Comments on Monte Carlos for Top Analyses

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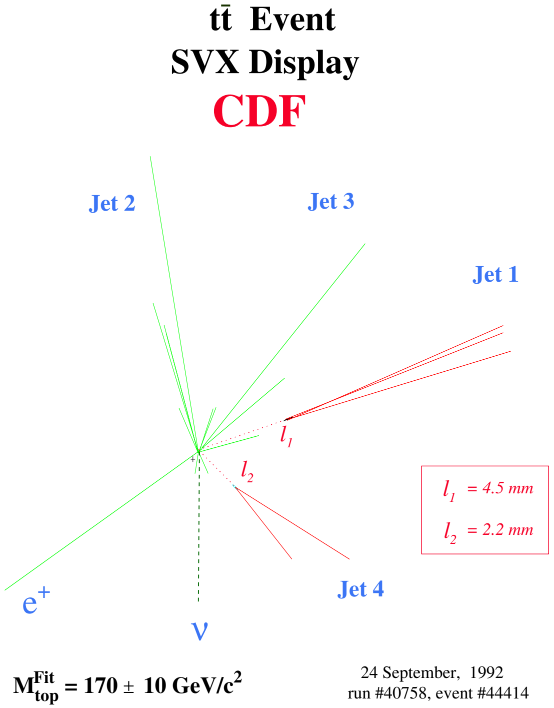
- Introduction
- Sample analysis: top mass measurement
  - backgrounds
  - systematics uncertainties
- Additional needs
- Summary and Conclusions



Introduction

Few top events were produced in Run I.

- Only Standard Model decays $t \rightarrow Wb$ with $W \rightarrow \ell\nu$ or $W \rightarrow q\bar{q}'$ observed.

- Production of $t\bar{t}$ agrees with Standard Model prediction.
- Kinematics of events agree with SM
- Obtained a direct top mass measurement

Run II: more data, new regime

- Precision measurement of the top mass
- Look for new physics by checking Standard model predictions.
  - Branching ratios, rare decays
  - Kinematics variables, Decay correlations
  - Production mechanisms: M($t\bar{t}$), etc.
- Measurement of V$_{tb}$ in Single top production.

CDF: Run I Signal and Backgrounds. Run II ($2 fb^{-1}$) signal estimates

Sample	Observed	signal	Run II
Produced $t\bar{t}$events	–	525	13600
Dileptons (e,μ)	9	6.6	155
$\ell + \geq$ 3jets	322	$\sim$ 64	1800
All-Hadr (1 SVX tag)	187	$\sim$ 45	n.a.
$\ell + \geq$ 3jets (SVX tag)	34	$\sim$24.8	900
$\ell + \geq$ 3jets (SLT tag)	40	$\sim$ 17.4	n.a.
W + 4jets(loose jet4)	151	$\sim$ 40	1200
Mass ($\geq$ 1 SVX tag)	20	$\sim$ 17.4	790
Mass ($\geq$ 2 SVX tag)	5	$\sim$ 4.8	240

Requirements:

- E_T(lepton) $>$ 20 GeV
- $\not{E}_T > 20$ GeV
- Jets: calor. clusters with $E_T > 15$ GeV, $|\eta| < 2$. cone radius R=0.4. Loose jet4: $E_T > 8$ GeV, $|\eta| < 2.4$

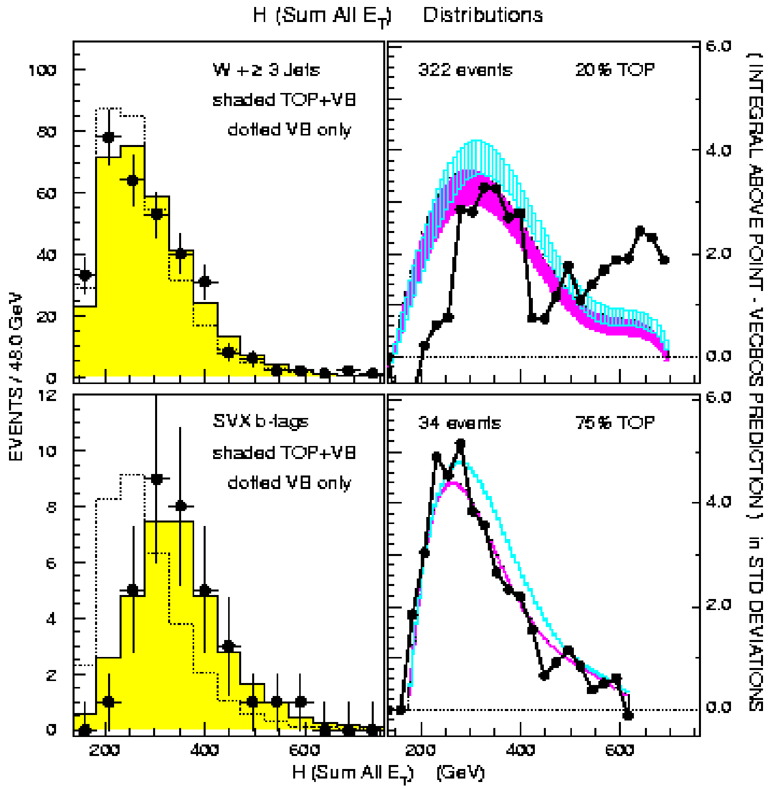
- Major backgrounds (more details later):
  - W + uds jets
  - W + $b\bar{b}$, Z + $b\bar{b}$
  - W + $c\bar{c}$, Z + $c\bar{c}$

Run II: We need to have good generators both for top signal and background processes

Run I Analyses

Top Monte Carlo generators used for signal: HERWIG, PYTHIA, ISAJET

- Agreed with the data within statistics.
- Example: lepton+$\geq$ 3jets topology.



H = Sum E$_T$ of all objects

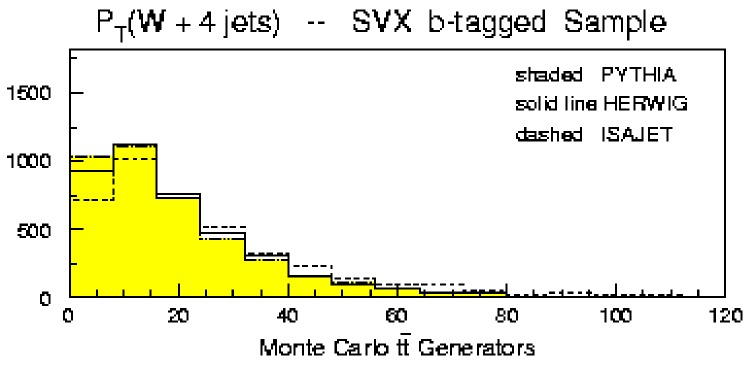
Compare data and Monte Carlo

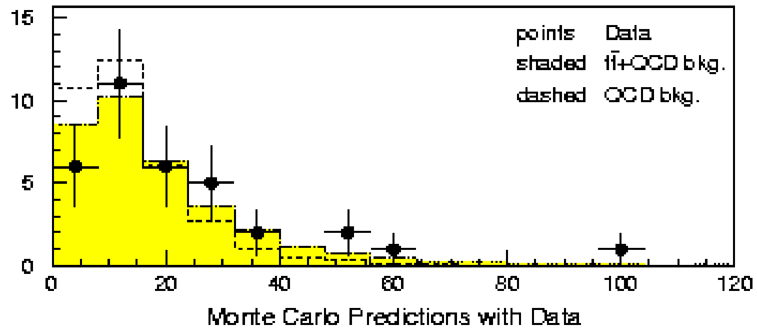
- HERWIG used for top signal
- VECBOS (interfaced with HERWIG) used for background.
- Lower plot, b tagged events (75% top) good agreement with expectation within statistics.
- Upper plot, all events (80% background). Background not so good at the low or high H regions.

Comparison of $t\bar{t}$ Generators

Run I comparison: PYTHIA V5.6, HERWIG V5.6, ISAJET V7.06

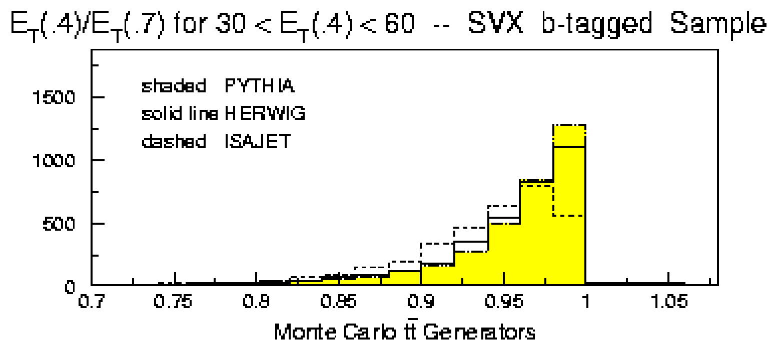
Sample with b tagged events.





P_T of W + 4 jets

Comparison of Energy flow in jets

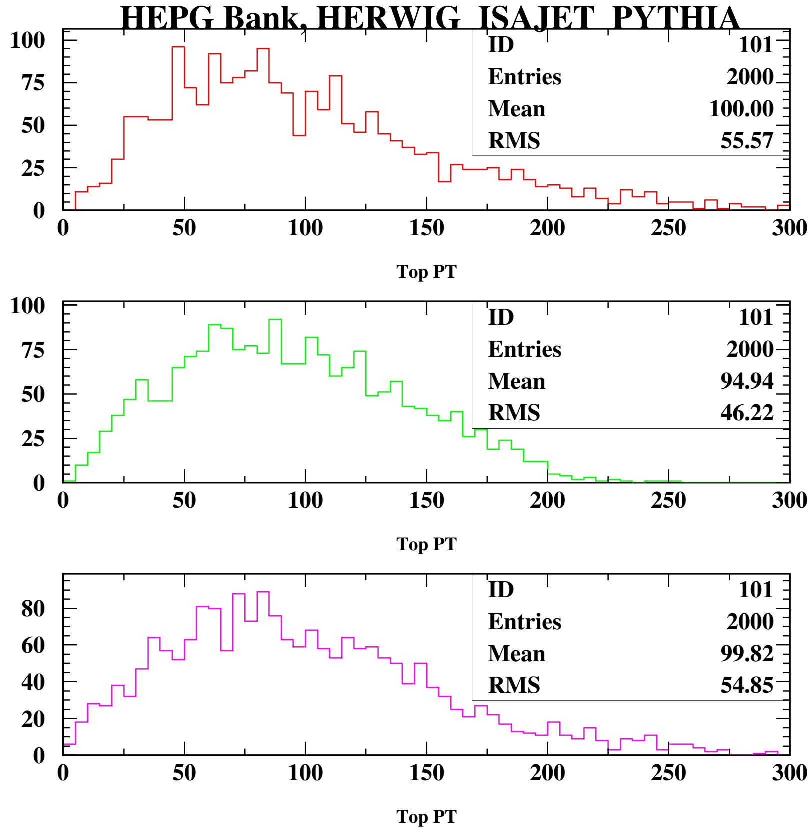


Ratio of Energy in cone with R$=$ 0.4 to energy in cone with R$=$0.7

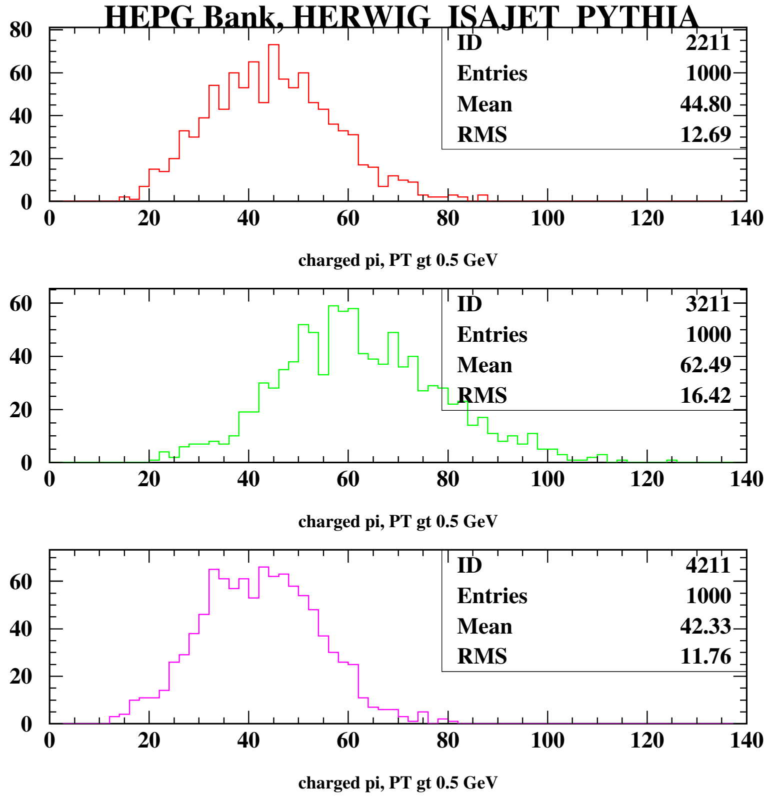
Generators differ for both variables, P_T of W + 4 jets and Energy Flow.

Run II: comparison of generators

HERWIG V6.1, ISAJET V7.31, PYTHIA V6.129



Comparison of top P_T



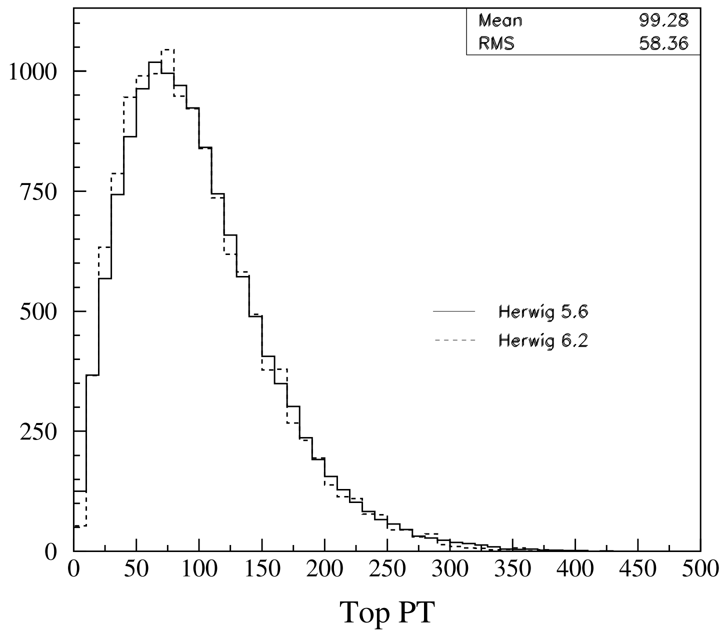
Number of pions with $P_T > 0.5$ GeV/c

CLEO MC used for b and c decays

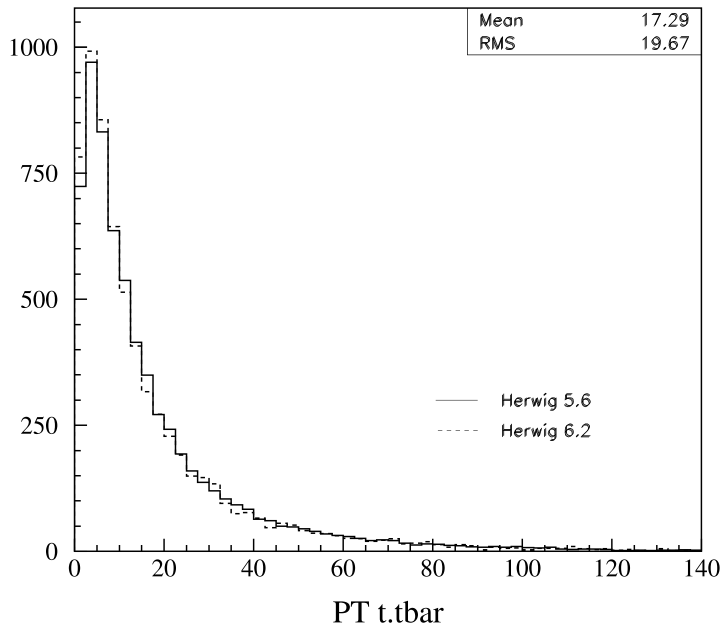
Comparison of HERWIG V5.6 (Run I) and HERWIG V6.2 (Run II)

- Improvements to the HERWIG generators have been made. Can we see the difference comparing a few variables?
- Comparison at the generator level, no detector simulation
- Make jets out of final particles, assigned to calorimeter towers.

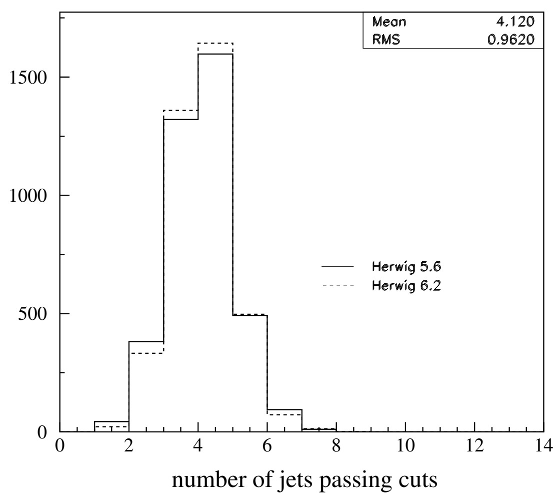
HERWIG V5.6 and HERWIG V6.2



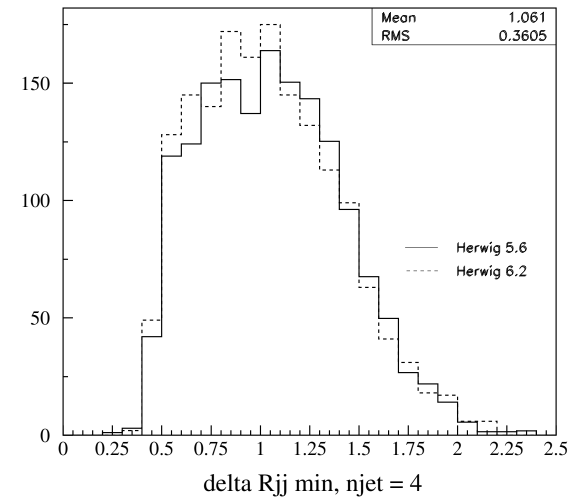
Comparison of top P_T



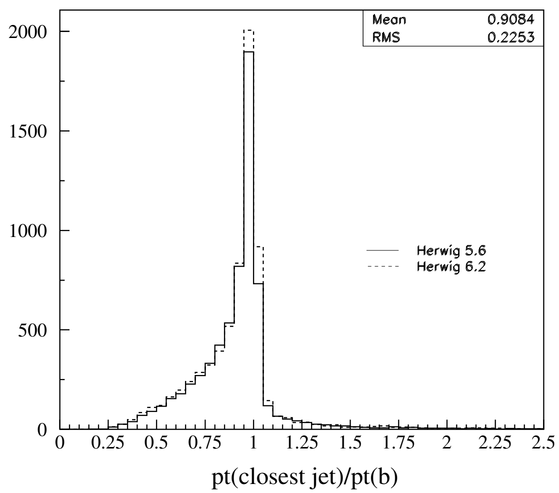
Comparison of P_T of $t\bar{t}$ system



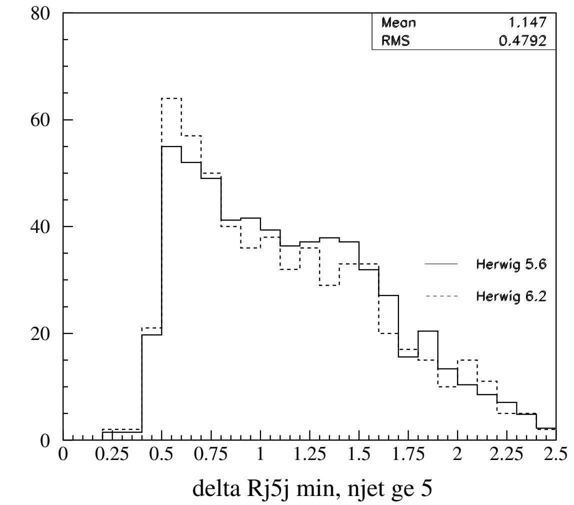
Number of jets/event(E_T > 20 GeV)



Minimum Δ R between two jets



P_T(jet)/P_T(b parton)



Minimum Δ R between jet 5 and any jet

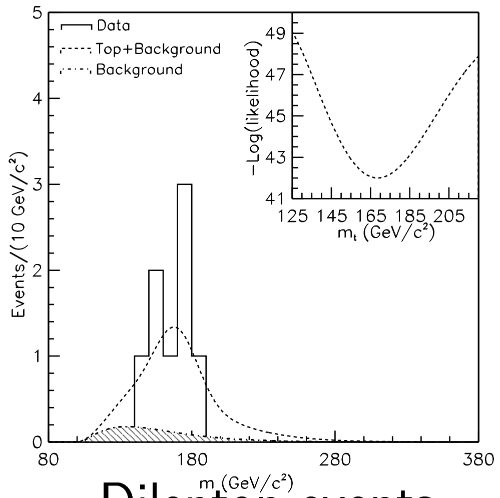
Sample Analysis: Top Mass Measurement

- Monte Carlo needs for the top mass measurement are similar to needs for most analyses with top events.
- CDF results on top mass from different channels

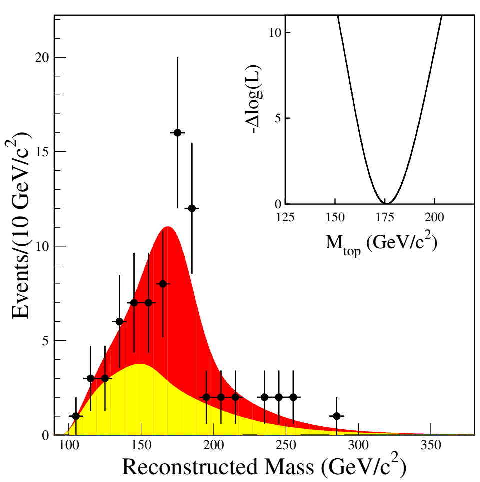
$$M = 176.0 \pm 4.0 \pm 5.1 \text{ GeV}/c^2 \text{ Combined}$$

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

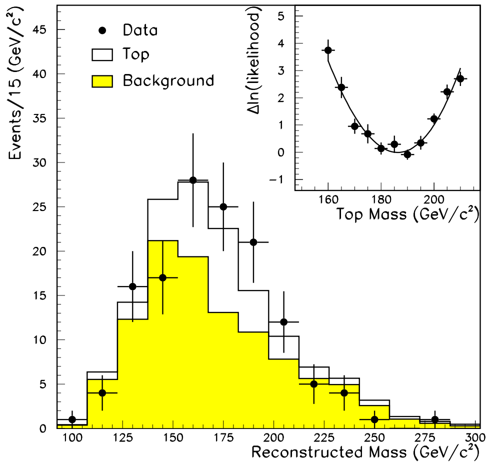
- Need to reduce systematic uncertainties !!



Dilepton events



Lepton + jets events

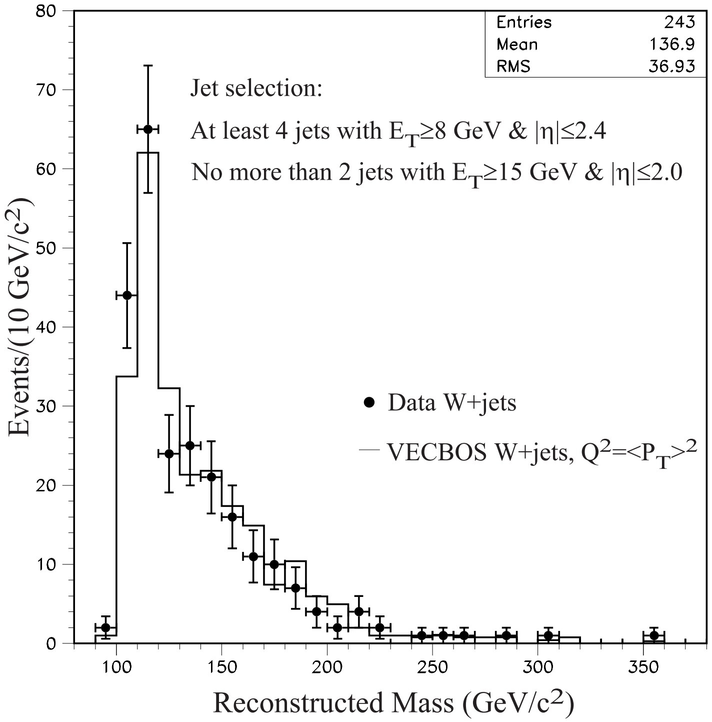


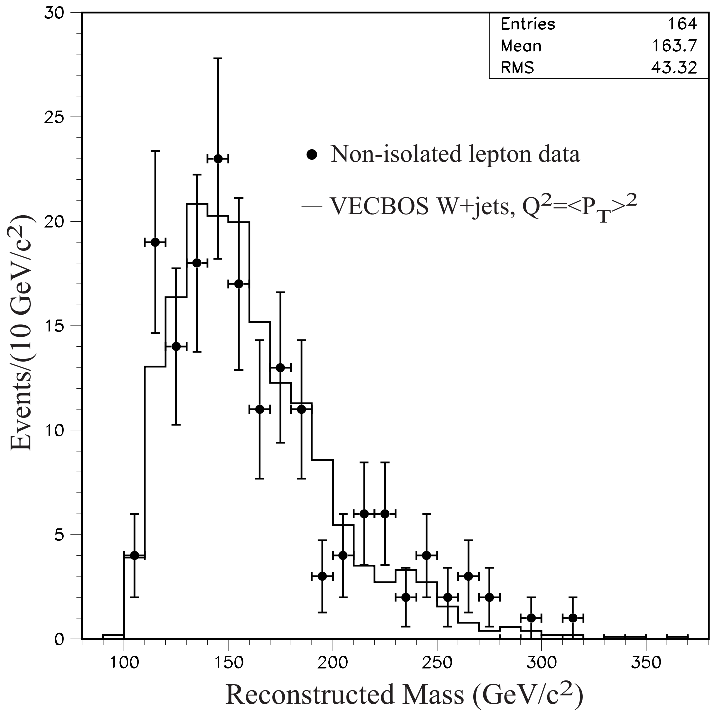
All hadronic channel

1. Backgrounds in the $\ell + \geq$ 3jets topology

Process	SVX tags	SLT tags	notag	Run I MC	Run II MC
non-W/Z	0.5	1.0	4.6	VECBOS	
WW	0.1	0.1	0.6	PYTHIA	
WZ, ZZ	0.0	0.0	0.2	PYTHIA	
Z $\rightarrow \tau\tau$	0.1	0.2	0.5	PYTHIA	
Single top	0.2	0.1	0.2	HER , PYT	
W/Z $b\bar{b}$	1.0	0.4	1.1	VECBOS, HER.	MLM
W/Z $c\bar{c}$	0.4	0.8	2.0	VECBOS, HER	
W/Z c	0.2	0.8	1.7	HERWIG	
W/Z u,d,s	0.2	4.1	19.6	VECBOS	
Sum background	2.6	7.6	30.4		
$t\bar{t}$ (expected)	17.4	6.4	11.6	HERWIG	
Observed events	20	14	42		

Total background 'b tags' $=$ 10.2 events (observed 34)
Total background 'notag' $=$ 30.4 events (observed 42)





Non top W + jets background
Comparison of VECBOS with data
Content of top expected to be 0.7%

Non W/Z background sample
Comparison of VECBOS with data
Mostly non-isolated leptons

- For top mass measurement we can use the SVX tag sample (little background).
- For new physics searches all channels have to be used.
- Need good background generators.

2. Jet Measurements in CDF

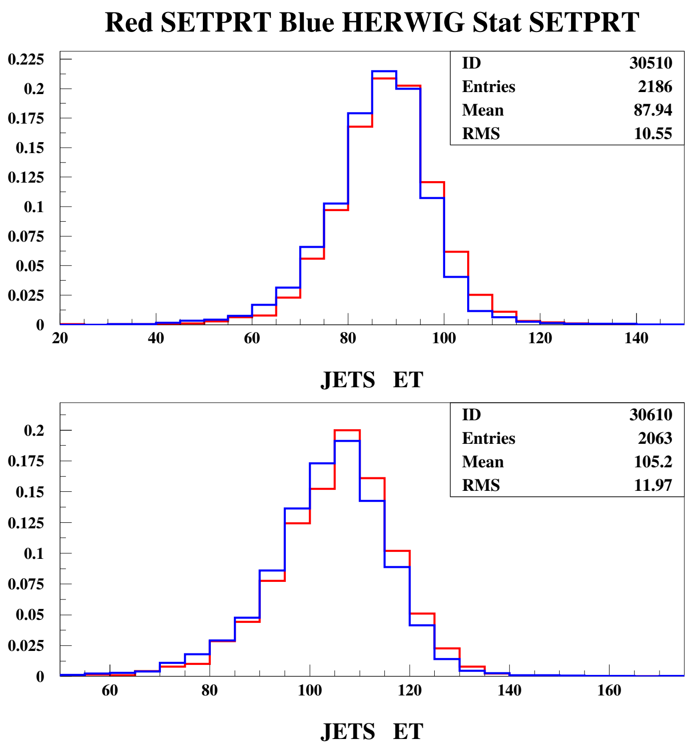


Figure 13: Comparison of SETPRT response function with HERWIG RF for true E_T =100 and 120 GeV.

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- Calorimeter was tuned to reproduce single particle response measured in test beam. Low P_T tracks from TeV data are also used.
- 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, Fraction of charged energy, dN/dz, M(charged tracks) etc. Five ISAJET fragmentation parameters were tuned: (XGEN(1), XGEN(2), SIGQT, SIGQT0, CONE2).
- By running these jets through the calorimeter simulation, calorimeter response functions were derived. This step takes into account calorimeter non linearities etc.

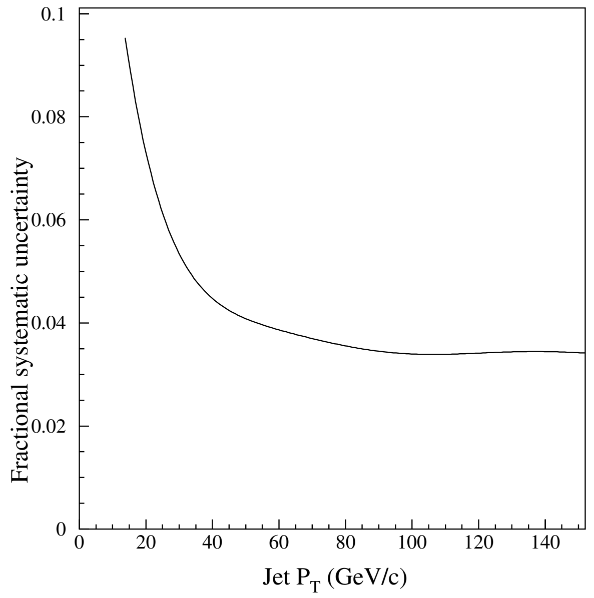
Response functions for ISAJET and HERWIG differ at most by 1.5%.

Jet Measurements in CDF (cont.)

- Next the jets get corrected for cracks and less sensitive regions.
- Out of cone corrections are applied.
- Finally they are corrected for the specific physics process, because the above procedure was done with a flat spectrum. Here again we rely on Monte Carlo. For the top mass measurement we have used HERWIG to determine a correction that brings the measured jet energy to the parton energy from which it originated.
- It is important to have reliable Monte Carlo!!!

3. Systematic errors (in GeV/c^2)

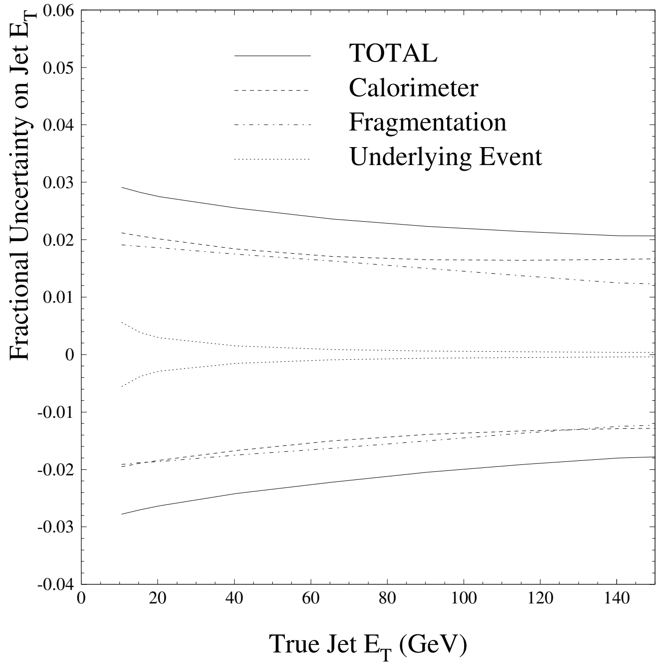
Channel	dilepton	ℓ+jets	all-had.
Jet energy scale	3.8	4.4	5.0
ISR, FSR	2.7	2.6	1.8
MC (PDF, b tag)	0.6	0.5	0.2
Generator	0.6	0.1	0.8
Background shape	0.3	1.3	1.7
MC statistics	0.7	n.a.	0.6
Total	4.8	5.3	5.7



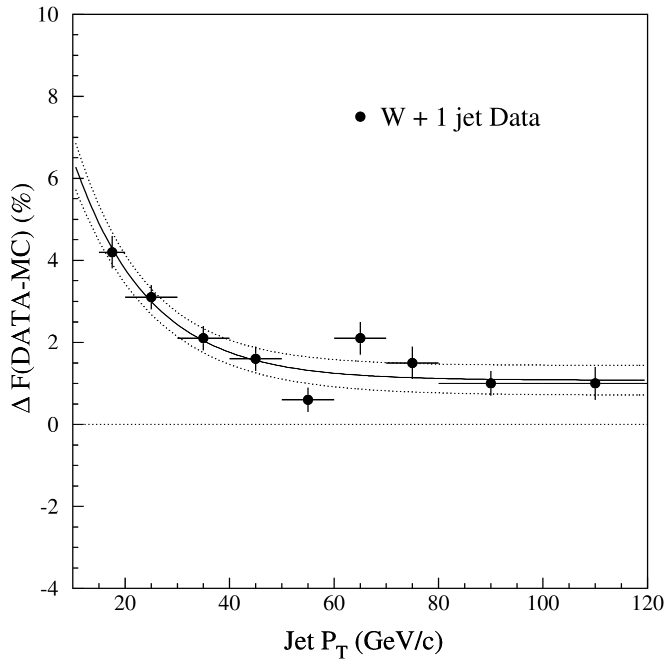
Total Systematic error on jet P$_T$
9.5% to 3.5% for P$_T$ $<$ 80 GeV/c

- Contributions to jet energy scale 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)

4. Jet P_T systematics from physics effects



Systematics within the 0.4 cone

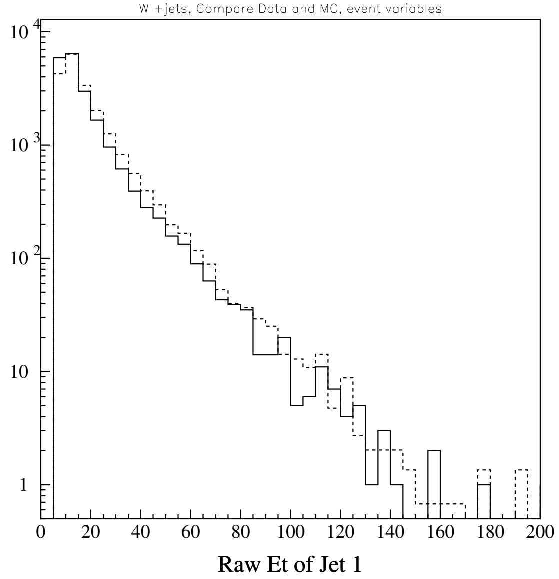


Systematics outside the cone.

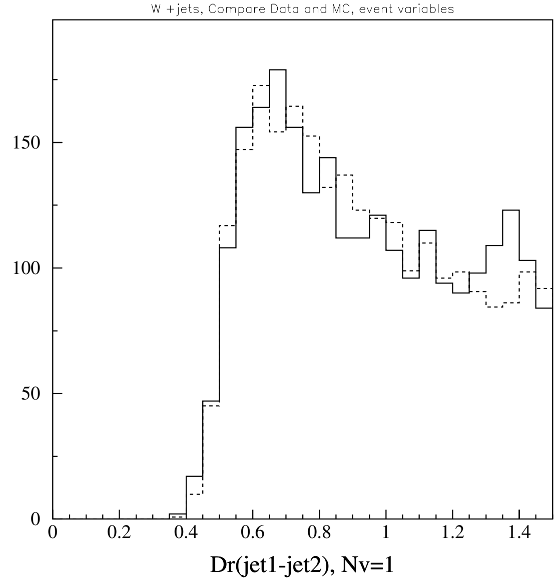
- Comparison of data with HERWIG Monte Carlo in W + 1 jet channel shows disagreement in energy contained in annulus between R=0.4 and R=1.0 (6% to 1%).
- This disagreement has already been observed in other CDF studies.

Are there tunable parameters to change the energy flow in the jets?

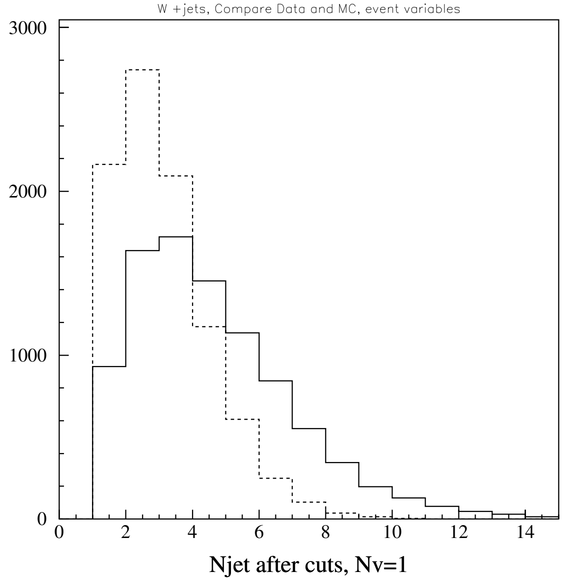
- Out of cone systematics determined using HERWIG V5.6 W +1 jet



High P_T Jet



Δ R Jet1-jet2

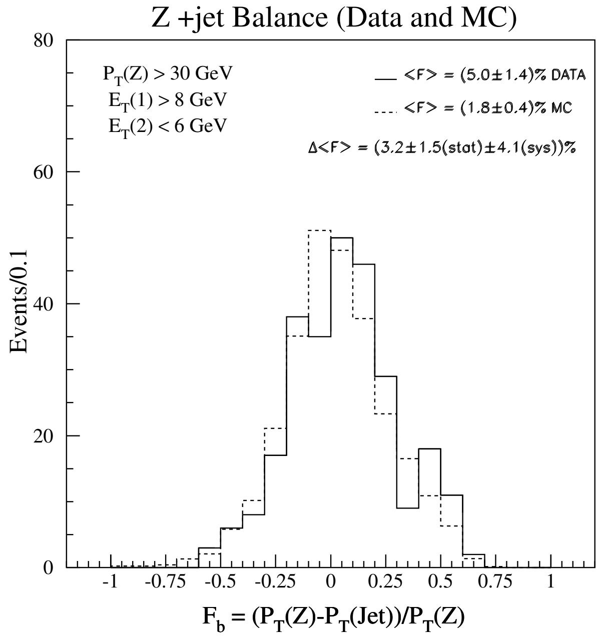


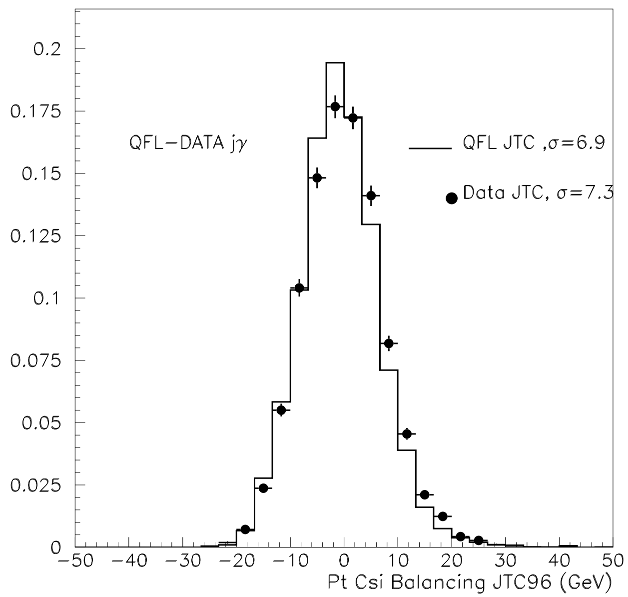
Number of jets in event

- Raw jet 1 $E_T > 8$ GeV and raw jet 2 $E_T < 8$ GeV are required.
- Distributions of the high P_T jet and jet separation agree in data(solid) and MC (dashed).
- The number of jets in the event disagrees, as expected (HERWIG uses W+1jet matrix element).

5. Use Z + jet balance and γ + jet balance for jet energy scale

- CDF has used these data as a check for the energy scale
- Since the jets were determined using the Monte Carlo, what counts is the difference between the data(solid) and Monte Carlo(dashed) distributions.





Z + jet balance

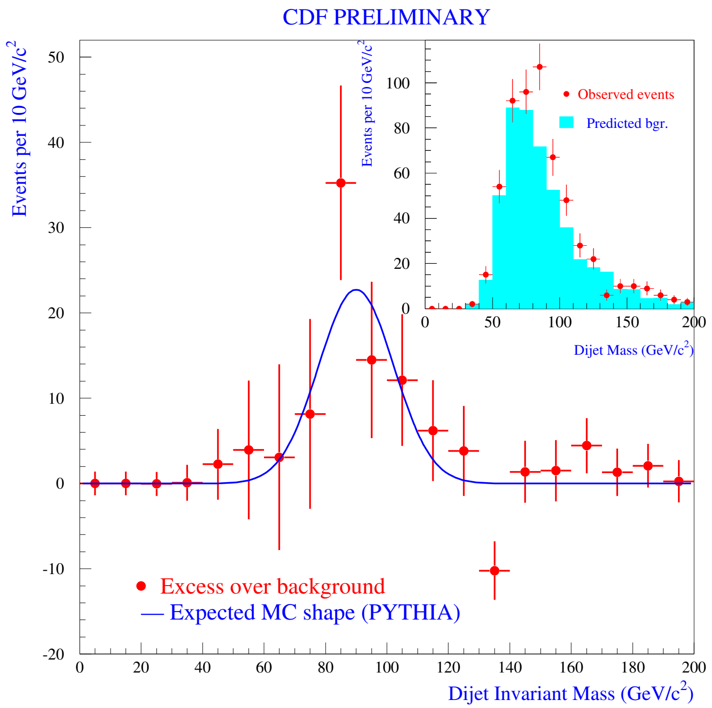
- Require $P_T(Z) > 30$ GeV
- Data and MC agree within 3.5 %

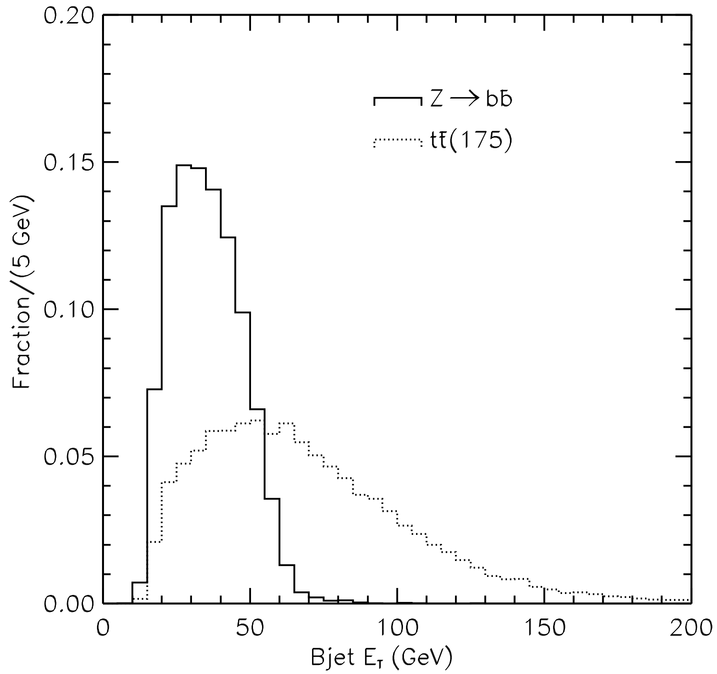
γ + jet balance

- P_T = 25-35 GeV/c
- Data and MC agree within 6%.

6. Using Z into $b\bar{b}$ to set the jet energy scale

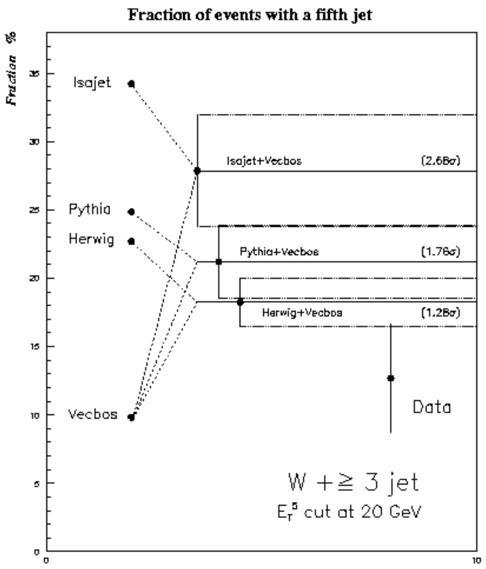
- Both CDF and D0 will be able to trigger on b jets using vertex Silicon detectors.
- The background is due to a very large QCD $b\bar{b}$ pair production.
- The correct description of the background is crucial to understanding the systematic errors.





7. Systematics from hard gluon radiation: ISR and FSR

- Extra jets can help understand ISR and FSR.
- Unfortunately we only had 9 such events in Run I.
- Agreement between the different Monte Carlos not great.



How do we determine the effects of gluon radiation?

Comparing different Monte Carlos does not seem appropriate.

We used PYTHIA to compare events with and without hard gluon radiation.

We determine the top mass using Monte Carlo events and our usual procedures, then we assign ISR and FSR according to the following prescription:

For the ISR we have used the formula:

$$\delta \text{ M} = 0.5^* \text{ (M(PYTHIA-standard)-M(PYTHIA-NOISR))}$$

For the FSR we have used the formula:

$$\delta \text{ M} = 0.5^* \text{ (M(PYTHIA-NOISR)-M(PYTHIA-NOISR, 4-jet matching))}$$

The reasoning for this choice is:

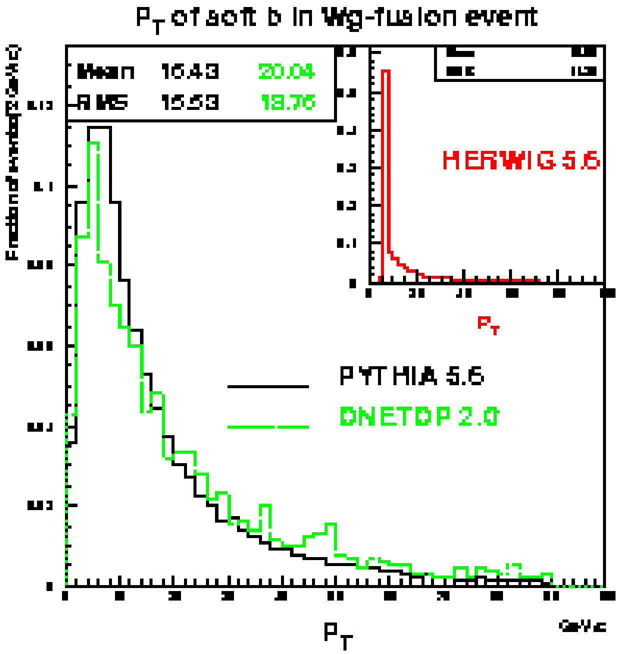
- The PYTHIA-NOISR includes all the FSR effects, without having the ISR to confuse the effect
- The sample with all-jet matching to original partons, has the smallest FSR effects.

As for the ISR effects case we take for the uncertainty 50% of the mass difference for the above samples. We also assume equal positive and negative errors.

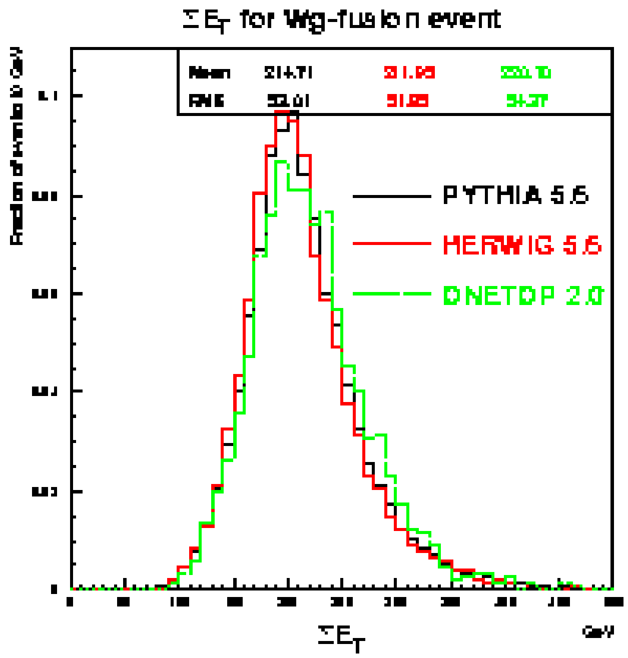
Any suggestions??

Other top studies

- Single top production. This is important because it potentially can be used to measure V_{tb}. There are two processes, W* and W-gluon fusion.



W-g, Comparison of soft b P_T



W-g, Comparison of Sum(E_T)

- Need reliable calculations (I believe they are being done). Important to have all variables well modeled. Neural network analyses would benefit by this.

- Angular correlations

  Deviations from Standard Model predictions would be indication of new physics.

  Studies have been done in Run I with little statistics.

  - W helicities, need V-A decay matrix elements
  - Included in PYTHIA and HERWIG
  - We need $t\bar{t}$ spin correlations.
  - HERWIG team plans to add these.

Summary and Conclusions

- Monte Carlo generators play a very important role in top physics analyses.
- Precise measurements of the top mass require reduced systematics on jet energies. Monte Carlos play an important role here, too.
- Search for new physics requires accurate estimates of the backgrounds.
- Matrix element generators are important to give theoretical uncertainties on complete generators.