JET ENERGY CALIBRATION ISSUES

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Top Thinkshop
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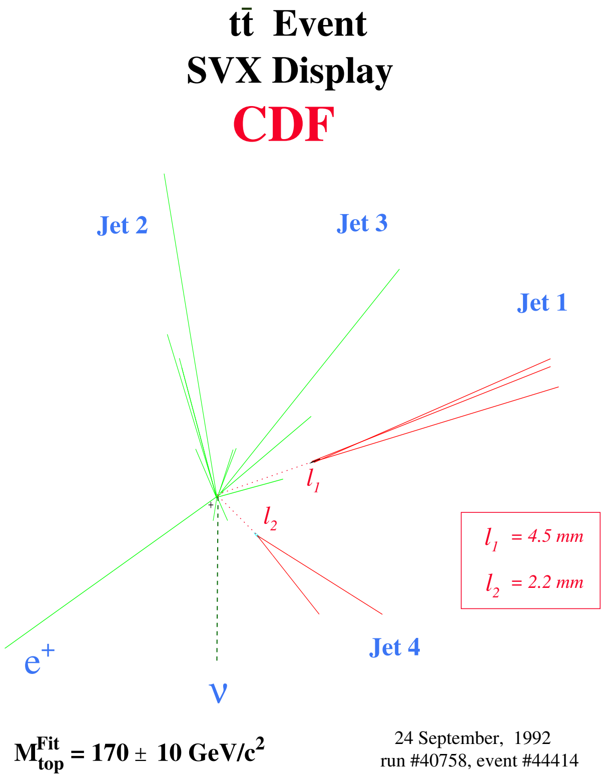
- CDF Jet Systematics
- Improvements in Run II
  - ◇ Z-jet balance
  - ◇ γ -jet balance
  - ◇ W into jet-jet
  - ◇ Z into $b\bar{b}$
- Combinatorics
- Gluon Radiation



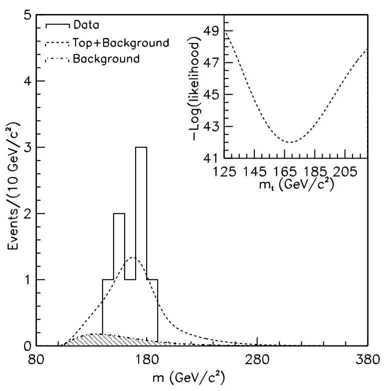
CDF Top Mass Measurement Summary

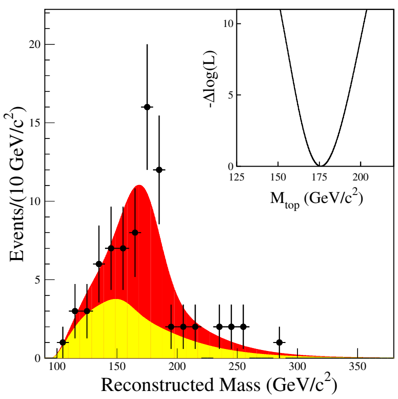
- CDF results on top mass from different channels

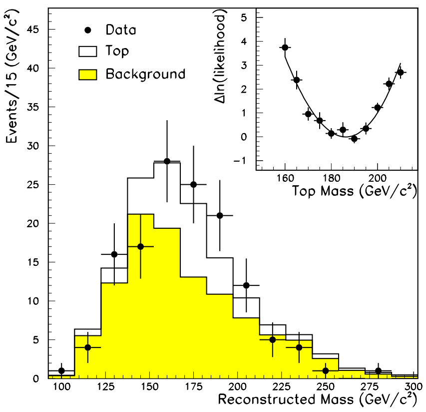
M =	167.4 ± 10.3 ± 4.8	GeV	dileptons	Submitted to PRL
M =	175.9 ± 4.8 ± 5.3	GeV	lepton+jets	Publis.+Rev. Sys
M =	186.0 ± 10.0 ± 5.7	GeV	all hadronic	Publis.+Rev. Sys
M =	176.0 ± 4.0 ± 5.1	GeV	Combined	

- Systematic errors (in Gev/c^2)

Channel	dilepton	ℓ+jets	all-had.
Jet energy scale	3.8	4.4	5.0
Initial and final state radiation	2.7	2.6	1.8
Monte Carlo modeling	0.6	0.5	0.2
Monte Carlo generator	0.6	0.1	0.8
Background shape	0.3	1.3	1.7
Monte Carlo statistics	0.7	n.a.	0.6
Total	4.8	5.3	5.7







Jet Reconstruction and Systematics

CDF uses Monte Carlo and Data to calibrate jet energy and evaluate the systematic uncertainty on the energy.

- We obtain calorimeter response to individual particles from test beam data at high momentum and from min-bias events at low momentum.
- We tune the Monte Carlo to agree with the data. We then use the calorimeter deposits for each particle to reconstruct jets.

We correct the measured (raw) energy in the jet as follows:

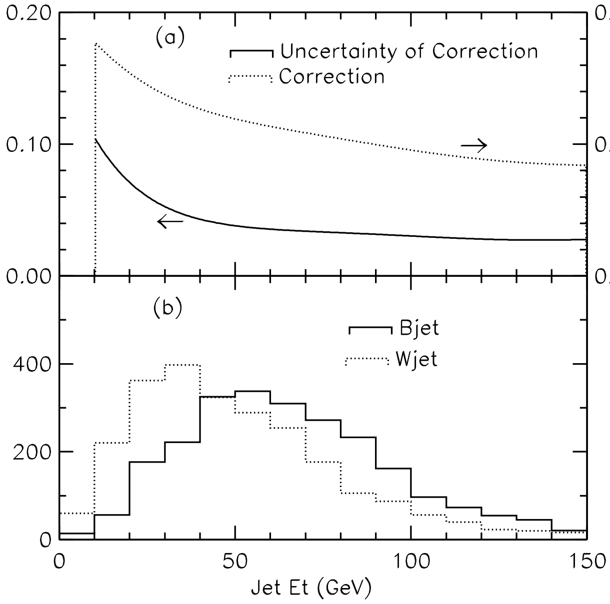
$$P_T(R) = P_T^{raw}(R) \times f_{rel} \times f_{abs}(R) - UE(R) + OC(R)$$

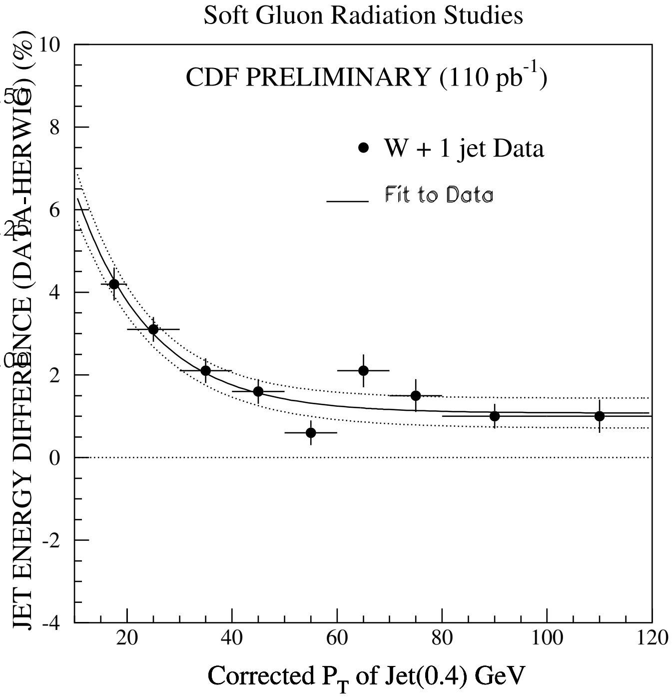
where R is the jet cone size used in the jet algorithm (0.4 for top events).

- f_{rel} is an η dependent correction. Uncertainty on this is 2%, except for 4% in the regions between detectors.
- $f_{abs}(R)$ was obtained by
  - taking into account detector effects, i.e., non linearity in calorimeter response, cracks and less sensitive regions, single tower threshold etc.
  - tuning the jet fragmentation in the Monte Carlo to reproduce some variables in the jet data: $N_{charged}$, E_{ch}/E_{tot} and others.

  the uncertainty on this factor is obtained by varying within 1σ all the quantities that enter in the calculation, like tracking efficiency etc.
- UE: we use Minbias data. Use 30% of the correction as uncertainty
- OC: we use Monte Carlo. For the uncertainty we compare data to Monte Carlo for the energy in an annulus between R=0.4 and 1.

The systematic errors on the jets is obtained by adding in quadrature each of the terms. Another term is added to the above: the "splash-out" uncertainty of 1 GeV to take into account additional energy beyond the cone of 1.0.





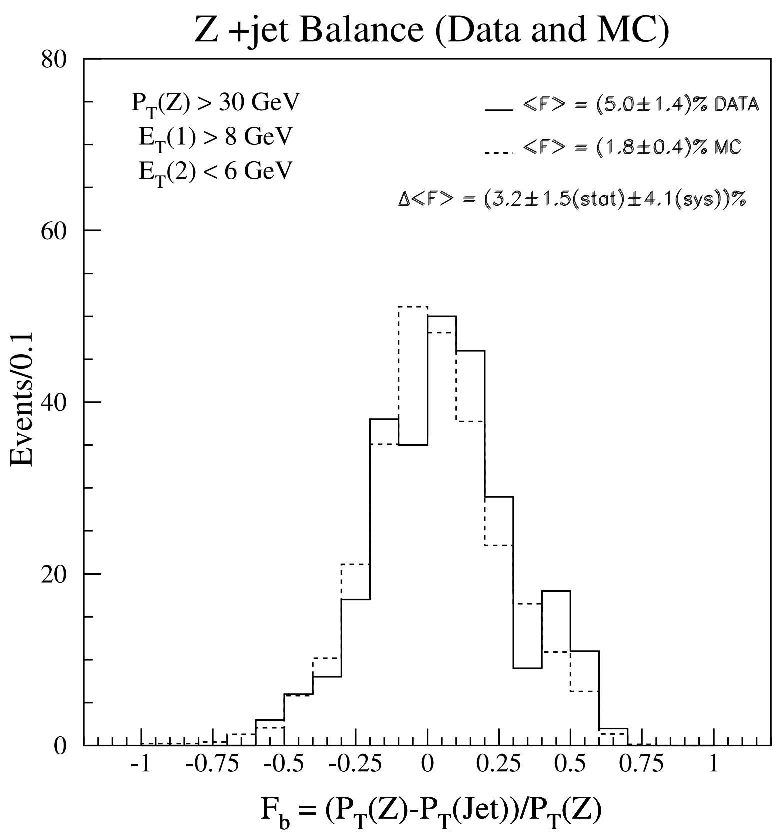
The above procedure uses information from the CTC (central tracking chamber) and the calorimeter.

A new study is being conducted within CDF to try to improve the resolution of jet energies, by adding information from other parts of the detector, like the shower max detector and others. Results obtained so far are very promising.

In Run II we expect to improve on the jet energy uncertainty because we will have more data from which to derive the corrections and the errors on these corrections. No estimate on how much we can improve is available at this time.

Z + Jet Balance

- We use Z+jet events to check the jet energy calibration and the systematic uncertainty on the energy scale.
- The Z mass and P_T are measured via the lepton pair decay modes. Jets recoil against the Z's.
- This check is complicated by the so called "K_T kick", i.e., the fact that the Z and the jets have an intrinsic unbalance due to the initial P_T of the system (HERWIG says it is about 5 GeV).
- Assuming the MC models well the "K_T kick", we can compare data and Monte Carlo and calculate the error on F_b from systematic errors on jets.



Z + Jet Balance (continue)

- **This uncertainty gives for the shift in energy scale:**

$$\Delta \text{ F} = (3.2 \pm 1.5 \pm 4.3)\%$$

What about Run II?

- **Statistics will be increased by at least a factor 20 (there are 270 events in this plot).**
- **We can study the component of the $\Delta(P_T)$ perpendicular to the bisector of the two vectors (the Z and the jet P_T), which is less sensitive to the "K_T kick".**
- **We should be able to extract an overall scale factor. However, we will need to study the jet P_T dependence of the uncertainty, as this is not flat, as seen earlier.**
- **Additional information comes from the photon + jet channel. So we will have information from:**

Z + jet Balance
γ + Jet Balance

Light quark jets : W into jet-jet

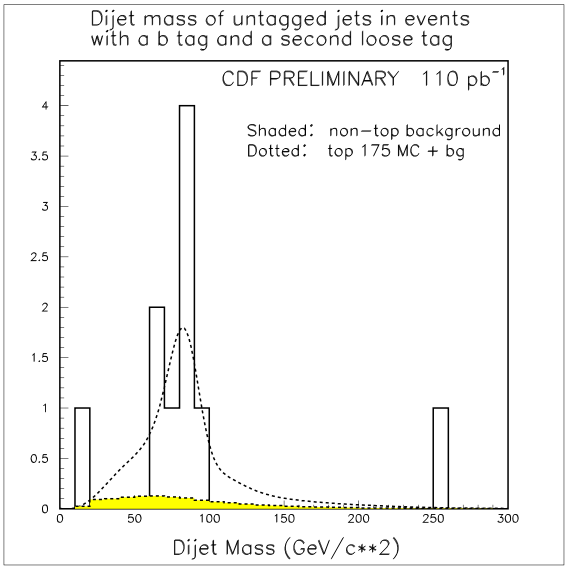
CDF Run I results using the lepton + jet sample, with two tagged jets.

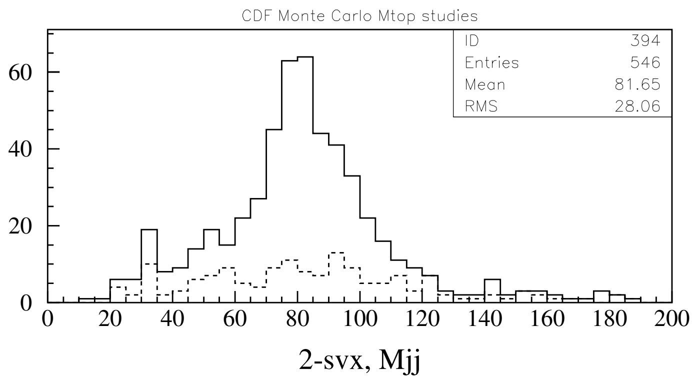
- **The invariant mass of the untagged jets gives:**

$$\mathbf{M} = 78.1 \pm 4.4 \pm 2.9 \;\; GeV/c^2$$

- **Expect about 300 events tagged by the SVX in run II**
- **What are the limitations of this sample?**
  - non-top background is small
  - Effect of "gluon" jets to be taken into account (30% of sample)

Sample	jet-jet mass GeV/c^2	σ GeV/c^2
Events with correct j-j combination	80.6	18
Events with one "gluon" in pair	83.1	36





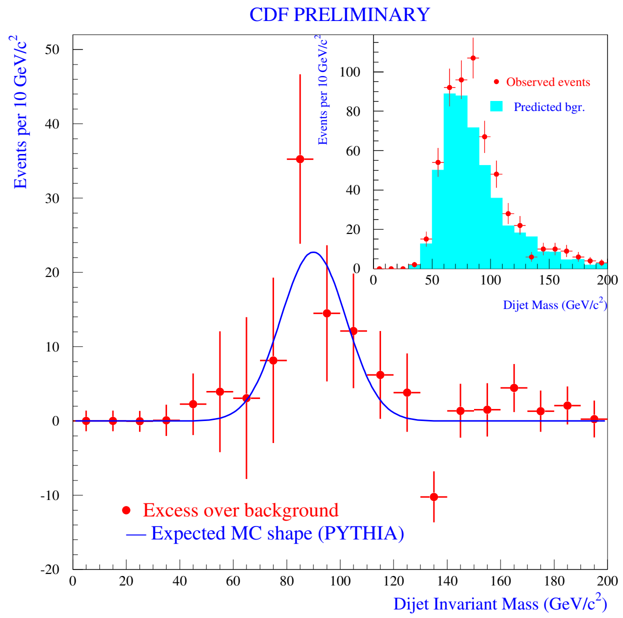
B jets: use Z into $b\bar{b}$

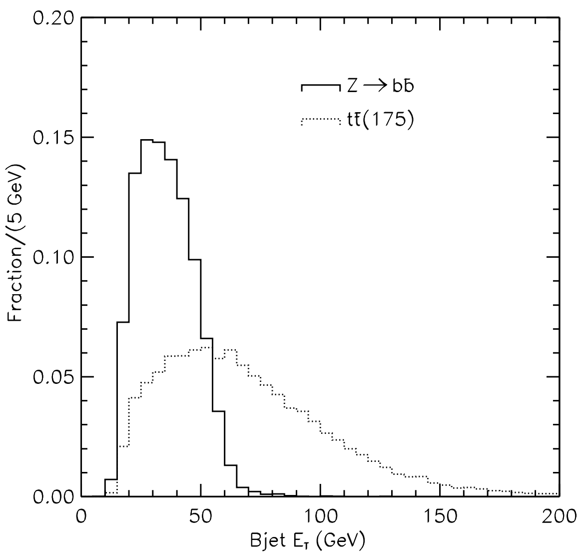
CDF Run I results.

- Background shape is very important. We need to go low enough in jet-jet mass
- Dijet-trigger not adequate. Choose inclusive muon trigger, i.e., semileptonic decay of one of the b jets
- Find 70 Z events with a background of 250 (3.4 σ signal)

What about Run II?

- Plans for an SVT trigger (secondary vertex). Require 2 Calorimeter clusters (> 5 GeV) and two tracks (5 GeV/c) tracks at L1. Use SVT requirements in L2 and L3.
- Good SVT efficiency, get all b jet decays. Expect about 32K events
- Main issue here is the background shape, i.e., understanding possible systematic shifts of the Z peak due to this uncertainty.

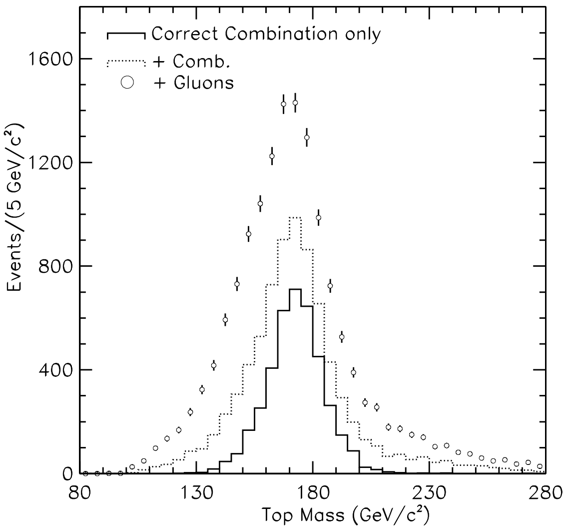


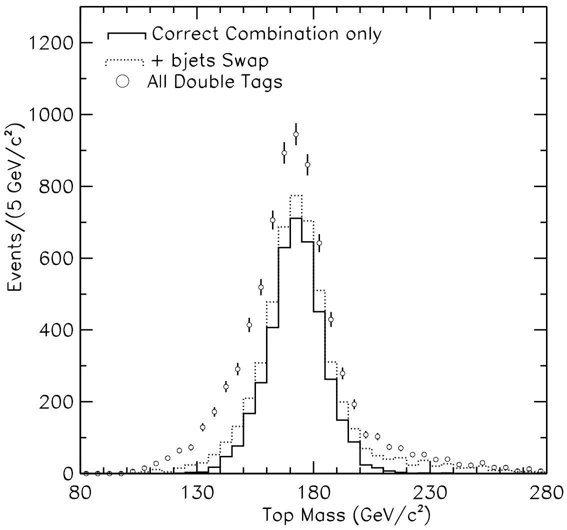


Effects due to Combinatorics

$$t\bar{t} \to \ell\nu b\ q\overline{q'b}$$

- Widening of top mass distribution is due to two effects: combinatorics and gluon radiation
- There are 24 combinations if no b tags, down to 6 combinations for events with 2 b-tagged jets.
- There are two types of effects in combinatorics:
  - Assigning a W-jet to a b (produces mass shifts)
  - Assigning a b jet to the wrong top.
- Is there something to gain by reducing the combinatorics?
  - Distributions become narrower (see double tag)
  - Systematic error may be smaller (present calculation gives a 12% smaller error on double tag event).





Effects Due Gluon Radiation

- Soft gluon radiation produces widening of jets. These effects are included in the jet calibration. The jet energy uncertainty was determined by comparing data with Monte Carlo
- The hard gluon radiation uncertainty could not be determined from the data in Run I, because of low statistics (see N_{jet} distribution below). We have 34 tagged events only, and for the 42 untagged events, the background is 56%.
- For Run II the situation should improve. The increase of data (about 1000 b-tagged events) should allow more careful studies, using many variables to asses the agreement of Monte Carlo and data.
- Studies should be done to understand from the Monte Carlo, if we can optimize the cuts to improve resolution. This would mean reducing statistics, but maybe an overall optimization is possible.
- The plot below, shows the E_T of jet 4 for two cases: (solid) all jet match (i.e., no "gluon" radiation) and (dashed) at least one of the jets is a "gluon". It shows that by cutting at very high in P_T, one could reduce gluon" radiation, but not by very much.

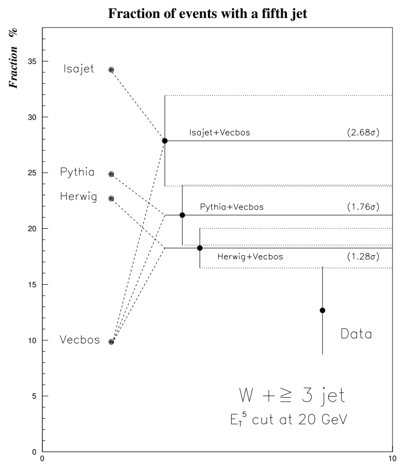


Figure 7: The measured value of f_5 under optimised cuts is shown, again with the various Monte Carlo predictions.

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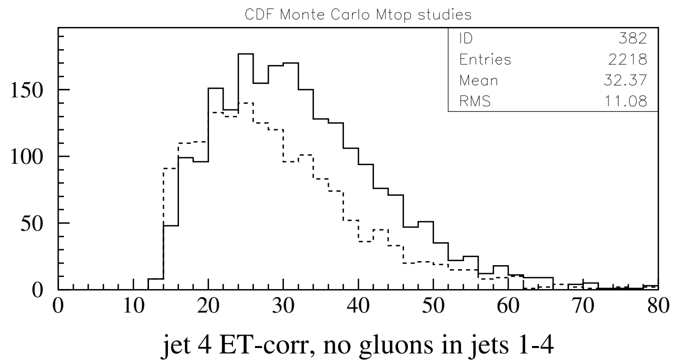

Summary of Jet Energy Issues

- Largest contributions to the top mass measurement error comes from jet energy scale and from gluon radiation.

- Many handles from a large data sets can be used to improve on the energy scale uncertainty. However, we should not expect the improvement to go like $\sqrt{N}$, i.e., by a factor 5.

- With the larger data set, it would be possible to understand better the gluon radiation effects and improve on the modelling.

- Widening of top mass distribution is due to two effects: combinatorics and gluon radiation
  - The combinatorics can be reduced by using double tags events. This improves the mass resolution as well as the systematic error
  - Studies need to be done to assess the feasibility of more stringent cuts in the data, so as to reduce the effects of hard gluon radiation, hence improving the resolution and uncertainty.