STUDY of PYTHIA TUNES with CDF JET SHAPES

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Thanks to Peter Skands for his guidance in these studies

Motivation
MC and data comparison
light quarks and gluons
W-> jet jet and Jet Energy scale
b-jets studies

Summary
Motivation of this study: Systematic uncertainties from MC

Precision measurements which have low statistical error, are dominated by systematic uncertainties with large contributions from Monte Carlo modeling. This is the case for the top mass measurement at the Tevatron.

World Average

\[ M_{\text{top}} = 173.1 \pm 0.6 \text{(stat)} \pm 1.1 \text{(syst)} = 173.1 \pm 1.3 \text{ GeV} \]

New CDF result (MTM, to be included in the world average)

\[ M_{\text{top}} = 172.8 \pm 0.7 \text{(stat)} \pm 0.7 \text{ (MC sys)} \pm 0.8 \text{ (syst)} = 172.8 \pm 1.3 \text{ GeV} \]

Statistical uncertainties can be reduced with more data
Other systematics come from detector effects, background uncertainties, analysis methodology
MC systematics: this is the subject of this workshop
CDF analyses (including the top mass analysis) are done mostly using PYTHIA V6.2.16

Changes in V6.4.20 with respect to V6.2.16

- Parton shower uses $P_T$ ordering rather than mass ordering
- Multiparton (MPI) interactions are part of the parton shower
- ISR and FSR also use $P_T$ ordering algorithm
- New model for beam remnants, including baryon junctions
- Model interleaves MPI process with ISR evolution off the hard process
- Color reconnection added with an “annealing model” by M. Sandhoff and P. Skands
Compare PYTHIA V6.2 and V 6.4

All of the above changes are expected to have an effect on the top mass measurement of the order of 1 GeV. See references below

- D. Wicke and P. Skands TOP08 (May 2008)

➢ Color Reconnection (CR) expected to contribute to top mass shift

➢ Jet Shapes expected to be different

➢ Tunes being investigated (used for the top mass analysis)
  - A-pro : Rick Field's tune A (just submitted to PRD) retuned with the “professor” tools
  - ACR-pro : as above with color reconnection added
  - Perugia0 : includes the new parton shower + CR
    - Peter Skands tune 320, includes TeV min bias info +\(P_T(Z)\)
  - NOCR : as Perugia0 without CR
CDF has published jet shapes, obtained in pp collision at 1.96 TeV. Jets are reconstructed using a cone-based midpoint algorithm with a cone of 0.7. The jet shapes are corrected to the hadron level (PRD 71, 112002, 2005).

Evaluate fractional $P_T$ in subsequent annuli as a function of the radius

Integrate over a radius $r$ in different $P_T(jet)$ bins

$$\Psi(r) = \int_0^r \frac{p_T(r')}{p_T^{jet}} \, dr' = \frac{1}{N_{jets}} \sum_{jets} \frac{p_T(0, r)}{p_T(0, R)}$$

Jets Composition: ~30% quarks at low $P_T$, ~80% quarks at high $P_T$
QCD JET SHAPES (2)

We compare here data with 4 tunes of PYTHIA V6.4.20

Tune A-pro and Tune ACR-pro fit the data very well
Tune Perugia0 and Tune Pg0-NOCR have narrower jets

\[ P_T = 37-45 \text{ GeV/c} \quad \text{and} \quad P_T = 229-250 \text{ GeV/c} \]
Jet $P_T$ dependence of $F(OOC) = 1 - \psi(r)$ for $r=0.3$.

$F(OOC) = P_T$ fraction outside of cone of 0.3

Perugia0 has narrower jets for $P_T < 100$ Gev/c

The color reconnection term has negligible effect on jet shapes

This should be Perugia0
Comparison of older tunes with data
Tune S0-pro and corresponding NOCR show larger discrepancy with the data. Minbias data added for the Perugia0 tune.
QCD JET SHAPES: MORE TUNES

PYTHIA V6.4 tune A
PYTHIA V6.4 tune A-pro
PYTHIA V6.4 tune D6T: Rick Field's tune (less ISR, more MPI)
HERWIG with Jimmy

$P_T = 37-45 \text{ GeV/c}$

$PT= 229-250 \text{ GeV/c}$

Difference between these tunes are very small
More PYTHIA tunes and HERWIG

- None of the tunes fits the data perfectly

- HERWIG seems to fit the data better below 100 GeV, where most of the jets in top events are.
Summary of QCD jet studies

➢ The latest PYTHIA V6.4 tunes have been compared with CDF data, i.e., jets with radius=0.7 obtained with a cone based mid-point algorithm

➢ Integrated jet shapes as a function of radius are compared to new and old PYTHIA tunes and with HERWIG+Jimmy

➢ Tune Perugia0 (which uses $P_T$ ordered showers) predicts narrower jets below 100 GeV/c

➢ Effects of Color reconnection are negligible

Plan:
Study jets in e+e- to separate the effects of UE, MPI, CR, ISR, from effect due to the new parton shower
Include these data in future tuning
Studies of New Tunes in Top events

\[ t \bar{t} \rightarrow W^+ b W^- \bar{b} \] sample used to measure the top mass

\[ W \rightarrow l \nu \]

\[ W \rightarrow q \bar{q}' \]

Events in the lepton + jets topology (832 events)
4 jets with \( P_T > 20 \text{ GeV} \), \( \geq 1 \) b-tag (1000 b-jets)
Background: 21%

2D likelihood with top mass and jet energy scale as variables.
JES calibration in “situ”, constraint of \( M_{jj} \) to \( M_W \)

Is the event topology with PYTHIA V6.4 different from that of V6.2?
What do we learn about jets?
Comparison at the event level

Given a MC sample of lepton + jets top events, we can match the simulated jets with the initial partons. The algorithm uses only the $\Delta R$ between the parton and the jets, calculates an overall $\chi^2$ for the event and applies some $\chi^2$ cut. (Used by the MTM mass analysis).

- For “good match” we find:
  - V6.2 (tune A) 68%
  - V6.4 ACR 68%
  - V6.4 NOCR-Pg0 59%
  - V6.4 Perugia0 59%

- The N(jet) distribution is not very different, but the topology for the new tunes is different. More ISR/FSR?
Reconstructed $M_W$ and $M(\text{top})$ using the matched jets

$172.5 \text{ GeV}(6\text{M ev.})$

Perugia0 - Nominal

$\Delta M_W = +0.73 \pm 0.05$

$\Delta M_{\text{top}} = -0.44 \pm 0.08$

The quark jets of the Perugia0 tune have too much energy in the cone, which confirms our earlier observation.

The $b$-jets have less energy in the cone than PYTHIA V6.2
Determination of $\Delta_{\text{JES}}$

2D likelihood determination of the top mass, provides a value for $\Delta_{\text{JES}}$. This is related to the systematic uncertainty of the jet Energy Scale. Each jet is divided by a factor

$$F = 1 + \Delta_{\text{JES}} \cdot \sigma(P_T)$$

Calibration of the method uses PYTHIA V6.2

Note that the OOC systematic is $\sim$50% of $\sigma(P_T)$. It comes from MC

Linear relationship between input and reconstructed mass
Using the methodology of the MTM analysis the constraint imposed on $M_{jj}$ requires a $\Delta_{JES}$ of 0.32 for the new tunes, but also 0.26 for ACR-pro.

<table>
<thead>
<tr>
<th>Sample</th>
<th>$\Delta m_t$ (GeV/$c^2$)</th>
<th>$\Delta_{JES}$ $\sigma$</th>
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<tbody>
<tr>
<td>V6.2 (nominal)</td>
<td>–</td>
<td>0.11±0.03</td>
</tr>
<tr>
<td>V6.4 A-pro</td>
<td>-0.02±0.18</td>
<td>0.08±0.03</td>
</tr>
<tr>
<td>V6.4 ACR-pro</td>
<td>-0.39±0.18</td>
<td>0.26±0.03</td>
</tr>
<tr>
<td>V6.4 NOCR-pro</td>
<td>-1.36±0.23</td>
<td>0.33±0.04</td>
</tr>
<tr>
<td>V6.4 Perugia0</td>
<td>-1.29±0.23</td>
<td>0.32±0.04</td>
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All jet momenta are reduced by a factor 1.32 in the Perugia0 tune. This gives a top mass shift in excess of the 0.44 GeV seen earlier.

Other component is the fact that the topology has changed, less events with parton-jets matching.

Systematics from color reconnection is taken to be $(ACR(pro)-A(pro))=0.37 \pm 0.25$ GeV.
What can we learn from b-jets in top events? Compare Number of charged tracks in a cone of 0.4.

- PYTHIA V6.2 compared with ACR-pro, Perugia0, HERWIG. Tune ACR and Perugia0 have less charged particles in the cone than tune A in PYTHIA V6.2 (as expected from the $\Delta_{JES}$ result)

- We need more information on b-jets at hadron colliders
We have compared jet shapes obtained in di-jet events (quark and gluon jets) with some PYTHIA V6.4 tunes expectations.

We find that the Perugia0 tune does not fit the data as well as tune A. Jets have more energy in the cone of 0.4, i.e., they are narrower. A small change in the parameters moves the jet shapes considerably.

Precision measurements like the top mass measurement are now limited by systematic uncertainties. The contribution from MC is quite large (0.73 out of 1.05).

Constraining the $M_{jj}$ to the W mass helps reducing the systematics. This constraint requires reducing the jet energies in Perugia0 by 1%.

Color Reconnection effects contribute 0.37 GeV.

The Perugia0 tune results in a large negative shift of the top mass. N(charged) in the cone for Perugia0 are less than for default PYTHIA and HERWIG, as expected from the mass shift.
Backup slides
Pythias Underlying Event Models

- Old: UE generated after the ISR is done, i.e. uncorrelated.
- New: Parton showers interleaved with UE. (Requires $p_T$ ordered shower).

\[
\frac{dP}{dp_{\perp}} = \left( \frac{dP_{\text{MI}}}{dp_{\perp}} + \sum \frac{dP_{\text{ISR}}}{dp_{\perp}} + \sum \frac{dP_{\text{II}}}{dp_{\perp}} \right) \times \exp \left( - \int_{p_{\perp}}^{p_{\perp,1}} \left( \frac{dP_{\text{MI}}}{dp_{\perp}'} + \sum \frac{dP_{\text{ISR}}}{dp_{\perp}'} + \sum \frac{dP_{\text{II}}}{dp_{\perp}'} \right) dp_{\perp}' \right)
\]

- successive "fininggraining" of all perturbative activity
  - correlated multiparton pdfs (with flavour/momentum cons)
  - Impact parameter dependence
  - String fragmentation developed for baryonic colour topologies
    improved description of beam remn.

Daniel Wicke, Non-perturbative QCD and Top Mass, Modelling

Top2008, La Biodola, Elba, 18–24 May 2008

Study of PYTHIA tunes in V6.4.20 with CDF Jet Shapes - Lina Barbaro Galtieri, MC4LHC 29-3-2010
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

<table>
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<th>Tevatron</th>
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<td>CR effects on the ( M_W ) measurement at LEP contribute to systematics</td>
<td>Preliminary MC studies have indicated possible contributions to the top mass systematics of order</td>
</tr>
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<td>( \text{CR(sys)} = 8 \text{ MeV} )</td>
<td>( \text{CR(sys)} \approx 0.5 \text{ GeV} )</td>
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<tr>
<td>out of 22 MeV (total sys)</td>
<td>(LEPEWWG hep-ex/061203)</td>
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We find the following Color Reconnection values:
- $-0.37 \pm 0.18 \text{ GeV}$ from A-pro - CR
- $+0.07 \pm 0.27 \text{ GeV}$ from Pg0 - NOCR

The Perugia0 tune gives $\Delta M_{\text{top}} = -1.3 \text{ GeV}$
this is related to different jet shapes, i.e., different p-shower
and different topology (more ISR)

Present systematics from MC
- generator: $\Delta(m_t) = 0.25 \text{ GeV}$ (HERWIG-PYTHIA)
- ISR/FSR: $\Delta(m_t) = 0.15 \text{ GeV}$
- Jets (OOC+JES): $\Delta(m_t) = 0.43 \text{ GeV}$
- b-jets: $\Delta(m_t) = 0.16 \text{ GeV}$
- Color reconnection: $\Delta(m_t) = 0.37 \text{ GeV}$

that is, MC related systematics (0.73 GeV)