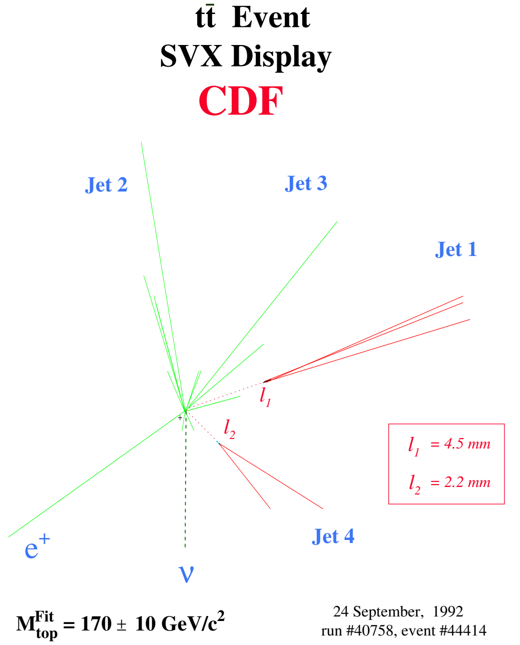
What do non-QCD people want from jets?

Lina Galtieri
CDF-D0-Theory Jet Workshop
January 23, 2002

- Introduction
- Sample Analysis: Top Mass Measurement
  - Jets in mass fit
  - Systematics in mass measurement
  - Jet measurements in CDF
  - Jet systematics
- Plans for Run II top mass measurement
- Conclusions



Introduction

Jets in other than production processes (QCD) are mostly jets due to decay products of produced particles.

In general there are also jets due to initial state radiation (ISR), as well as additional jets due to final state radiation (FSR). These are hard to disentangle.

Example of such processes are top production and decay:

$$p\bar{p} \rightarrow t + \bar{t} + X, with \;\; t \rightarrow W + b \tag{1}$$

and Higgs production and decay:

$$p\bar{p} \rightarrow W + H, with \;\; H \rightarrow b + \bar{b} \tag{2}$$

In top production jet energy measurements are important for top mass determination. Requirement of a b-tagged jet reduces background considerably. The main concern is to reduce systematic uncertainties on jet energy (see later).

For the Higgs process, jets are important for signal detection. The $b + \bar{b}$ background from QCD production is very high and jet energy resolution is very important.

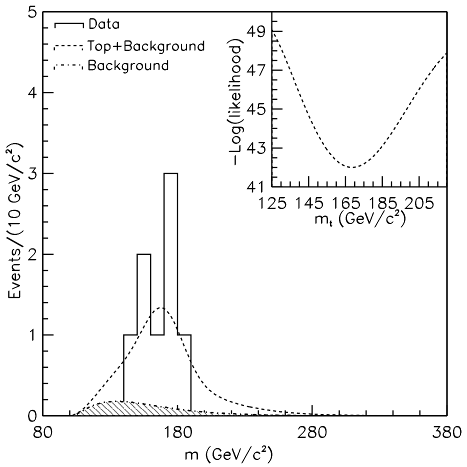
Work on improved jet resolution has started some time ago in CDF. The idea is to improve jet measurements by using more than just the calorimeter information.

Sample Analysis: Top Mass Measurement

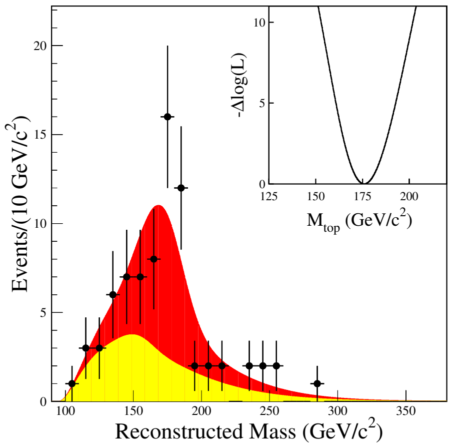
- CDF results on top mass from different channels

$$M = 176.0 \pm 4.0 \pm 5.1 \text{ GeV}/c^2 \text{ Combined}$$
$$M = 174.3 \pm 5.1 \text{ GeV}/c^2 \text{ CDF+D0 combined}$$

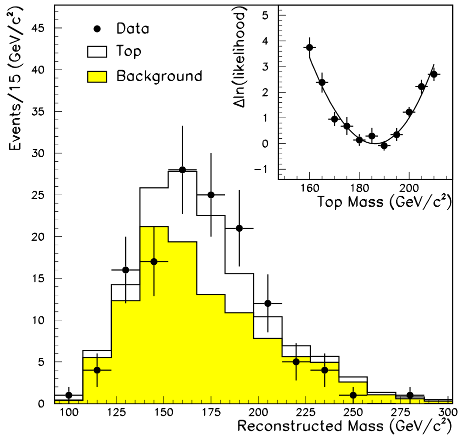
- In run II the statistical error is going to be quite small.
- Need to reduce systematic uncertainties !!



Dilepton events
2jets, 8 (6.7) events



Lepton + jets events
4jets, 76 (40) events



All hadronic channel
6jets, 187 (45) events

1. Top Mass Measurements in CDF

The hypothesis of standard model $t\bar{t}$ implies the production process

$$p\bar{p} \to t + \bar{t} + X, \tag{3}$$

followed by top decays. For the case in which one top decays leptonically, we have:

$$\begin{aligned} t &\to W^+ + b, &(4)\\ \bar{t} &\to W^- + \bar{b}, &(5)\\ W^\pm &\to \ell^\pm + \nu, &(6)\\ W^\mp &\to q + \overline{q}'. &(7) \end{aligned}$$

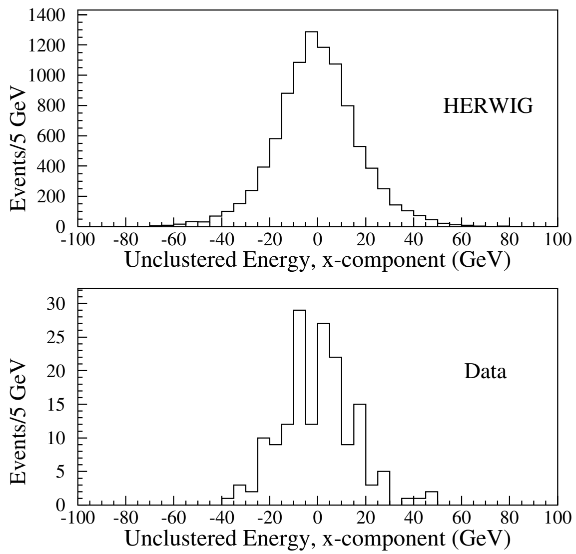
Energy-momentun conservation constraints are applied to Eq. 3-7 for each event. Any calorimeter tower with energy in it needs to be accounted for, every jet in the event needs to be corrected.

The quantity X, in $p\bar{p} \to t + \bar{t} + X$, represents the unspecified particles recoiling against the $t\bar{t}$ system. Only two components of X are measured.

The quantity X_T is computed from the energy left over after the lepton and the four jets from the $t\bar{t}$ system are removed from the total measured energy. This leaves two terms:

$$\vec{X}_T = \vec{U}_T + \sum_{i=5}^{N_{jets}} \vec{E}_T(jet) \qquad (8)$$

- Each component of the unclustered energy, $\vec{U}_T$,is defined as the vector sum of all energies in calorimeter towers after excluding the primary lepton and all the jets with raw $E_T > 8\ GeV$ and $|\eta| < 3.4$ in the event.
- The U_T also needs correction. Detailed studies have been done to obtain this correction.



Unclustered energy (x component) for data and $t\bar{t}$ Monte Carlo

After all the jet energies and the $\boldsymbol{X_T}$ are calculated and corrected, the $\not{E}_{\mathrm{T}}$ is calculated. It provides the starting point for the neutrino $\vec{\boldsymbol{P}}_{\boldsymbol{T}}$ in the mass fit.

$$-\vec{\not{E}}_T = \vec{E}_T(lepton) + \sum_{i=1}^{4} \vec{E}_T(jet) + \vec{X}_T \tag{9}$$

Summary:

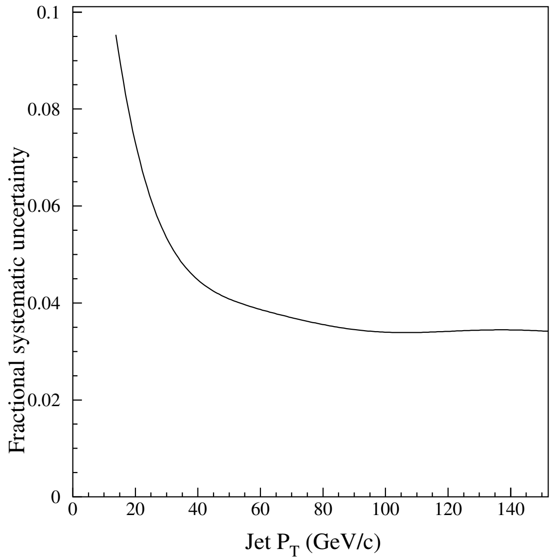
- Using Eq. 3-9 a mass measurement can be obtained for each event.
- Every energy deposit in the calorimeters is accounted for.
- To obtain a true mass value, we correct every jet and left-over energy deposits (unclustered towers).
- Corrections need to be done also for multiple interactions and underlying event.

The final top mass value is obtained applying a maximum likelihood procedure that takes into account top signal as well as background. Monte Carlo generators as well as detector simulation provide expected shapes of mass distributions for these two components.

2. Systematic errors on Top Mass (in GeV/c^2)

Systematic errors on the top mass measurement come from many sources.

Channel	dilepton	ℓ+jets	all-had.
Jet energy scale	3.8	4.4	5.0
ISR, FSR	2.7	2.6	1.8
MC (PDF, b tag)	0.6	0.5	0.2
Generator	0.6	0.1	0.8
Background shape	0.3	1.3	1.7
MC statistics	0.7	n.a.	0.6
Total	4.8	5.3	5.7



Total Systematic error on jet P$_T$
9.5% to 3.5% for P$_T$ < 80 GeV/c

- The major contribution comes from jet measurement uncertainties.
- In Run I choices were made ahead of time to optimize top discovery (R=0.4).
- New studies need to be done to minimize systematic errors.
  - Is the cone of 0.4 optimal?
  - Is the cone algorithms the best one for this purpose?

3. Jet Measurements in CDF

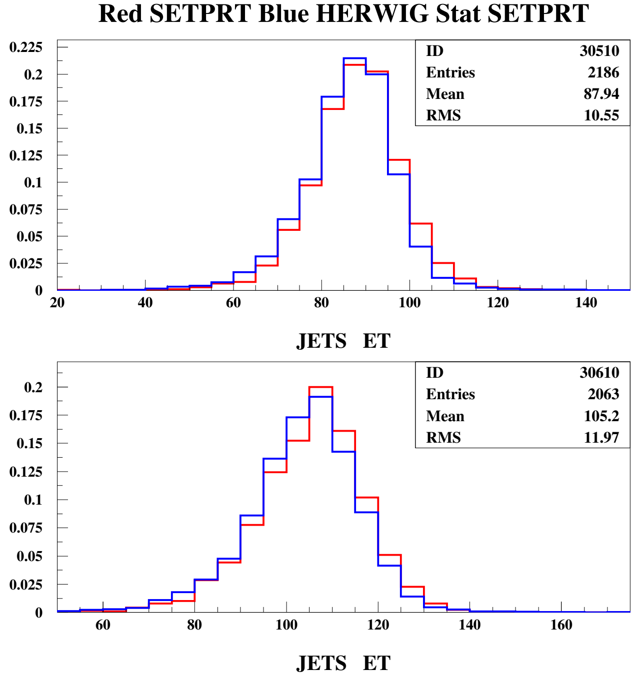


Figure 13: Comparison of SETPRT response function with HERWIG RF for true E_T =100 and 120 GeV.

Response functions for ISAJET and HERWIG differ at most by 1.5%.

- Calorimeter simulation was tuned to reproduce single particle response measured in test beam. Low P_T pions from TeV data were used to tune calorimeter non-linearity, face response, etc.
- Monte Carlo was used to go from single particles to jets. For this purpose the MC (ISAJET) was tuned to reproduce the observed distributions of N(charged), dN/dP_T in jets, DN/dz, M(charged tracks), dN/dP_T at 90^o from from jet and other UE variables. Five ISAJET fragmentation parameters were tuned: (XGEN(1), XGEN(2), SIGQT, SIGQT0, CONE2).
- Two-jet events were generated and run through the calorimeter simulation, to obtain calorimeter response function.
- Absolute corrections were obtained by comparing cluster energy for a given cone to the generated particles contained in that cone.

- For a new algorithm, we need to develop new absolute corrections.

4. Jet Measurements in CDF (cont.)

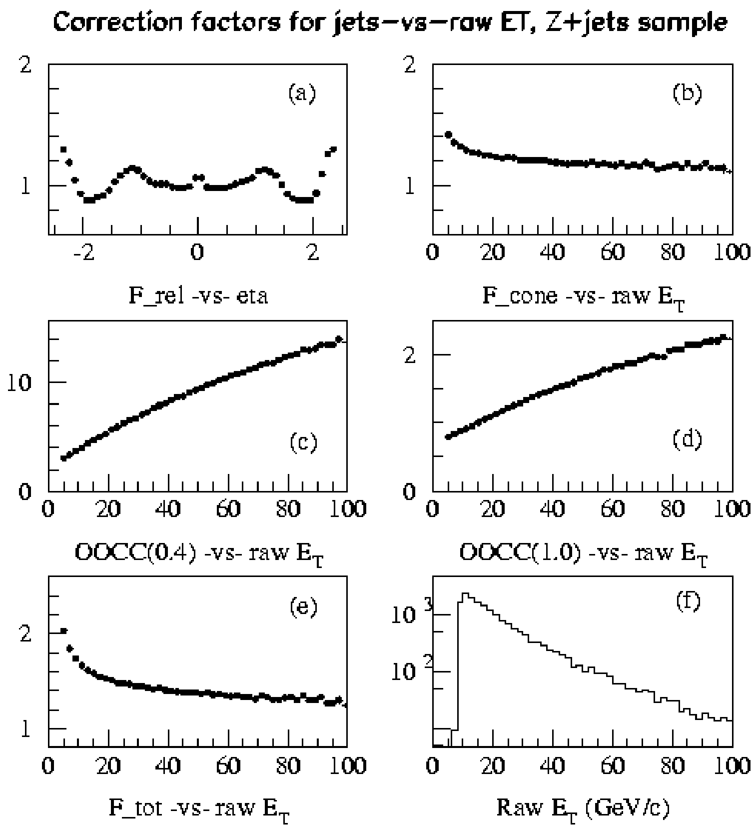
The corrections applied to raw cluster energies are :

$$P_T(R) = (P_T^{raw}(R) \times f_{rel} - UEM(R)) \times f_{abs}(R) - UE(R) + OC(R). \tag{10}$$

Here R$=\sqrt{(\Delta\eta)^2 + (\Delta\phi)^2}$ is the cone radius chosen for the jet measurement; R=0.4 for top analysis. The corrections are:

- f_{rel}, the relative energy scale. Corrects for non-uniformities in calorimeter response as a function of η.
- $UEM(R)$ subtracts the energy due to the additional interactions in the event.
- $f_{abs}(R)$, the absolute energy scale. Maps the raw jet energy observed in a cone of radius R into the average true jet energy. This average is determined in the central calorimeter assuming a flat $\mathbf{P_T}$ spectrum.
- $UE(R)$ takes into account the energy due to the underlying event. In Run I minbias events were used for this correction.
- $OC(R)$, corrects for the energy expected to be outside the radius R.

The $f_{abs}(R)$ and $OC(R)$ corrections are functions of the transverse momentum of the jet. The relative correction has only a weak dependence on jet P$_T$.

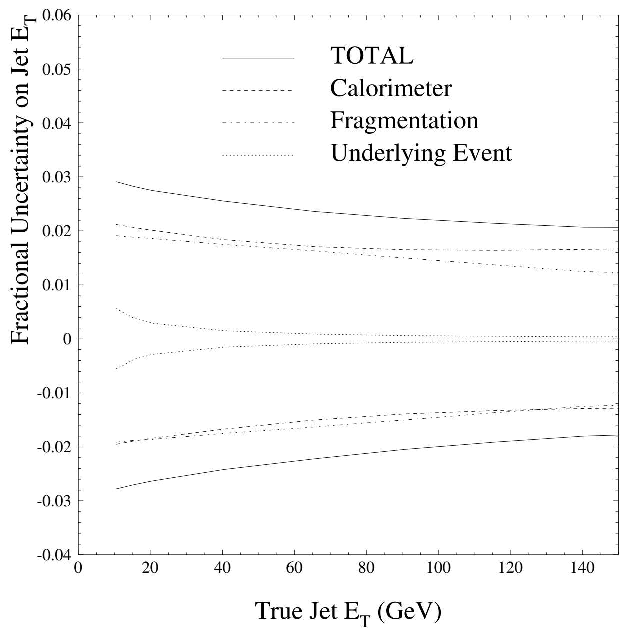


- The individual correction are shown to the right.
- The above procedure used a flat spectrum. In addition top specific corrections are made.
- Also, parton rather then jet energies are needed.
- HERWIG was used to evaluate the last two corrections, including b-jets with semileptonic decays

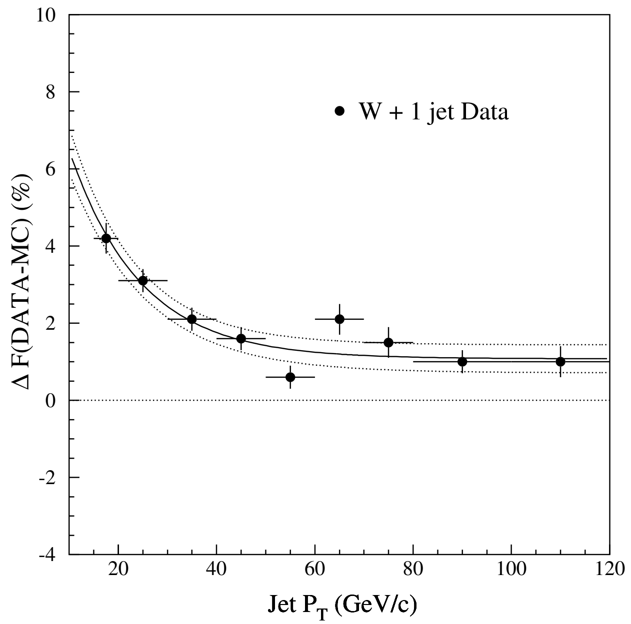
Conclusion: for a new algorithm we need new procedures for UEM, UE, f_{abs}, OC.

5. Jet Systematic Errors

- Contributions to jet energy systematics
  - Detector effects: calorimeter measurements (non-linearities, cracks etc)
  - Physics effect:
    - ∗ underlying event (used min-bias data)
    - ∗ fragmentation uncertainties (MC's tuned to data)
    - ∗ out of cone corrections (jet energy flow, studied with W+1 jet events)



Systematics within the 0.4 cone



Systematics outside the cone.

- Out of cone systematics determined using HERWIG V5.6 W +1 jet process.
- Comparison of W + 1 jet data with the HERWIG Monte Carlo shows disagreement in energy contained in annulus between R=0.4 and R=1.0 (6% to 1%).
- This disagreement has already been observed in other studies.
- The overall systematic uncertainty on jets is 9.5% to 3.5%.

The overall procedure was checked with Z+jet balance.

6. Improved Jet Energy Measurements

- Method used above applies average corrections to each jet.
- Effort under way to use tracking and other information to correct jet by jet.
- This method improves the resolution and may improve systematics.
- Improved resolution important for Higgs search.
- Whether the use of a different algorithm helps with improving jet resolution has not been fully investigated.

Run II plans for Top Mass Measurement

- Initially repeat analysis with the Run I method (cone algorithm).
- To reduce systematics optimize:
  - Cone size
  - Merging algorithm
  - Underlying event correction
- Investigate Kt algorithm:
  - Multiple interaction corrections
  - Underlying event corrections
  - E-scale uncertainties + other systematics
  - Cone size parameter, D
  - "out of cone" corrections?' Are they needed?
- Can systematics be reduced by using the KT algorithm?

Studies of KT algorithm have already started.

Conclusions

- For measurements of particle masses jet requirements are severe.
- It is necessary to evaluate the parton energy from which the jet has originated.
- For this, detailed corrections need to be done.
- In the top mass measurement case, every energy deposited in the calorimeter needs to be accounted for and corrected.
- Systematic errors in the jet correction process have to be kept to a minimum.
- Choice of algorithm depends on the ability to correct jet energies reliably and to keep the systematic errors small.