# Underlying Event in Top

Outtline:

- Motivation: top mass precision measurement
- What in the UE are we after?
- How different is the new shower model?
- What is the effect on the top mass measurement?
- Color Reconnection systematics
- Jet Shapes

CDF and D0 have been working together on these issues, as they are relevant to precision measurements of the top quark mass.

Work done with P.Lujan and contributions from other members of the CDF collaboration

# Underlying event in Top Events

All Top quark analyses in CDF have used the PYTHIA V6.2 generator.

This talk is about present efforts in CDF to understand the differences between V6.2 and V6.4 and its effects on our measurements.

PYTHIA v6.4 includes:

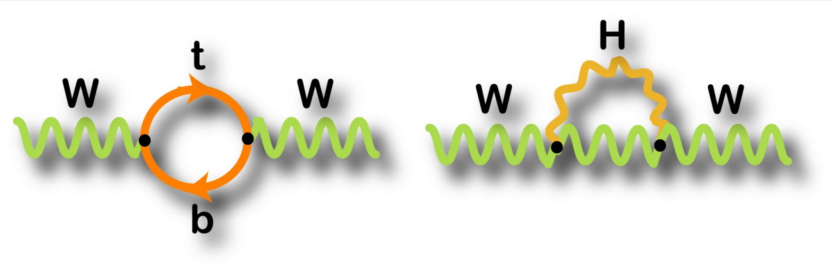
- New models for parton shower (ISR/FSR)
- New Models for Underlying event:
  - MPI
  - Beam renmants
  - Color Reconnection (CR)

In particular, the effect of Color Reconnection on the top mass measurement has been discussed in talks and publications. Estimate by these authors are around 0.5 GeV/$c^2$

P. Skands and D. Wicke hep-ph/0703081v1 (March 2007)
D. Wicke and P. Skands hep-ph/0807.3248 v1 (July 2008)
D. Wicke and P. Skands TOP08

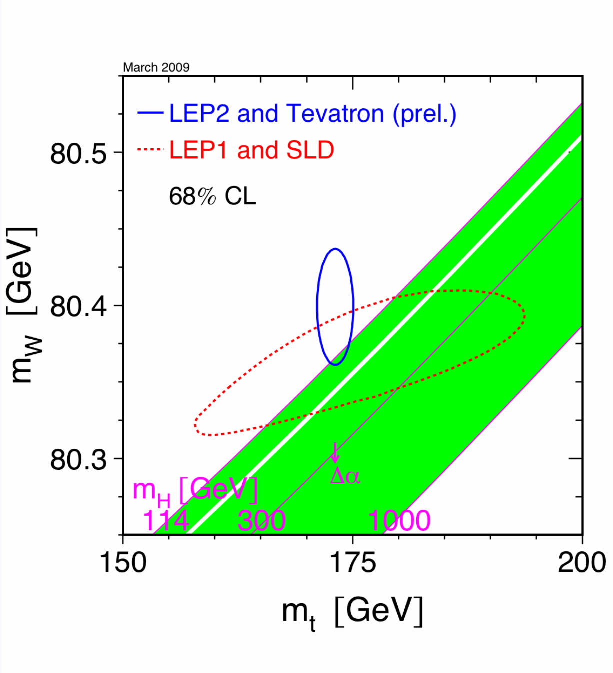
# Motivation: Top Mass

Precision measurements of the top quark mass provide information on the mass of the Higgs in the Standard Model




$\sim M_t^2$ $\sim \log(M_H)$

- Quantum loop corrections to many EWK observables are sensitive to the top mass
- Top Mass is highly correlated to $M_W$ and $M_H$ in Standard Model EWK theory



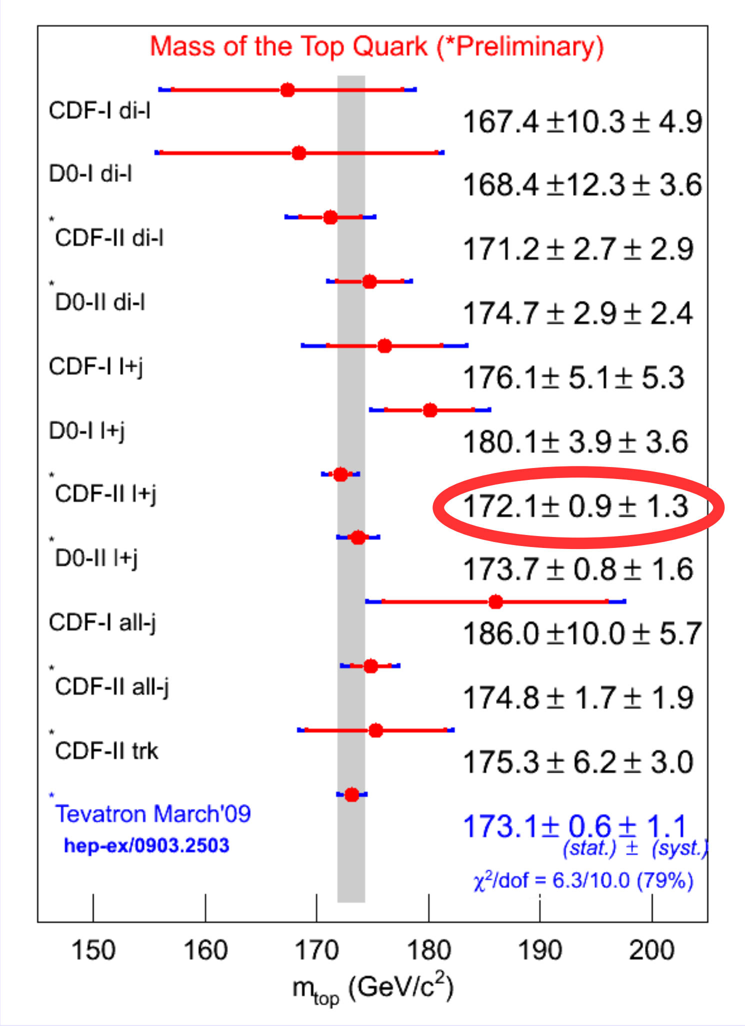

$M_H < 163$ GeV/c$^2$ @95% CL
including direct limit $M_H > 114$ GeV/c$^2$
$M_H < 191$ GeV/c$^2$ @95% CL

**Tevatron limits (Winter '09) $M_H$ = 160-170 GeV/c2 excluded @95% CL**

# Tevatron $M_{top}$ measurements

Winter '09 Average

$M_{top}$ = 173.1± 0.6 (stat.) ± 1.1 (syst) GeV/$c^2$




The uncertainty on the top mass is already dominated by the systematics term

Need to reduce the uncertainties.

For $\delta M_t$ = +1.2(-1.2) GeV $\delta M_H$ =+9 (-8)GeV

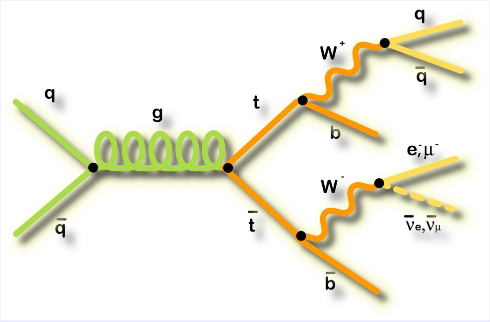
For $\delta M_W$= +25(-25) MeV $\delta M_H$= -13(+17)GeV

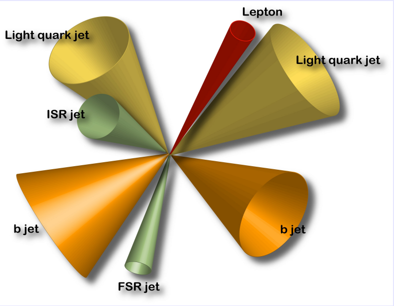
Taking as an example the measurement I am most familiar with, I will show how the MC enters in the evaluation of the systematics uncertainties.

CDFII l+jets obtains

$M_{top}$ = 172.1± 0.9 (stat.)±0.7(JES)±1.1 (syst) GeV/$c^2$

# Top Mass measurement




$$\bar{t}\ t \to W^{+}\ b\ \ W^{-}\ \bar{b}$$
$$\to j_1\, j_2\ b\ \ l\, \nu\ \ b$$

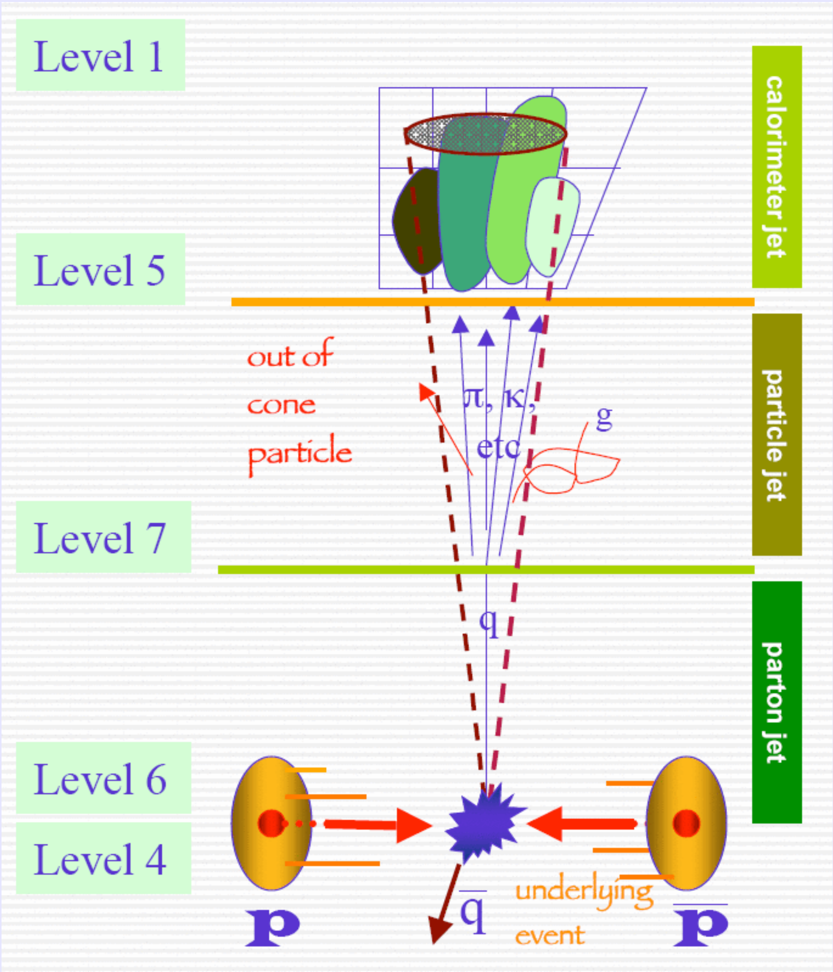
What ingredients in the measurement depend on the MC used?
Can we include the effects from the new MC in the systematics?

- Jet energy corrections and systematics
- ISR and FSR uncertainties (pQCD)
- Parton shower uncertainties (pQCD)
- Hadronization uncertainties (non-perturbative)

Jet energy scale uncertainties are the major contributors to the top mass systematics. To study this we use for jets the variable

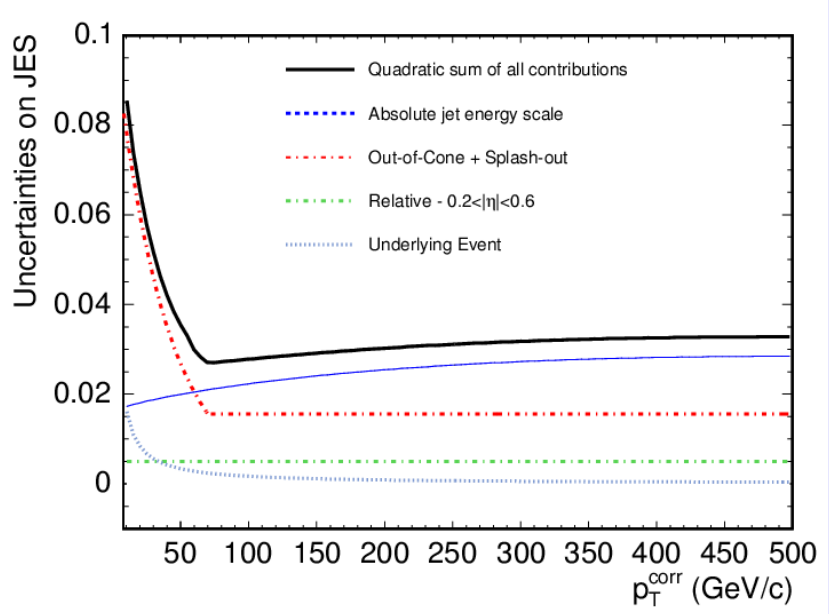
$\Delta_{JES}$ = number of s.d. Away from the central value

# Jet Reconstruction




Use cone algorithm

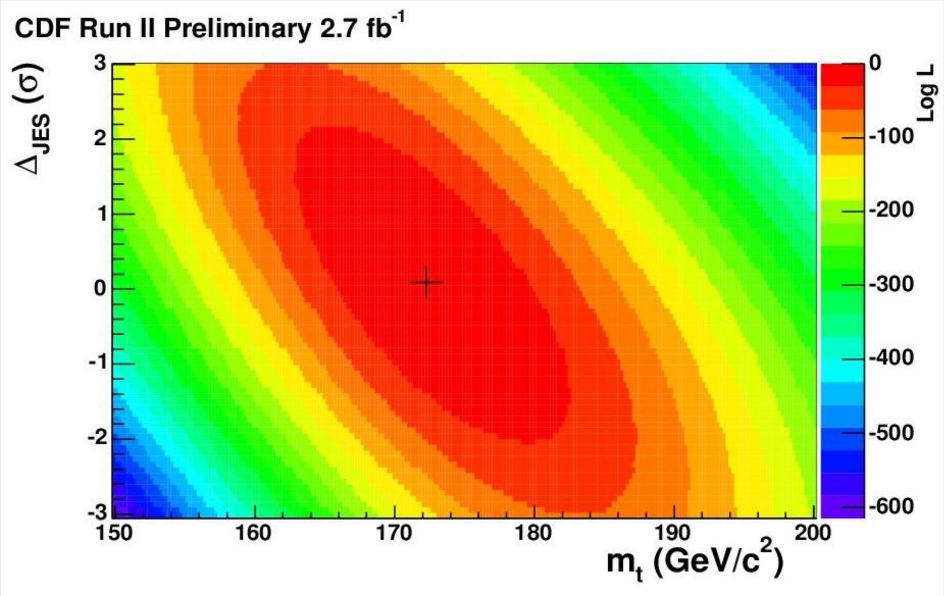
- Use calorimeter information only
- Jet calibration done in many steps
- 3% systematics at high $p_T$



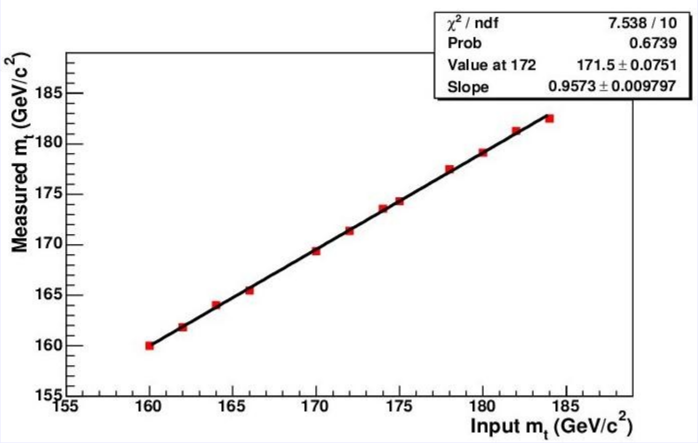

Source of the largest uncertainty on the top mass measurement

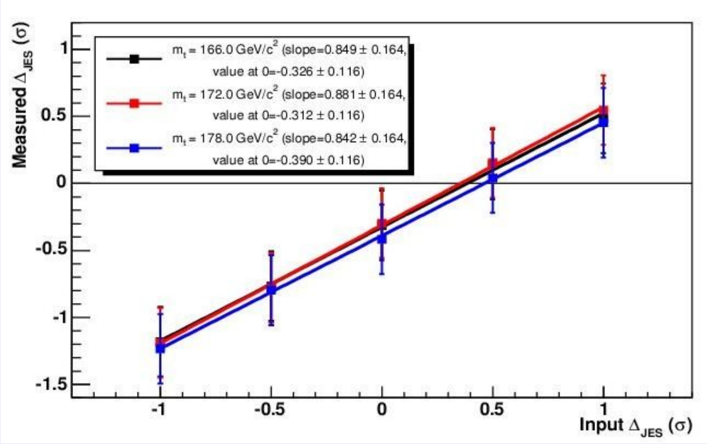
# $M_{top}$ Measurement (schematic)

To evaluate $\Delta_{JES}$ we use a 2D likelihood with $M_t$ and $\Delta_{JES}$.
We "constrain" the W mass to the measured value, using the 578 selected events (134 ± 35 backg), thus obtaining the $\Delta_{JES}$ from data.




## Mass and $\Delta_{JES}$ Calibrations




$M_{top}$ = 172.1 ± 0.9 (stat.) ± 0.7 (JES) ± 1.1 (sys) GeV/$c^2$ = 172.1±1.6 GeV/$c^2$

Also find $\Delta_{JES}$ = (0.40 ± 0.26)σ (statistics limited)

# Top Mass systematics

For the Winter Conferences Tevatron had delivered 5.8 fb$^{-1}$, of which 3.2 fb$^{-1}$ were used for the measurement. This will be ~4 fb-1 for Summer '09. Statistical error will get smaller, including the (JES) uncertainties.

Measurement soon will be dominated by systematic uncertainties.

| Systematic source | $\Delta m_t$ (GeV/$c^2$) |
|---|---|
| Calibration | 0.16 |
| MC generator | 0.51 |
| ISR and FSR | 0.29 |
| Residual JES | 0.52 |
| b-JES | 0.38 |
| Lepton $P_T$ | 0.18 |
| Permutation weights | 0.01 |
| Pileup | 0.09 |
| PDFs | 0.17 |
| Background: fraction | 0.36 |
| Backg: composition | 0.33 |
| Backg: average shape | 0.03 |
| Backg: $Q^2$ | 0.08 |
| Backgrounf:MC statistics | 0.05 |
| Color Reconnection | 0.41 |
| Total (MC Dependent) | 1.13 (0.88) |

Systematics dependent on MC used amount to

JES 0.7 GeV
CR 0.4 GeV
Other 0.9 GeV

Total 1.2 GeV (of 1.3 GeV)

MC dependent systematics, other the the Color reconnection, are in red.

Preliminary studies, which I will be showing today, have evaluated the systematic uncertainty from Color Reconnection to be 0.41 GeV

# Top Mass Systematics

There are three questions

1. Evaluate Color reconnection systematics

2. Study the differences between the new PYTHIA and the old one (parton shower model, as well as underlying event model). This because we have used PYTHIA V6.2 for the calibration of the method and the systematics

3. To what extend MC and data agree?

# Procedures

Use the l+jets sample: events with 1 lepton + 4 jets (Et>20 GeV)

A. Given a MC sample, for each event we match the partons from top decays to the observed jets (Ntight = 4). This is match of the 4 partons to the 4 jets in the event.
We then know which jet are light quark jets and which ones are b-jets.
To check the changes between MC's we compare a number of variables for the different tunings, for example:

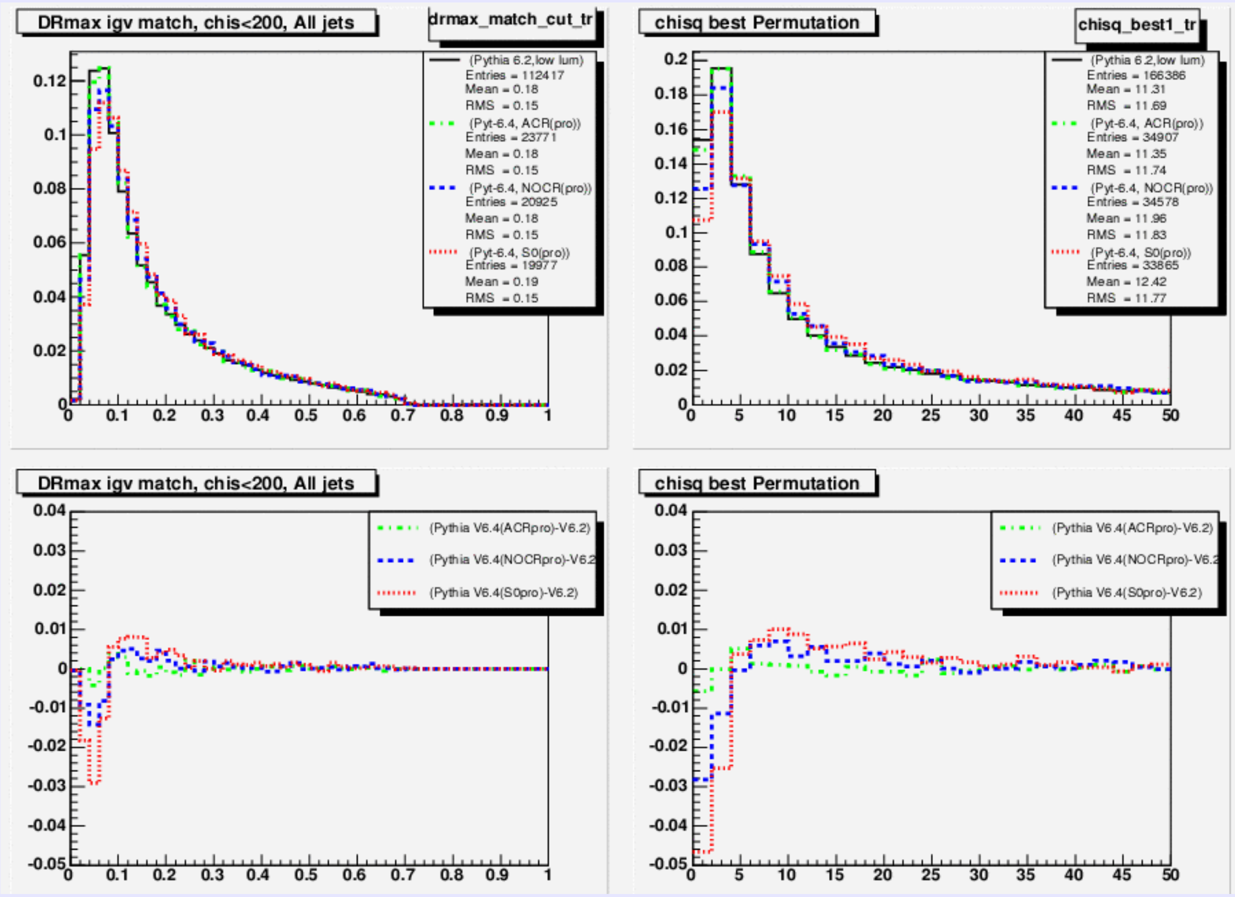
- Compare E(parton) and E(jet) in cone of R=0.4
- Compare M(W) and M(top) using the matched jets

B. We apply to each sample the top mass measurement analysis to obtain a mass and an uncertainty.

- For methods A and B, we compare results obtained for
  V6.2(tune A) old MC (used for CDF measurements )
  V6.4 (tune ACR) only CR added to old shower
  V6.4 (tune NOCR, S0) new shower, wo/w CR

# Results of matching for different tunes

The whole event is matched using $\Delta R$ for each parton-jet pair. An overall $\chi^2$ is calculated, best $\chi^2 < 200$ are accepted as matched




M=175 GeV

| | |
|---|---|
| V6.2 (tune A) | 68% |
| V6.4 ACR | 68% |
| V6.4 NOCR | 60% |
| V6.4 S0-pro | 59% |
| | |
| V6.4 NOCR | 59% |
| V6.4 S0-pro | 59% |

Samples with new parton shower have:

wider $\chi^2$ distributions

wider $\Delta R$ "

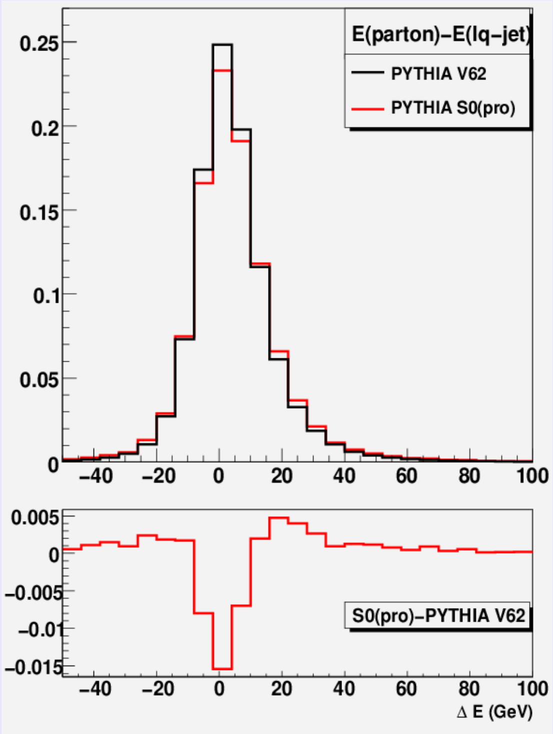
The new parton shower model gives less matched events .

# Comparison of Energy in cone of 0.4

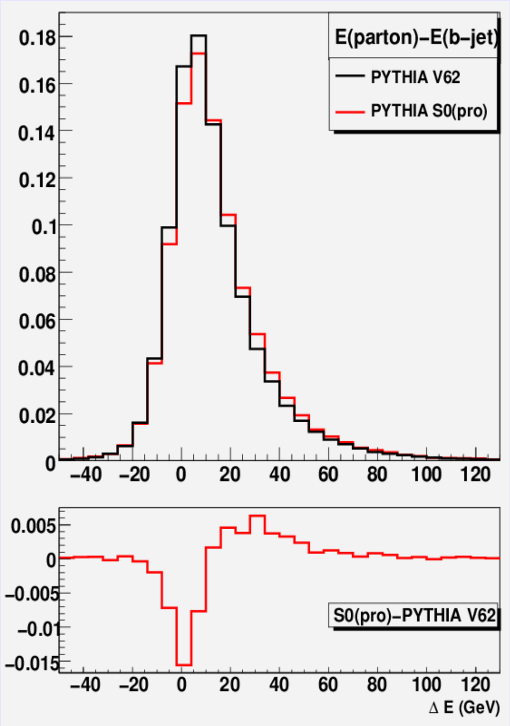
We have compared jet properties after generation + detector simulation.
Preliminary studies find the ACR(pro) jets agree with PYTHIA V6.2, but:

E ($\Delta$R=0.4 cone) S0 sample < E ($\Delta$R=0.4 cone) PYTHIA V6.2 sample

Light quark jets




b-quark jets




Jets in the S0(pro) sample are wider and shifted

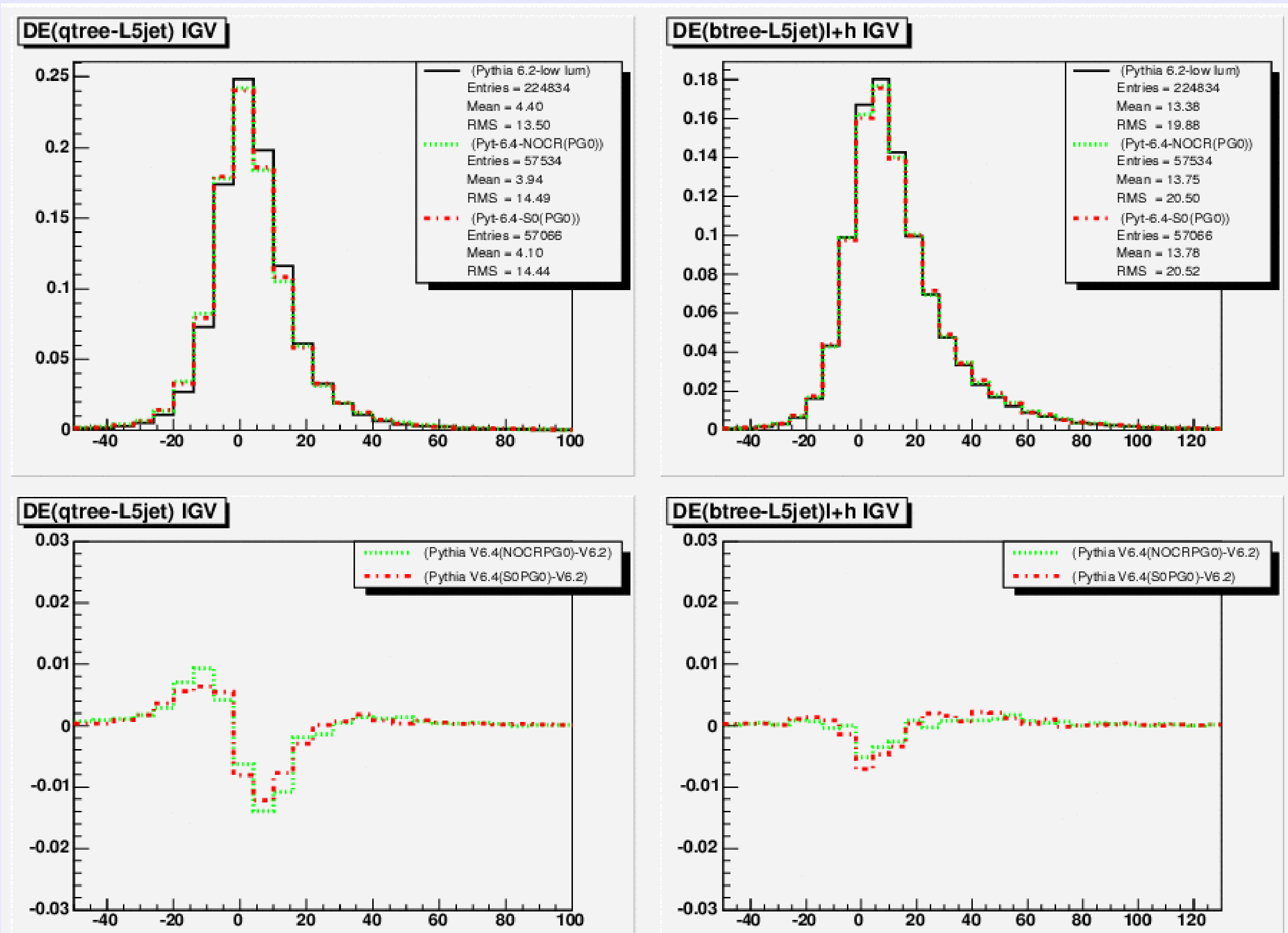
S0(pro) -Nominal

| | $\Delta$ E (cone) GeV |
|---|---|
| W-jets | -0.38 ± 0.15 |
| b-jets | -1.43 ± 0.15 |

Energy in the cone for the S0-pro tune is smaller by 1.43 GeV for b-jets

# Comparison: E in cone of 0.4

S0Pg0 (S0Perugia0) compared with our defalt (V6.2 tune A)




S0(pro) -Nominal

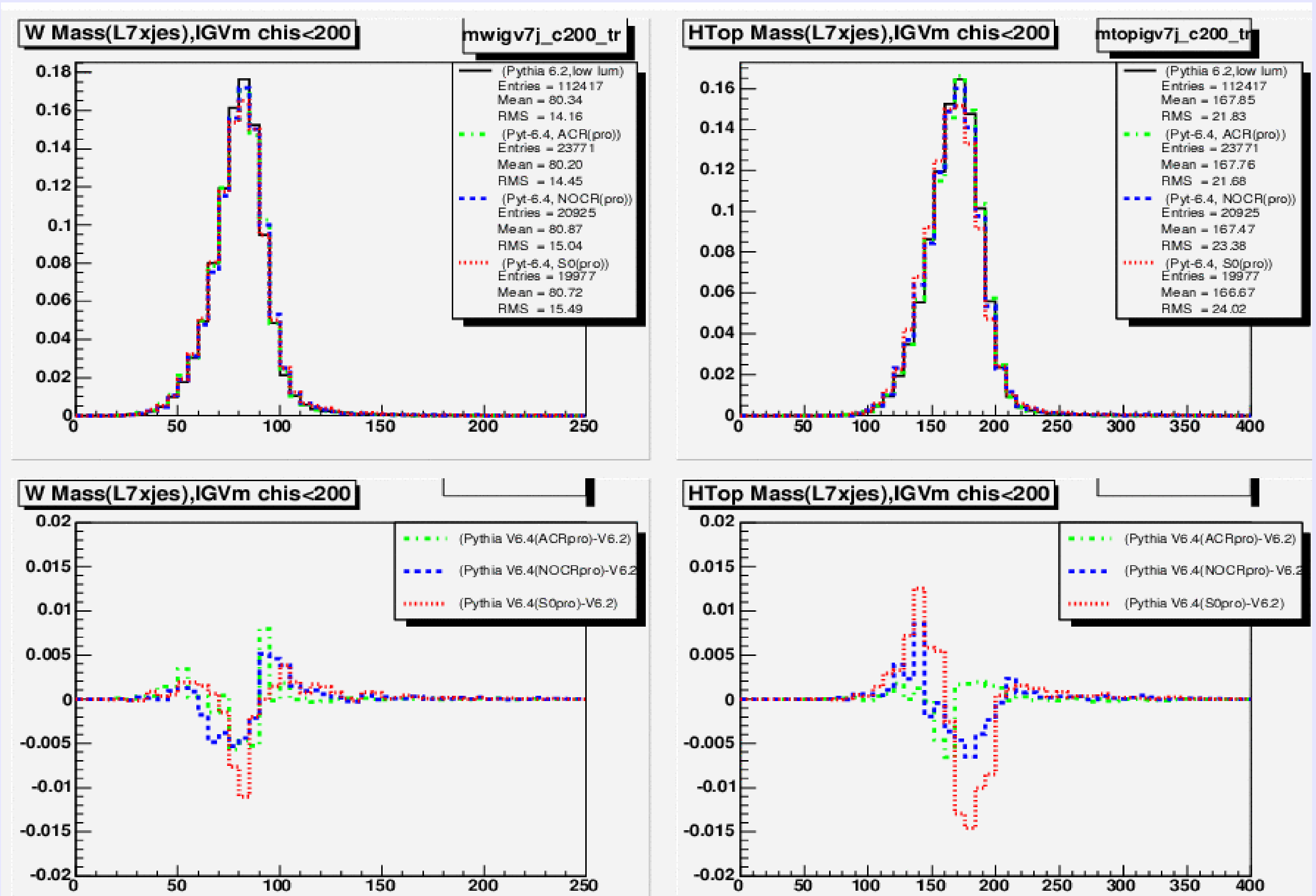
$\Delta$ E (cone) GeV

W-jets -0.30 ± 0.15

b-jets +0.40 ± 0.15

The S0-Perugia0 tune has different behavior for the b-jets

# Compare $M_W$, $M_{top}$ after matching



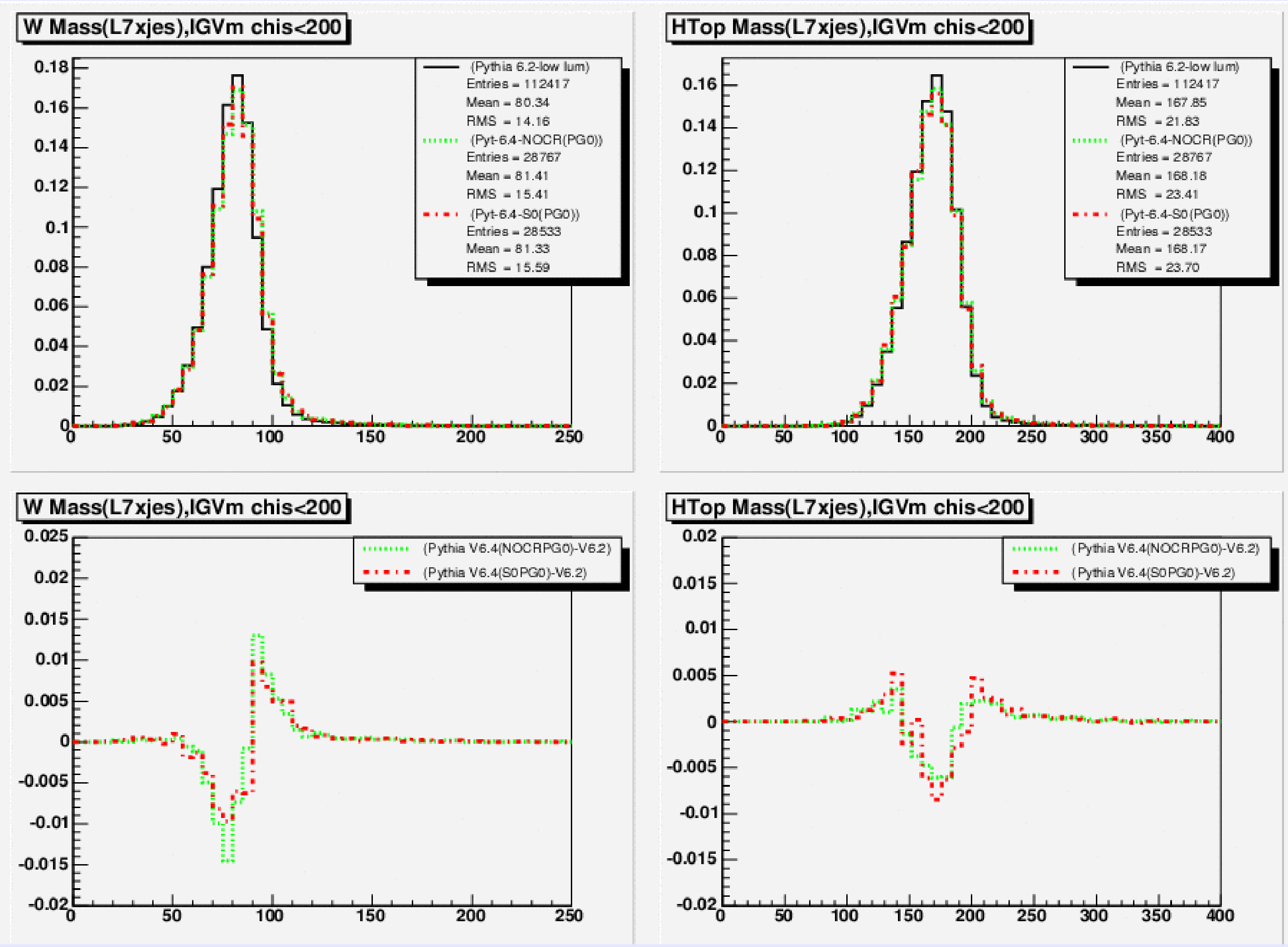

| M=175 GeV | ΔMw |
|---|---|
| V6.4 (A-pro) | -0.15 |
| V6.4 ACR-pro | -0.14 |
| V6.4 NOCR | +0.53 |
| V6.4 S0-pro | +0.39 |

| M=175 GeV | ΔMtop |
|---|---|
| V6.24(A-pro) | -0.05 |
| V6.4 ACR | -0.09 |
| V6.4 NOCR | -0.09 |
| V6.4 S0-pro | -1.18 |

Tune A and ACR have small mass shifts. Here only CR is different.

S0-pro has a 1.18 GeV top mass shift: here both parton shower and UE models are different

# S0-Perugia0 W and Top mass shifts




M=175 GeV ΔMw

V6.4 NOCR +1.07
V6.4 S0-Pg0 +1.00

M=175 GeV ΔMtop

V6.4 NOCR +0.33
V6.4 S0-Pg0 +0.33

The S0- Perugia0 and corresponding NOCR have a small top mass shift

# Summary of studies on $M_{top}$

Comparison of V6.2 (nominal) to V6.4 (the “pro” files)
Using both methods, i.e., reconstructing top mass with event matching and with our ME method.

| Sample | $\Delta m_W$ ($GeV/c^2$) | $\Delta m_t$ ($GeV/c^2$) | $\Delta m_t$ ($GeV/c^2$) | $\Delta$ JES $\sigma$ |
|---|---|---|---|---|
| | MC event matching | | MTM3 Pseudo-Experiments | |
| V6.2 (nominal) (ttkt75) | – | – | – | 0.01±0.05 |
| V6.4 tune A-pro (otop45) | -0.15±0.13 | -0.05±0.20 | -0.12±0.26 | 0.04±0.06 |
| V6.4 ACR-pro (otop46) | -0.09±0.12 | -0.14±0.20 | -0.53±0.26 | 0.08±0.06 |
| V6.4 NOCR-pro (otop47) | +0.53±0.14 | -0.09±0.21 | -1.46±0.27 | 0.22±0.06 |
| V6.4 S0-pro (otop44) | +0.39±0.14 | -1.18±0.22 | -1.80±0.28 | 0.11±0.06 |
| V6.4 NOCR-Pg0 (ctops4) | +1.07±0.09 | +0.33±0.14 | -1.60±0.32 | 0.34±0.07 |
| V6.4 S0-Pg0 (ctops3) | +1.00±0.09 | +0.32±0.14 | -1.45±0.33 | 0.27±0.07 |

- ACR (old shower+CR) shows little effect from CR = -0.41 ± 0.37 GeV
- NOCR: Event matching finds large $\Delta M_W$, ME fit compensates for this with a large value of $\Delta$JES, resulting in $\Delta M_{top}$ = -1.5 GeV .
  For $\Delta$JES= 0 we get $\Delta M_{top}$ = -0.7 ± 0.2 GeV

# Color Reconnection Systematic

- S0-pro : $\Delta M_{top}$ = -1.8 GeV, expected because of -1.3 GeV b-jet shift.
- S0-Perugia0 : the light quark jets are more shifted then the b-jets. This shifts the W mass considerably (~ 1GeV). The top mass goes up for this reason. The ME fit gets a large DJES to recontract the W mass properly, this moves the jets down resulting in a large DMtop
- NOSR-Pg0: same as above .
- Bottom line: what is the CR systematics?

From ACR (pro)-A(pro) CR = -0.41 ± 0.37

From S0(pro) and NOCR CR = -0.34 ±0.38

From the Perugia0 tunes CR = +0.15± 0.45

- More statistics will help. At this point it seems that CR ~0.5 GeV

# Summary of Matching and ME fits

- We find the following CR values from the "pro" tune files:
  -0.41 ± 0.37 GeV from ACR (-0.4 ± 0.3 GeV used for Winter Conf)
- CR = -0.34 ± 0.38 from S0-NOCR,
  CR = +0.15 ± 0.45 from the Perugia0 tunes

- The S0-pro (S0Pg0) tune gives $\Delta M_{top}$ = -1.8 GeV (-1.4 GeV)
  this is directly related to different jet shapes, i.e., different p-shower
- Tune S0 tunes include systematics that we are already taking into account ,i.e.
  generator : $\Delta(m_t)$ = 0.51 +- 0.37 GeV
  ISR/FSR : $\Delta(m_t)$ = 0.29 +- 0.26 GeV
  OOC : $\Delta(m_t)$ = 0.52 GeV
  b-jets : $\Delta(m_t)$ = 0.38 GeV
  that is 0.88 GeV, most of the MC related systematics.

- More comparison of the S0 tune with Tevatron data needs to be done before we use it. We also need to disentangle the various systematics contributions

# Color Reconnection: Jet Shapes

Continuing studies on color reconnection systematics require the understanding of jets from PYTHIA V6.4

We have looked at jet variables and compare them to jets in top data. Only b-tagged jets are considered in this comparison.

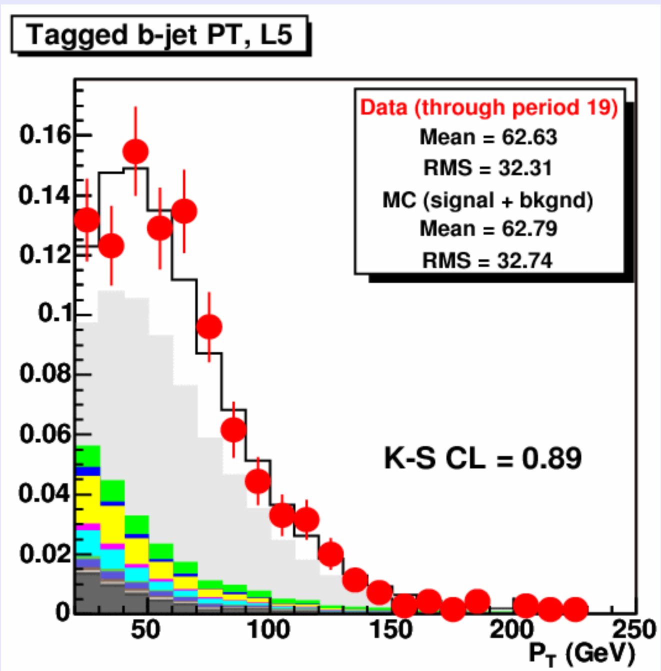
There are 698 jets tagged by our secondary vertex algorithm.
N(events)= 578 with the topology lepton+4 jets (PT>20 GeV) .
N(background)= 134 $\pm$ 34 events.

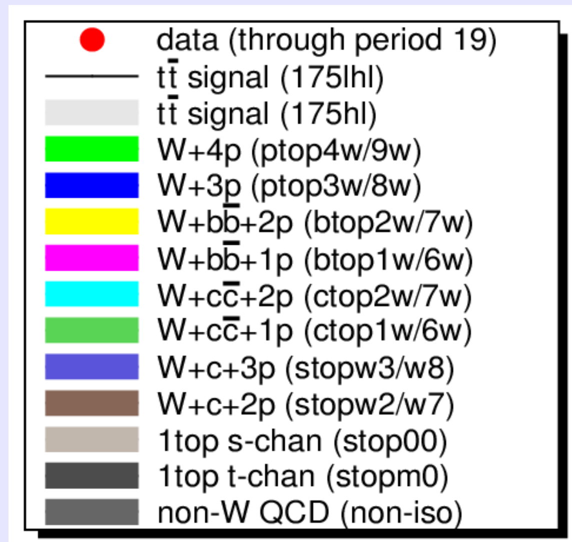
Variables:
- Jet mass
- Number of charged particles
- Eta moments
- Phi moments

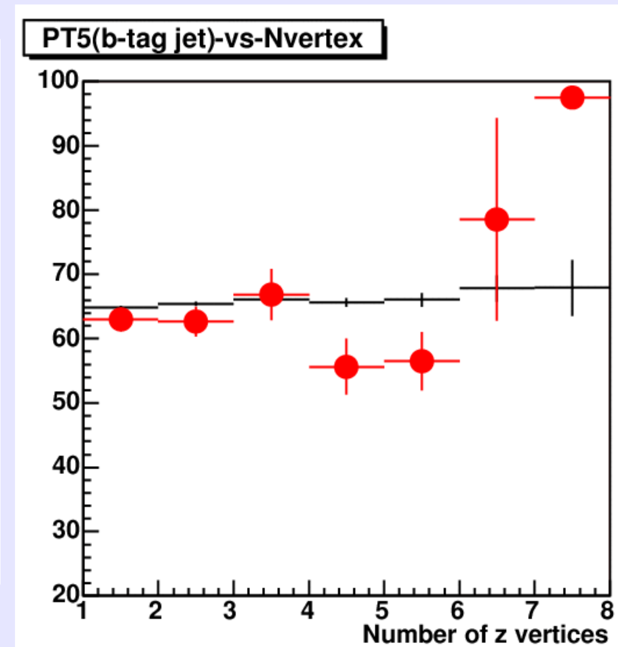
We have many histograms. We only show a few of them.

# Tagged Jet PT

Comparison of data and MC for the default PYTHIA V6.2.
Only events with Ntight=4 included (698 jets)



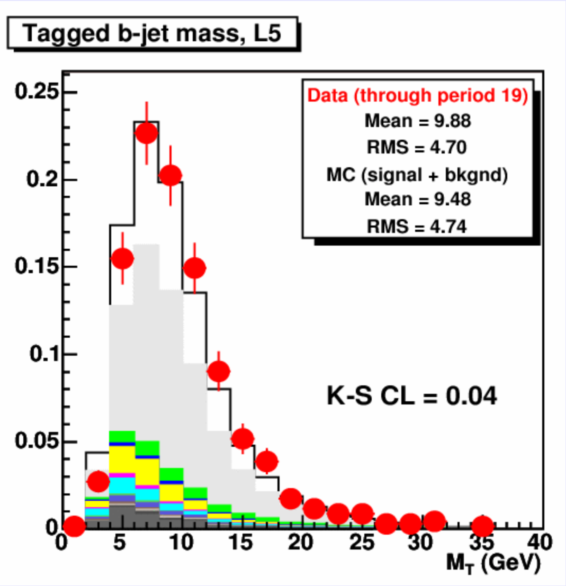



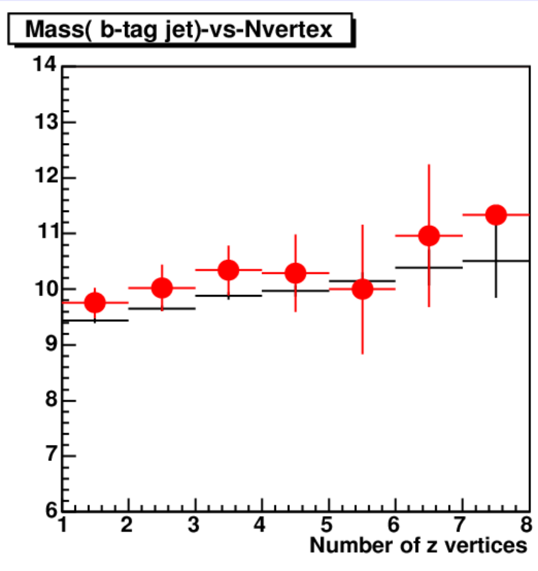



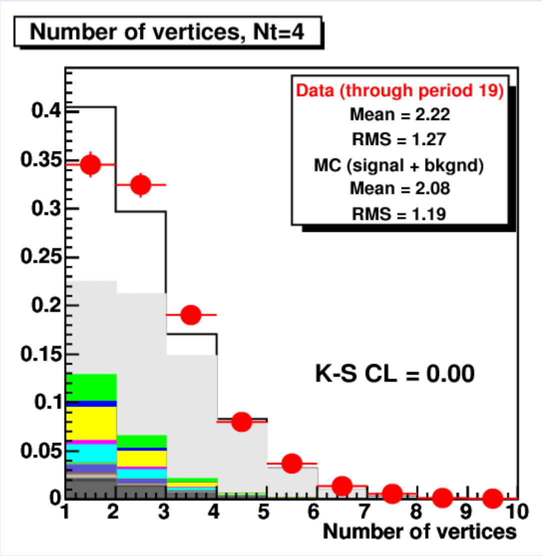

The measured jet $P_T$ agrees with the PYTHIA V6.2 tune A which is our default. The dependence on Nvtx is minimal which means we are correcting the jets properly. The lumi profile is not very good, as the background luminosity is limited to the first 1/3 of the data. (next page).

# Jet Mass in tagged jets

Jet mass agrees poorly with MC. Dependence on Nvtx is strong.
Jet corrections are based on PT, do they correct the mass properly?
Can we use this variable to distinguish between different tunes?



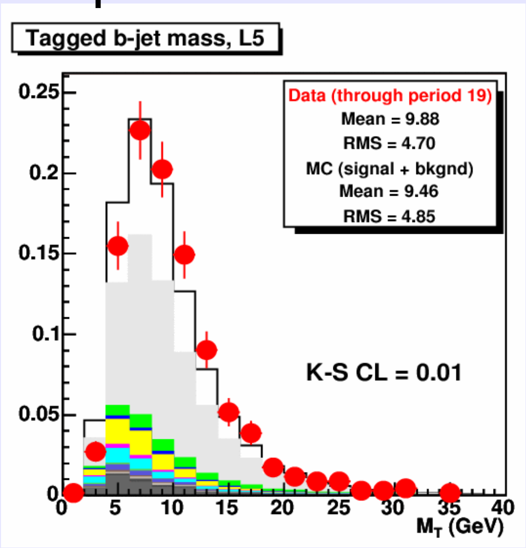




MC expects the average jet mass to vary from 9.6 to 11.0 for 1-7 vertices. We notice, however, that the data is higher than MC for the first three points where there is more data.

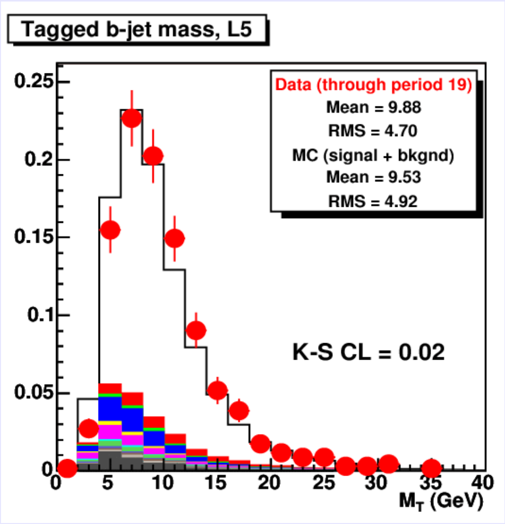
| Aprolhl | ACRlhl | S0-pro | NOCRPg0 | S0Pg0 |
|---|---|---|---|---|
| 0.01 | 0.10 | 0.02 | 0.02 | 0.02 |

# Jet Mass

A-pro

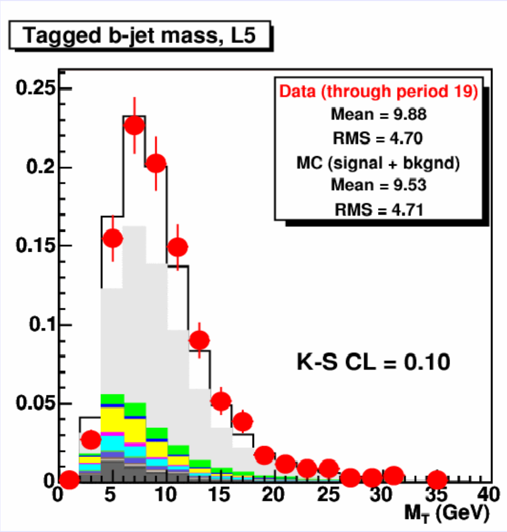



S0-pro

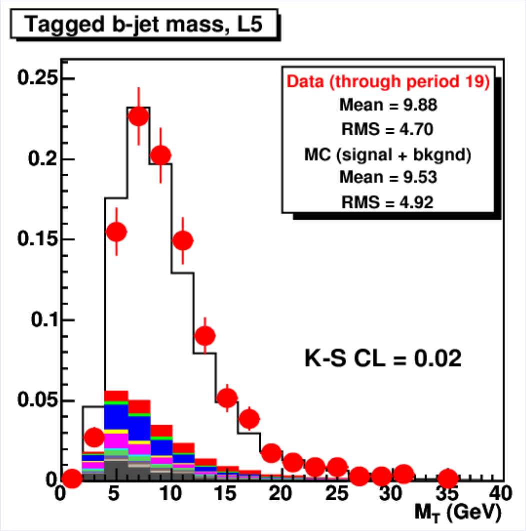



Comment: Luminosity profile for the S0 files is not correct

ACR-pro

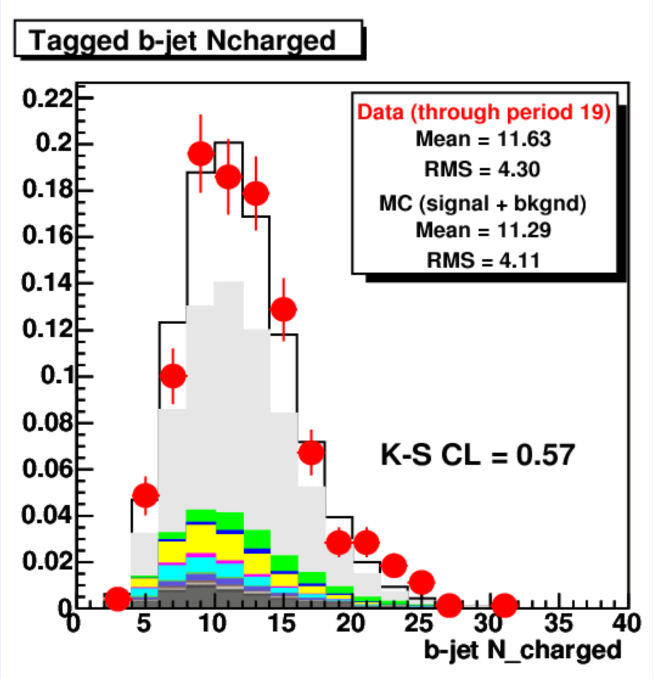


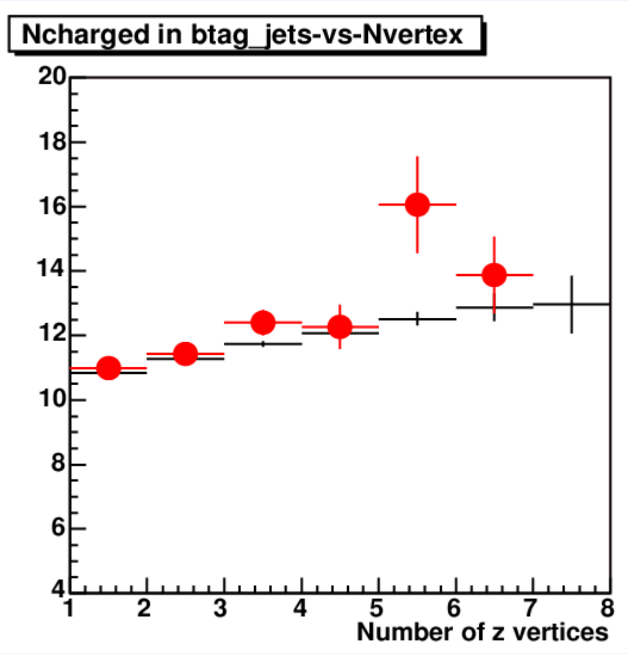

S0-Perugia0



# Charged tracks in tagged b-jets

Expect large dependence on luminosity. V6.2 tune AV does well



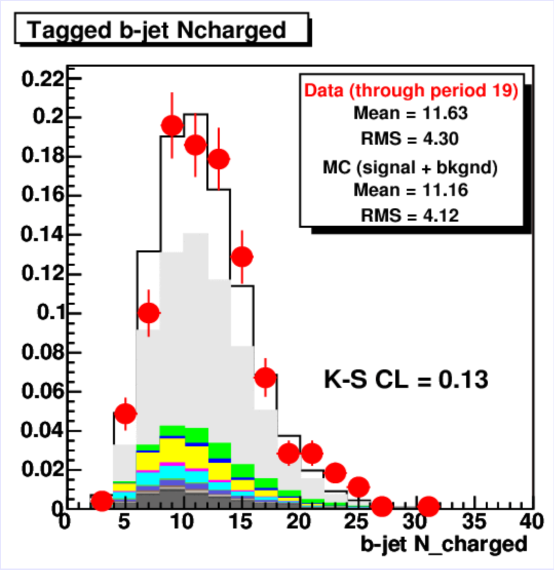




KS values for other samples:

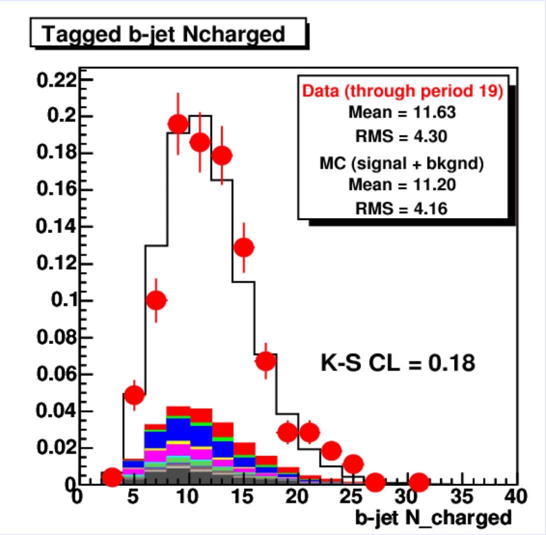
| Aprolhl | ACRlhl | S0pro | NOCRPg0 | S0Pg0 |
|---|---|---|---|---|
| 0.13 | 0.84 | 0.20 | 0.18 | 0.30 |

# N charged Particles

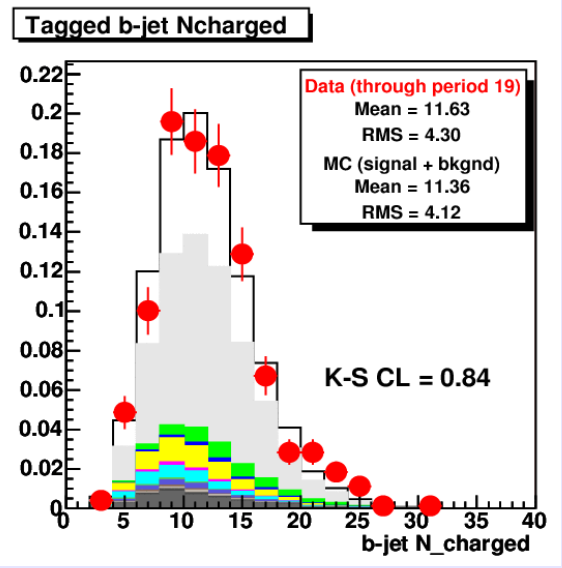
A-pro



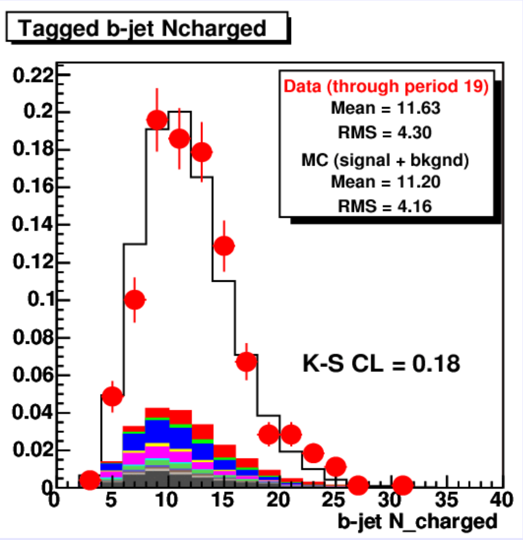

S0-pro




ACR-pro




S0-Perugia0




Comment: Luminosity profile for the S0 files is not correct

# Jet Shapes:moments

The eta and phi moments are sensitive to the width of the parton shower. We use calorimeter (both electromagnetic and hadronic components) information to evaluate the moments

We sum over all towers:

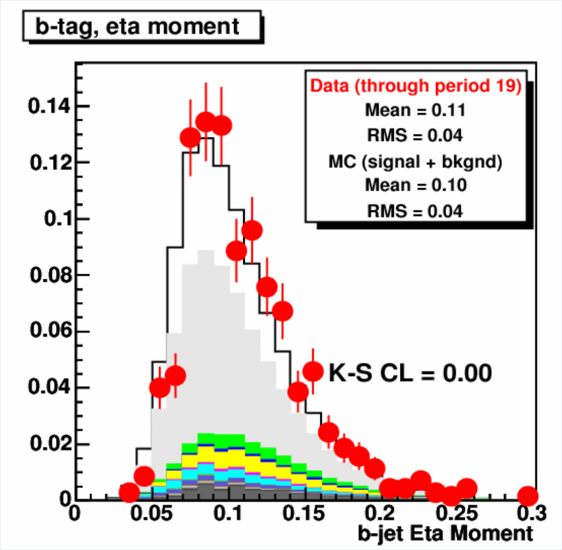
$$M_\eta \equiv \sqrt{\sum_{towers} \frac{E_T^{tower}}{E_T^{jet}} \eta^2_{tower} - \eta^2_{jet}}$$

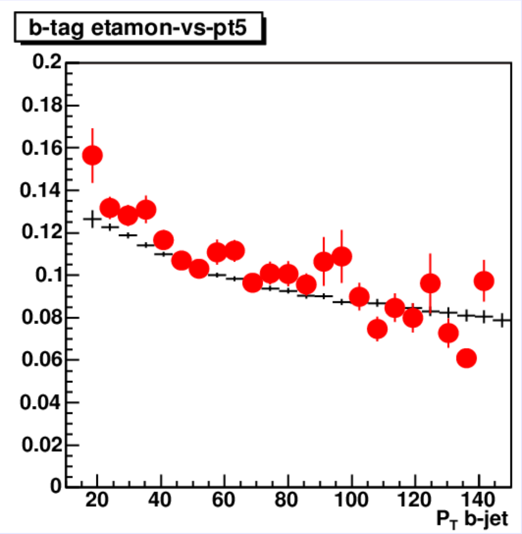
And similar expression for the phi moments,

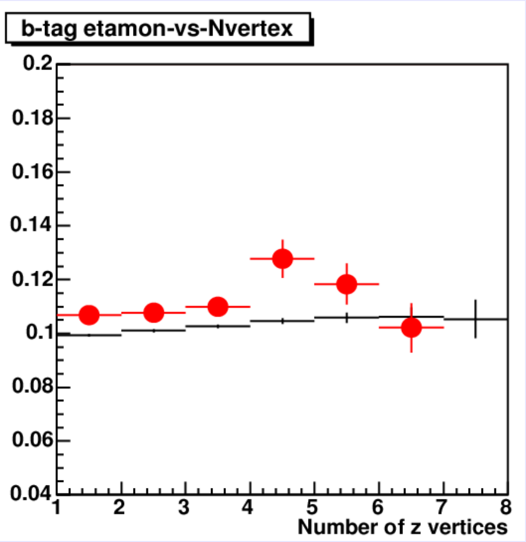
Used in CDF to distinguish quark jets from gluon jets in ttbar production in the 6 jets topology

# Eta Moments for b-tagged jets

PYTHIA V6.2 , our default is shown here. As noted by Andrea and Hyunsu, they do not fit the data. Here we have not normalize to PT=50 GeV, as the PT distributions for data and MC agree quite well.



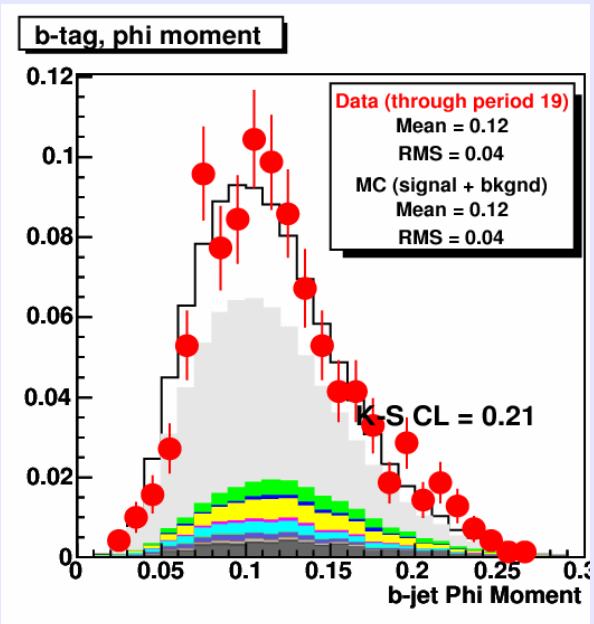

The Moment dependence on PT(jet) is in clear disagreement with the data and very likely is at the origin of the disagreement on the left.

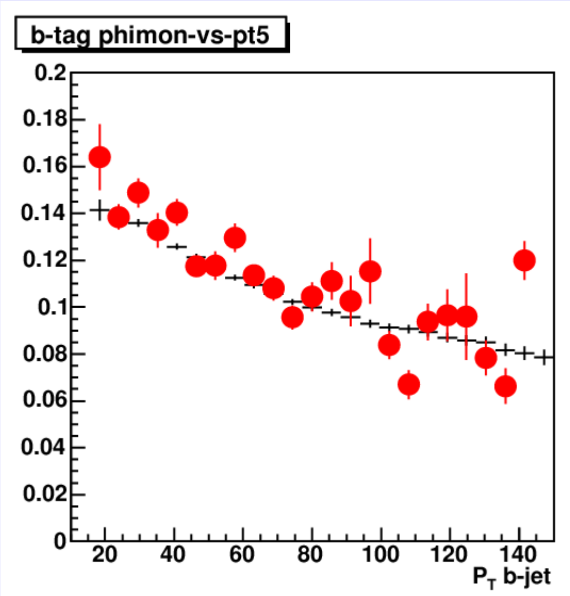
KS values for other samples:

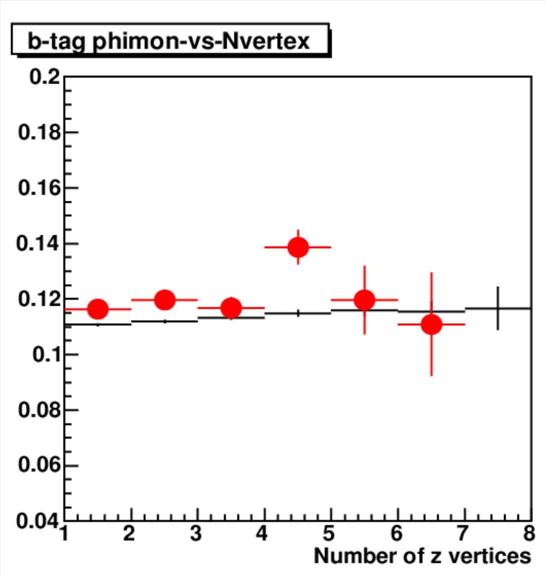
| APROlhl | ACRlhl | S0-Pg0 | NOCR-Pg0 | S0-pro |
|---|---|---|---|---|
| 0.00 | 0.01 | 0.00 | 0.00 | 0.00 |

# PHI Moments for b-tagged Jets

The Moment dependence on PT(jet) has a better agreement with the data than the eta moment of the previous page. This is reflected in the KS value.




KS values for other samples:

| AproIhI | ACRIhI | S0pro | S0Pg0 | NOCRPg0 |
|---|---|---|---|---|
| 0.10 | 0.47 | 0.37 | 0.26 | 0.24 |

# Summary

Top Mass systematics depend on the Version of PYTHIA and Tunes used.

We have looked at a number of variables to explore the possibility to distinguish between different PYTHIA tunes by making comparisons with the b-tagged jet data.

The top Mass, N(charged), Eta Moment and Phi Moment seem to be possible variables to use.

We have used 698 b-tagged jets in l+jets with Ntight=4. Adding the N(tight)=3 will help.

It is not clear on how to choose between the different tunes as none of the ones considered fair well on all of these variables. We need to do additional work to understand the situation.

Additional studies are being done in CDF
- quark jet shapes in di-jets events
- b-jet studies in di-jet events

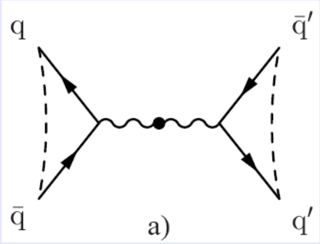
Backup slides

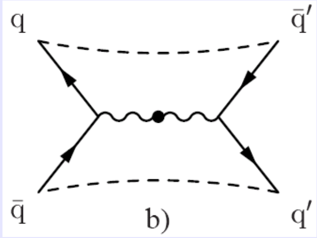
# Color Reconnection Systematics

Strong color correlations between the hard process and the underlying event are implied by tune A and similar tunes. These effects may be interpreted as sign for color reconnection.

The issue has been studied at LEP for the W mass measurement

## LEP




CR effects on the $M_W$ measurement at LEP contribute to systematics

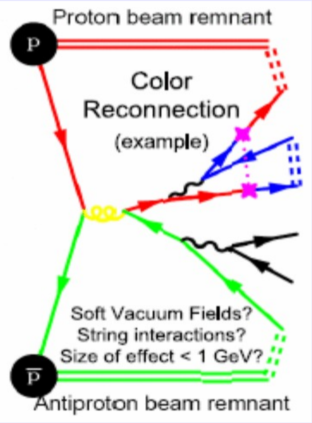
CR(sys) = 8 MeV

out of 22 MeV (total sys)

(LEPEWWG hep-ex/061203)

## Tevatron

Preliminary MC studies have indicated possible contributions to the top mass systematics of order



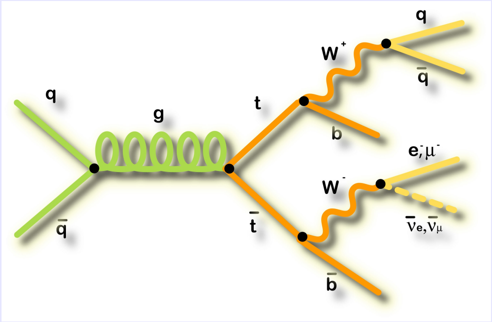

CR(sys)≈ 0.5 GeV

D. Wicke and P. Skands arXiv:0807.3248V1

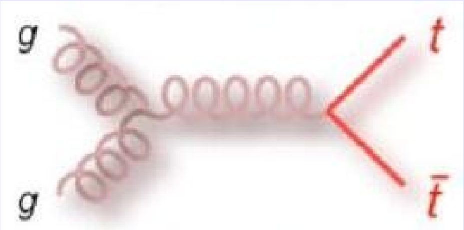
# L+jets:Sample Composition

- Event Selection
  - Isolated lepton, $P_T$ > 20 GeV
  - MET > 20 GeV (neutrino)
  - N (jets): only 4 jets with $E_T$ >20 GeV
  - ≥1 b-tag by the SVX algorithm
- Background :
  - Mistag in W+light quarks
  - non-W QCD
  - Physics background: Wbb, Wcc
  - Single top, WW, WZ etc.

~85%




~15%




| Background | 1 b-tag | ≥ 2 b-tags |
|---|---|---|
| non-$W$ QCD | 13.8 ± 11.5 | 0.5 ± 1.5 |
| $W$+q(mistag)+WW,WZ,ZZ | 21.8 ± 3.6 | 0.8 ± 0.1 |
| $W + b\bar{b}, c\bar{c}, c$ | 26.1 ± 10.2 | 3.4 ± 1.4 |
| Single top | 3.0 ± 0.2 | 0.9 ± 0.1 |
| Total background | 64.7 ± 16.3 | 5.5 ± 2.6 |
| Predicted $t\bar{t}$ signal | 182.6 ± 24.6 | 69.4 ± 11.2 |
| Events observed | 284 | 87 |

In 1.9 fb-1 find 371 events

Estimated background:

70 ± 17 events

But: are these events

only top+SM background?

# Top Mass Measurement ME(1)

- For each event we evaluate a likelihood as a function of the top mass and $\Delta_{JES}$ (related to the jets momenta measurements)
- All possible jet permutations are included with weights = wi.

$$L(\vec{y}\,|\,m_t, \Delta_{\rm JES}) = \frac{1}{N(m_t)}\frac{1}{A(m_t, \Delta_{\rm JES})}\sum_{i=1}^{24} w_i L_i(\vec{y}\,|\,m_t, \Delta_{\rm JES})$$

measured quantities | normalization | acceptance | 24 Permutations

$$L_i(\vec{y}\,|\,m_t, \Delta_{\rm JES}) = \int \frac{f(z_1)f(z_2)}{FF}\,{\rm TF}(\vec{y}\,|\,\vec{x}, \Delta_{\rm JES})\,|M(m_t, \vec{x})|^2\,d\Phi(\vec{x})$$

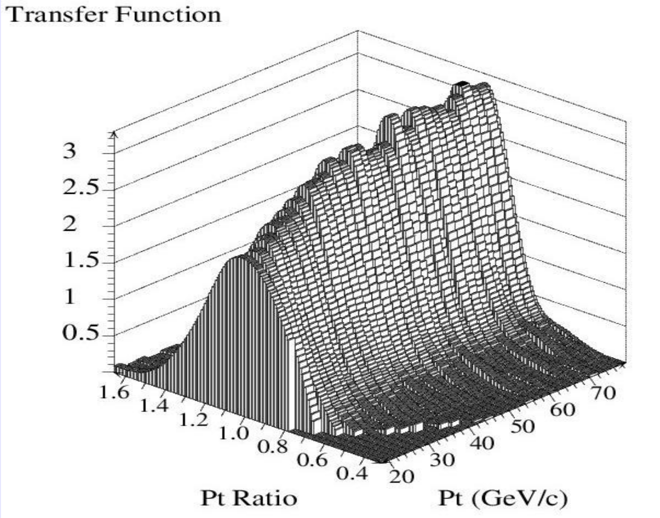
Incoming partons | Transfer functions | parton level quantities

- We integrate over phase space (d Φ) and Matrix Element (M) for t t production and decay.

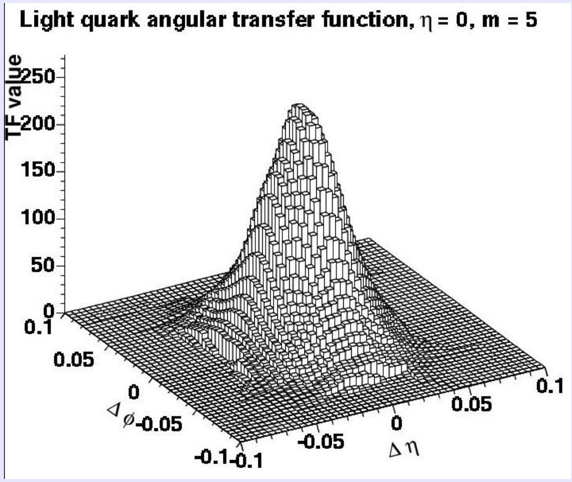
# Top Mass: Transfer Functions (2)

- The transfer functions for a given parton x, give the probability that we observe y. Detector effects, resolutions etc. are included
- Both angular and $P_T$ transfer functions are used
- Multiplied by efficiency for proper normalization
- Transfer functions depend on jet mass as well as on $P_T$ (in $\eta$ bins). Also they are evaluated for 25 values of $\Delta_{JES}$.

$P_T$ ratio= $P_T$(jet)/$P_T$(q)




$P_T$(q)=40 GeV, $m_{jet}$=30 GeV



# Top Mass : integration (3)

- From 32 parameters in

  $z_1 + z_2 = q\ q'\ b_1 + lep\ \nu\ b_2$,

  assumptions on incoming partons, lepton masses, charged lepton P and energy-momentum conservation leave a 19-dimensional integration, performed by Quasi-Monte Carlo method.
- Integration variables:

  $M_1^2$ and $M_2^2$ , the hadronic and leptonic top mass squared

  $m_1^2$ and $m_2^2$ , the hadronic and leptonic W mass squared

  $\beta = \log(\rho_q/\rho_{q'})$ , log of ratio of momenta of the two q from W

  $P_T$(t t), priors from MC

  $\Delta\eta$ (parton-jet) , $\Delta\Phi$ (parton-jet) for each jet.

  Mass of each p-jet. All jet priors from MC

# In Situ JES calibration (4)

- Likelihood parameters are $m_t$ and $\Delta_{JES}$
- We shift each jet by the factor

$$JES = 1 + \Delta_{JES} \times \sigma_{JES}(p_T,\eta)$$

where $\sigma_{JES}(p_T,\eta)$ is the systematic uncertainty on the jet $p_T$

- $\Delta_{JES}$ is determined using the decay

$$W \rightarrow j_1 j_2$$

and using the measured value for the W mass

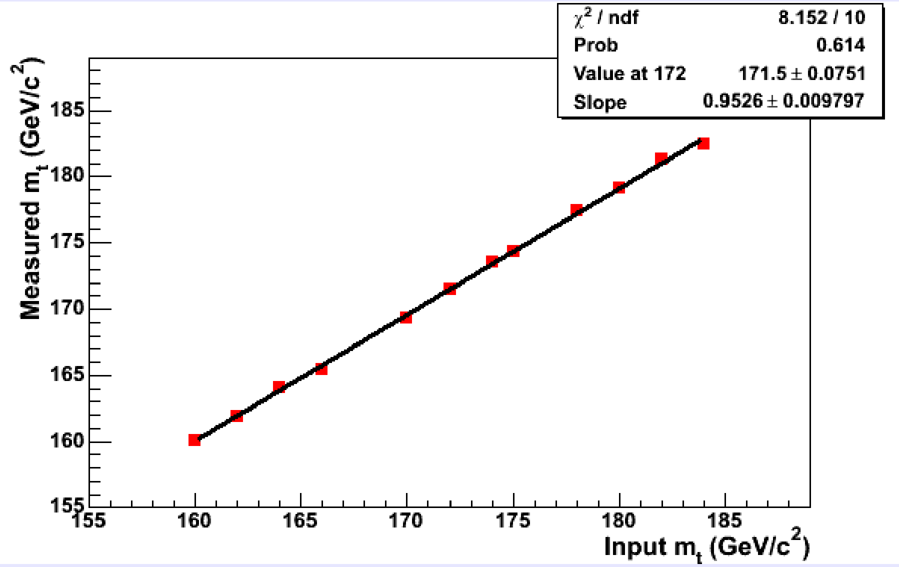
- Precision on $\Delta_{JES}$ is determined by the statistics we have, thus a systematics uncertainty is now a statistical one

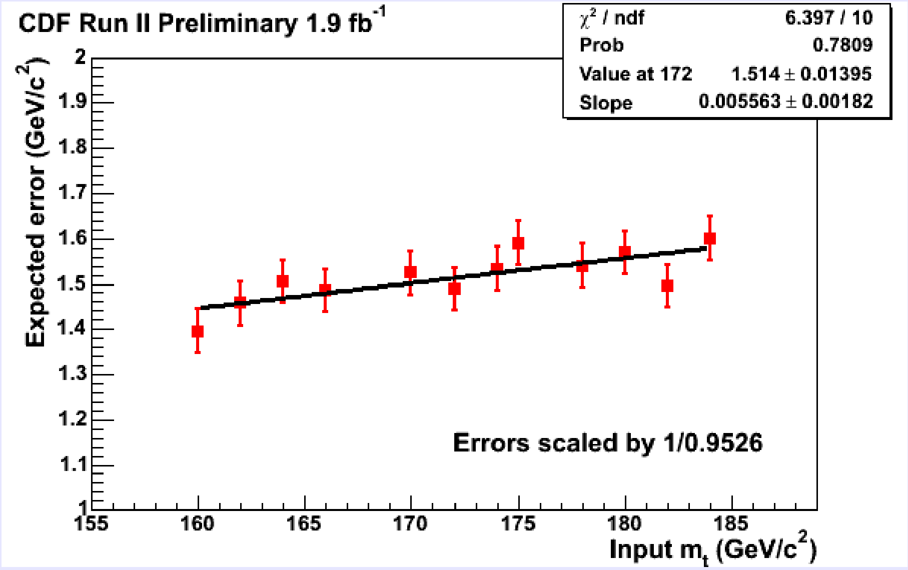
# Top Mass: MC Calibration(5)

We use 12 mass point between 160 and 185 GeV/$c^2$ to calibrate the method

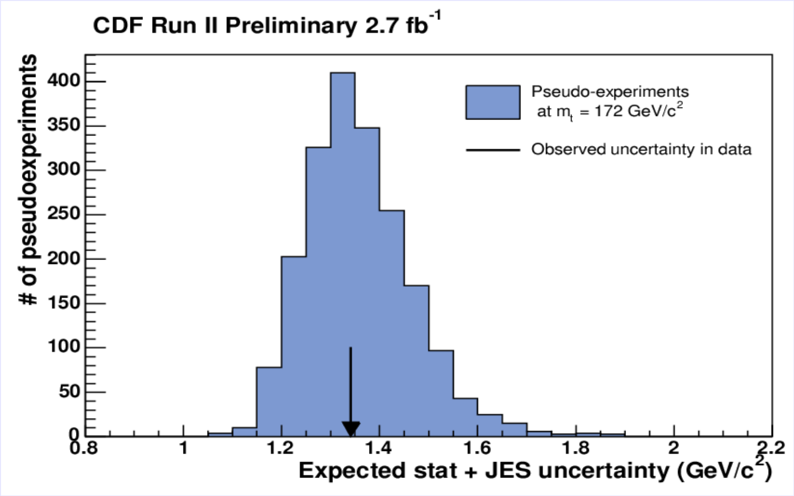
$M_{meas}$ =( 0.953± 0.009) □ $m_{input}$

δm(172)=1.5 GeV/$c^2$

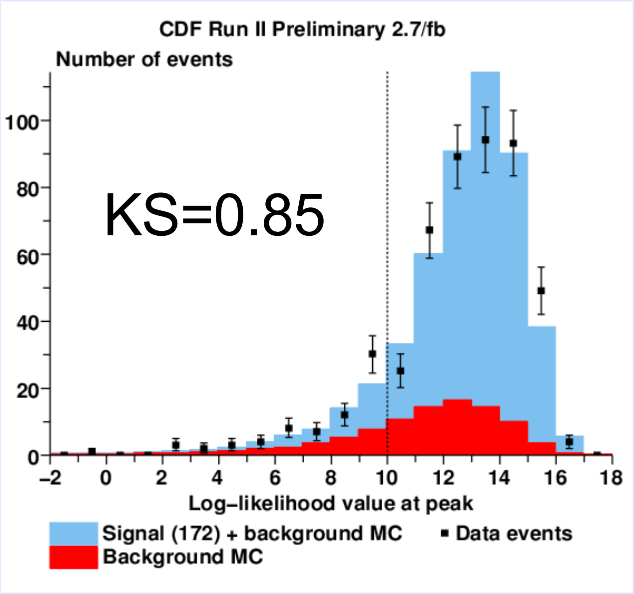


# Top Mass Results (6)




Expected uncertainty distribution from MC. The arrow shows the uncertainty for the data sample (422 events). 49% of the pseudoexperimets are below the arrow.




The peak of the likelihood for each MC events compared with the distribution for the 494 events. We cut the likelihood at a value of 10 to reduce background and badly reconstructed events