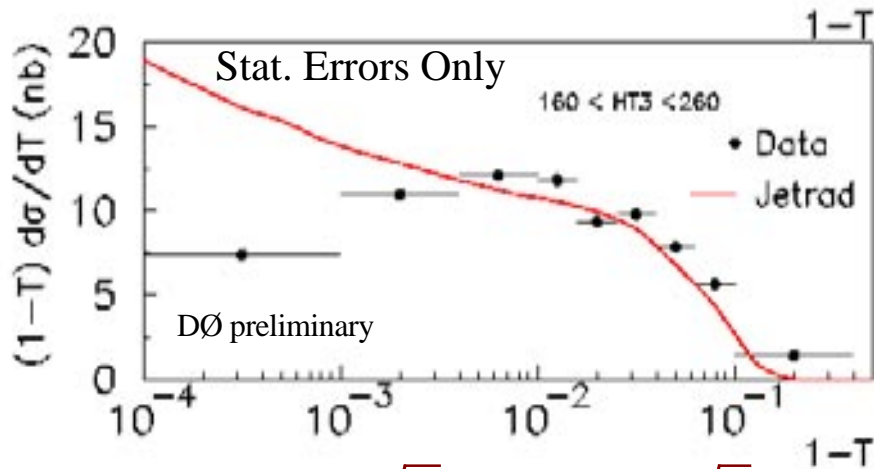
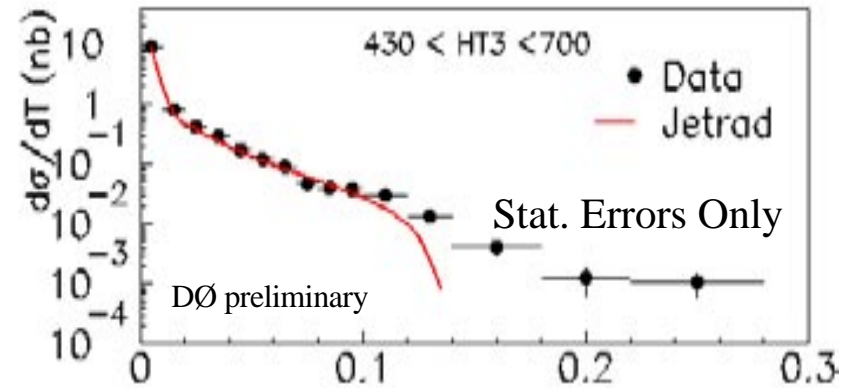
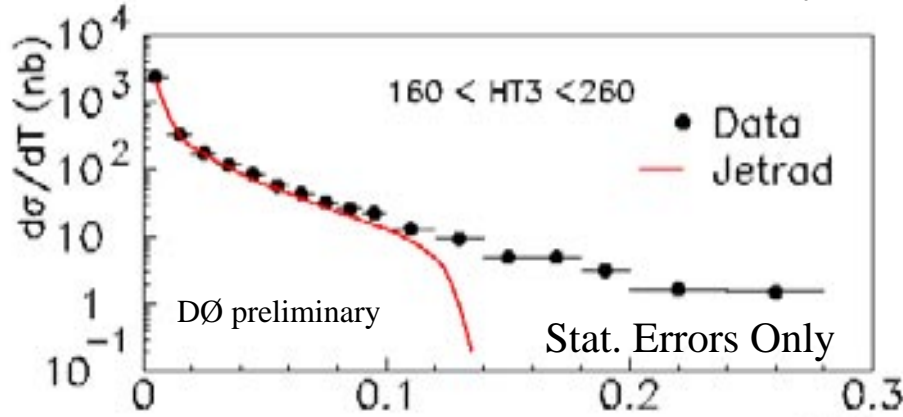
α_s^4 is NLO

Dijet Transverse Thrust cross section

JETRAD Giele, Glover, Kosower, Nucl.Phys.B403 633,1993

CTEQ4HJ,

$$\hat{t}_F = \hat{t}_R = \frac{P_T^{\max}}{2}$$



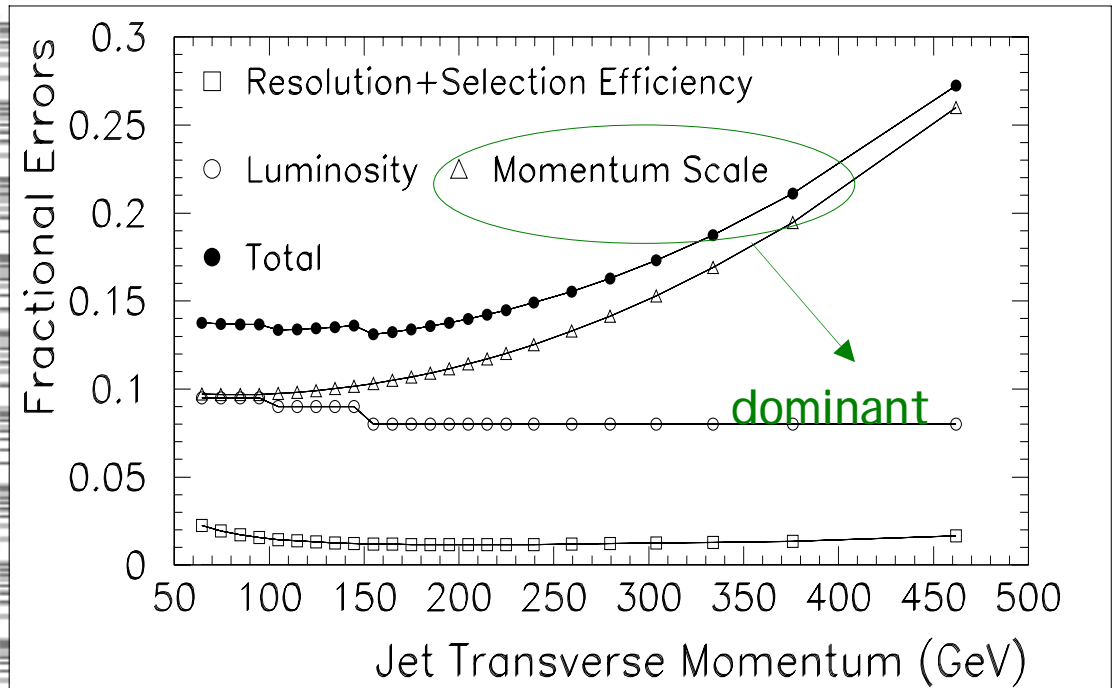
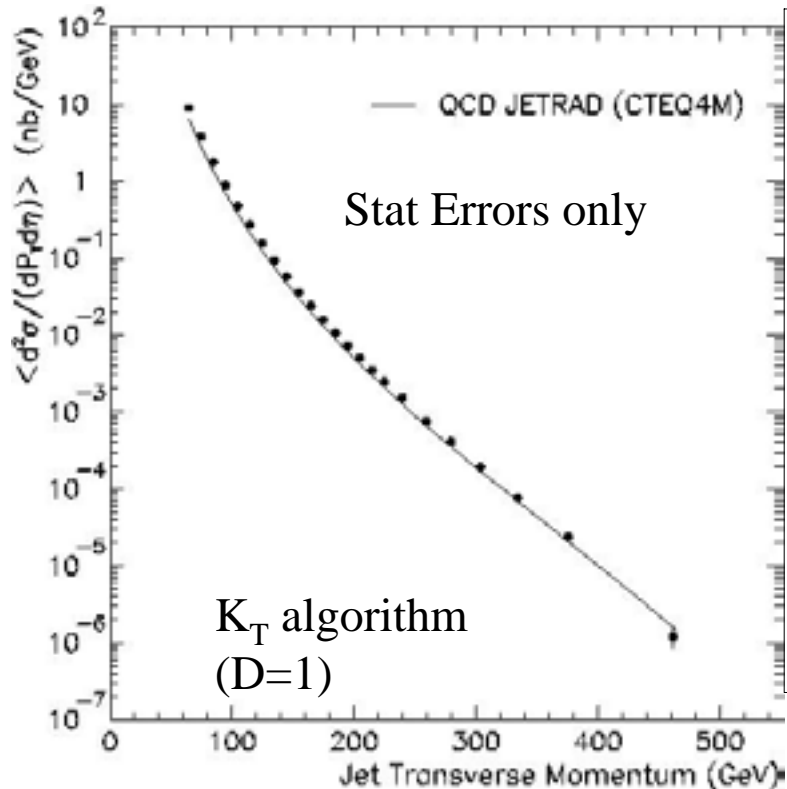
- In the range $\sqrt{2}/2 \leq T_2^T \leq \sqrt{3}/2$, the LO calculation is $O(\alpha_s^4)$
 - In the limit $(1-T) \ll 1 \rightarrow$ emission of soft and collinear gluons \rightarrow logarithmic terms $\ln(1-T) \rightarrow$ need to be identified and resummed at all orders
- } Disagreement with JETRAD (need NLO & resummation)

Inclusive Jet Cross Section

Phys. Lett. B525 211, 2002

Motivation: test pQCD predictions, study proton structure, search for quark compositeness

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



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

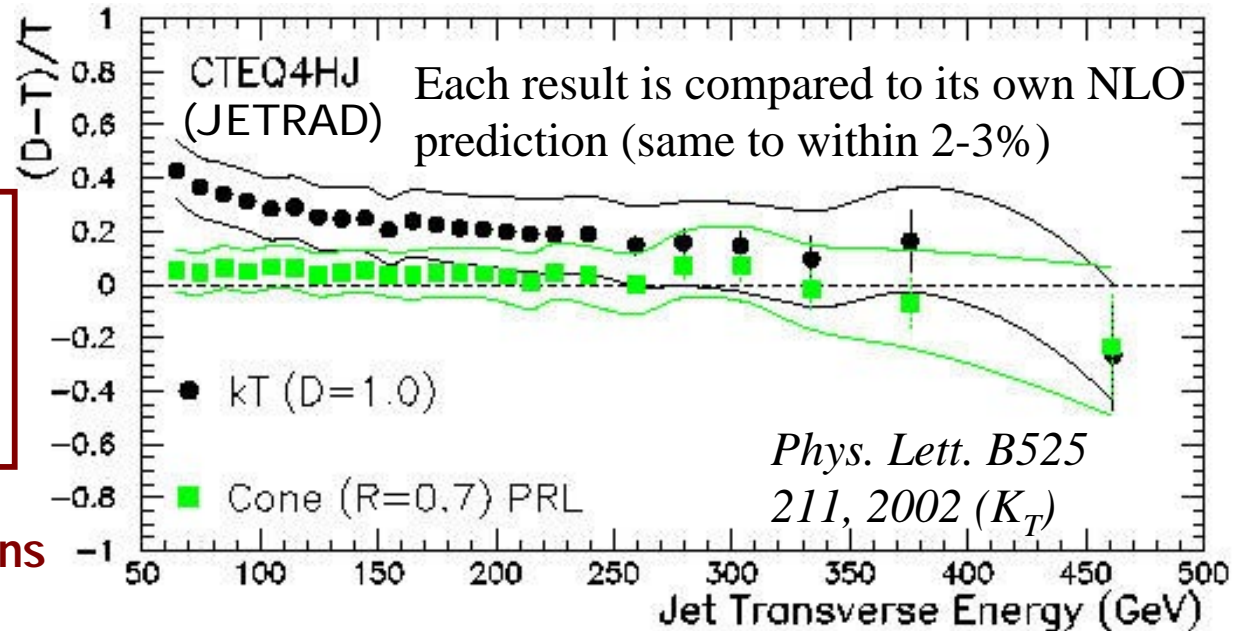
Comparison with Theory & Cone Result

(See PRD 64, 032003, 2001 for cone measurements)

Using full covariance matrix:

PDF	χ^2 / ndf	Prob (%)
CTEQ4HJ	1.13	29
CTEQ4HJ	0.75	77

Leaving out the first four bins



- K_T data/theory agreement is reasonable; marginal at low P_T
- NLO predictions: $\sigma(KT, D=1) = \sigma(\text{cone}, R=0.7)$ within 2-3%
data nominal results diverge at low p_T

Remember:

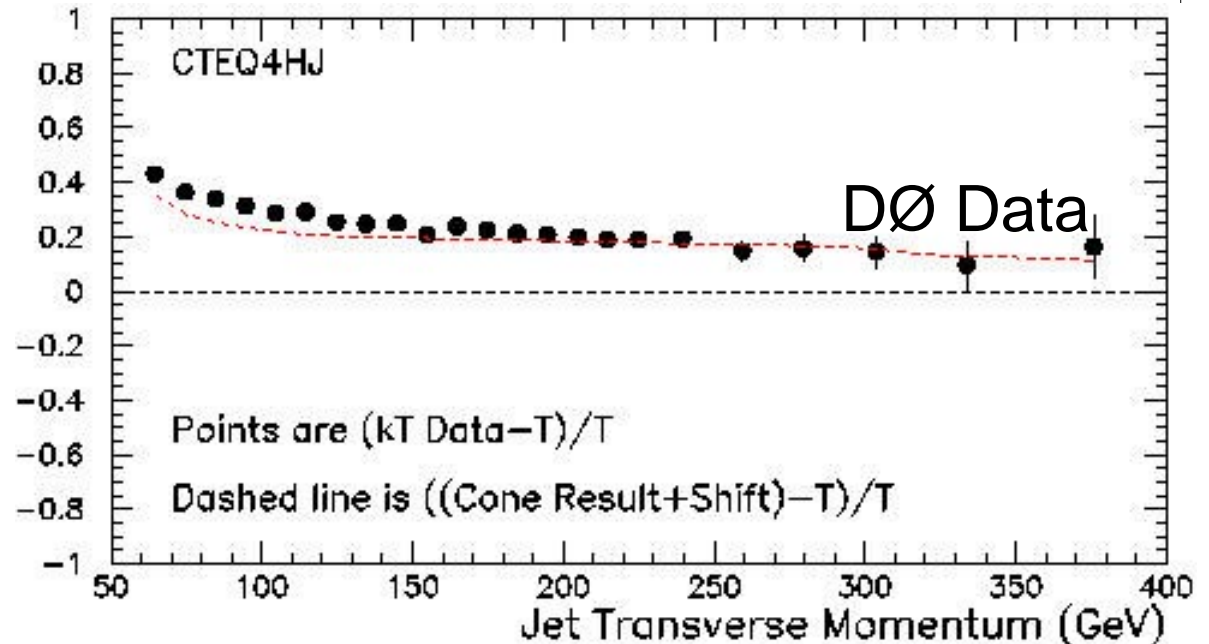
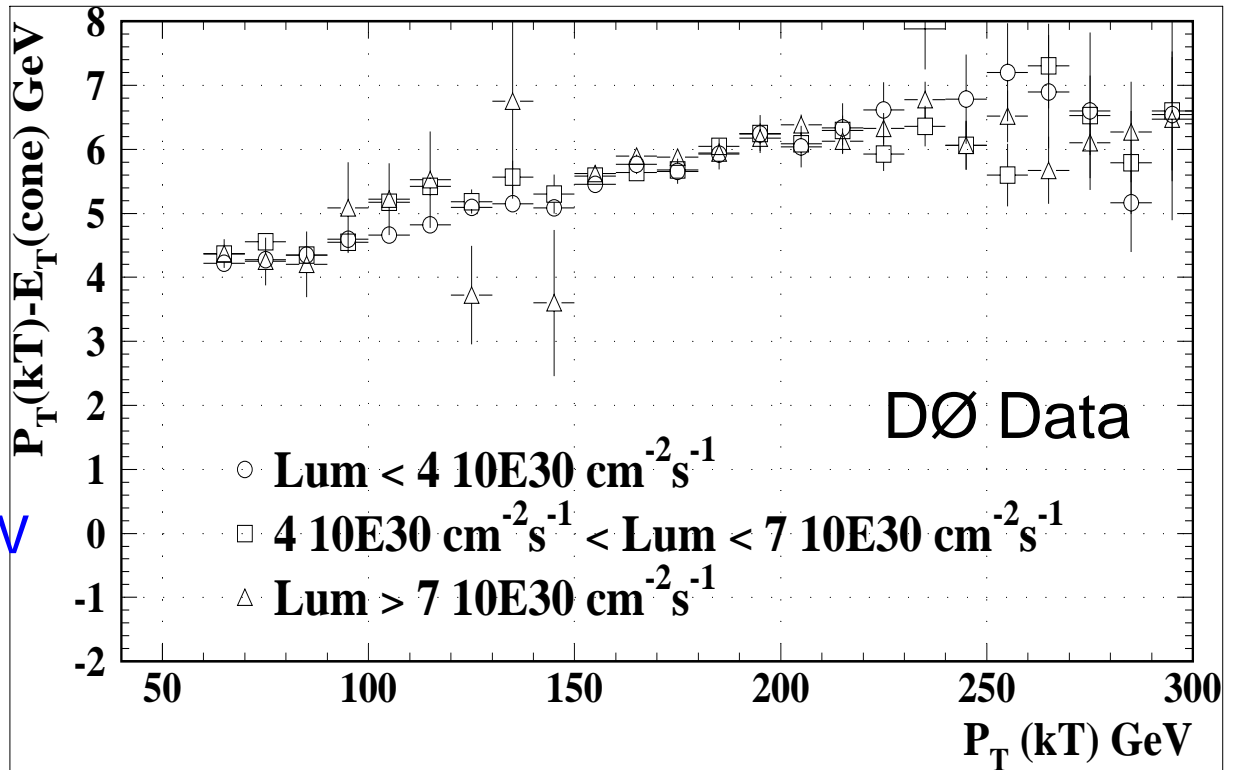
- the data is corrected back to particle level
- Error correlations are large point-to-point in p_T , but largely uncorrelated between the two measurements.

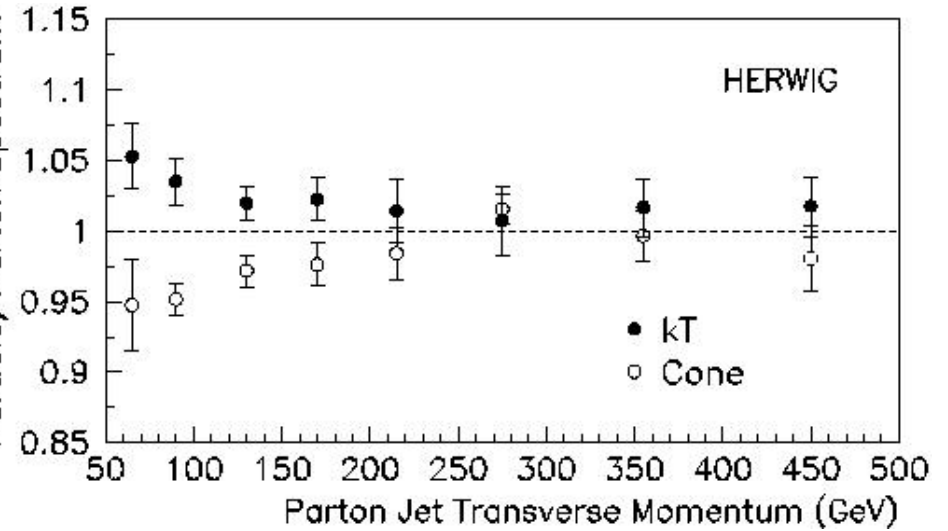
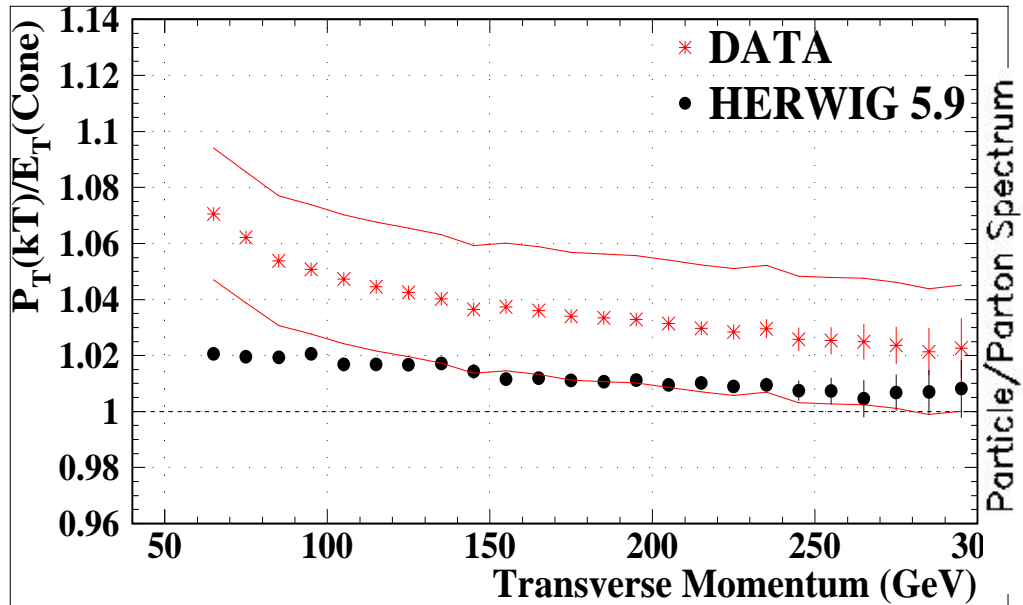
Match KT and cone jets in space:

- k_T jets include more energy than cone: 4 (7) GeV at 60 (300) GeV

Not luminosity dependent!
(KT jets are not bigger due to spurious energy from busy environment)

- I insert this difference into the cone cross section and they match!





Energy difference between
matched K_T and cone jets:

consistent with HERWIG
(only within 2σ at low P_T)

Ratio between
HERWIG particle &
parton cross sections

Particle cone & K_T
cross sections must
be different

- K_T absorbs energy

Some statements for discussion.....

- D0's α_s^3 JETRAD implementation of cone cross section (Snowmass, $R=0.7$, $R_{\text{sep}}=1.3$, $\mu=E_T/2$, cteq4hj) agrees with CDF implementation of the same thing, agrees within 2-3% with D0's JETRAD implementation of K_T cross section (4-vectors, $D=1$, $\mu=E_T/2$, cteq4hj), agrees with the D0 cone particle level measurement within a few percent.
- D0 reports a nominal difference of up to 40% (at 60 GeV) between its K_T and cone measurements, and therefore a difference of the same order between the K_T measurement and the associated prediction.
- S. Ellis predicts (private communication) agreement within less than plus/minus 3% between EKS cone ($R=0.7$, $R_{\text{sep}}=1.3$, $\mu=E_T/2$, cteq6m) and K_T ($D=0.8-0.9$) cross sections using Snowmass or 4-vector recombination.
- Z. Nagy predicts agreement to within 10% between the D0 K_T measurement and his NLO++ (α_s^3) calculation of the same observable.

Therefore

It would not be possible for Z. Nagy to predict agreement of his NLO++ calculations with both the D0 cone and K_T measurements, except if he also predicted a significant difference (much larger than 3%) between his K_T and cone calculations.

In order to understand things better, we need.....

- All parties to calculate with their own prediction tools the same observables, coincident with the available measurements. For example, cone ($R=0.7$) & K_T ($D=1$)
- Report absolute cross section values as well as ratios ($\text{theory_KT} - \text{theory_cone} / \text{theory_cone}$, and $(\text{data} - \text{theory}) / \text{theory}$)
- For example, it would be very useful if Zoltan could produce a NLO++ prediction of the cone cross section.

Summary

- D0 has successfully implemented and calibrated a K_T jet algorithm in a hadron pp collider
- Articles on subjet multiplicities & inclusive jet cross sections were published or are in preparation (Thrust Distributions)
- q & g jets show a different structure consistent with HERWIG prediction
- Thrust distributions offer an excellent opportunity to test the recently developed NLO 3-jet generators
- The marginal agreement of the particle level inclusive K_T jet cross section with NLO theory opened a discussion on matters such as hadronization, underlying event, and