The Universality of PYTHIA Tune A

We would like to have a “universal” tune of PYTHIA!
- QCD Hard Scattering
- Direct Photon Production
- Z-Boson Production
- Heavy Flavor Production

Outline of Talk

Review of PYTHIA Tune A (tuned on CDF Run 1 data).
Show some comparisons with CDF Run 2 data.
Discuss the progress toward a “universal” tune.
- Must specify PDF!
- Must specify MPI parameters!
- Must specify Q^2 scale!
- Must specify intrinsic kT!
Look at charged particle correlations in the azimuthal angle $\Delta \phi$ relative to the leading calorimeter jet ($\text{JetClu R} = 0.7$, $|\eta| < 2$).

Define $|\Delta \phi| < 60^\circ$ as “Toward”, $60^\circ < -\Delta \phi < 120^\circ$ and $60^\circ < \Delta \phi < 120^\circ$ as “Transverse 1” and “Transverse 2”, and $|\Delta \phi| > 120^\circ$ as “Away”. Each of the two “transverse” regions have area $\Delta \eta \Delta \phi = 2 \times 60^\circ = 4\pi/6$. The overall “transverse” region is the sum of the two transverse regions ($\Delta \eta \Delta \phi = 2 \times 120^\circ = 4\pi/3$).
PYTHIA: Multiple Parton Interaction Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>MSTP(81)</td>
<td>0</td>
<td>Multiple-Parton Scattering off</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>Multiple-Parton Scattering on</td>
</tr>
<tr>
<td>MSTP(82)</td>
<td>1</td>
<td>Multiple interactions assuming the same probability, with an abrupt cut-off PT_{min}=PARP(81)</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>Multiple interactions assuming a varying impact parameter and a hadronic matter overlap consistent with a single Gaussian matter distribution, with a smooth turn-off PT_{0}=PARP(82)</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>Multiple interactions assuming a varying impact parameter and a hadronic matter overlap consistent with a double Gaussian matter distribution (governed by PARP(83) and PARP(84)), with a smooth turn-off PT_{0}=PARP(82)</td>
</tr>
</tbody>
</table>

Pythia uses multiple parton interactions to enhance the underlying event.

Multiple parton interaction more likely in a hard (central) collision!

and now HERWIG!

Jimmy: MPI
J. M. Butterworth
J. R. Forshaw
M. H. Seymour

Proton AntiProton
Underlying Event

Underlying Event

PT(hard)
PYTHIA uses multiple parton interactions to enhance the underlying event.

Pythia uses multiple parton interactions to enhance the underlying event.

**Parameter** | **Value** | **Description**
--- | --- | ---
MSTP(81) | 0 | Multiple parton interaction more likely in a hard (central) collision!
1 | Multiple interactions assuming the same probability, with an abrupt cut-off $P_T^{min}=\text{PARP}(81)$
MSTP(82) | 1 | Multiple interactions assuming a varying impact parameter and a hadronic matter overlap consistent with a single Gaussian matter distribution, with a smooth turn-off $P_T^0=\text{PARP}(82)$
 | 3 | Multiple interactions assuming a varying impact parameter and a hadronic matter overlap consistent with a double Gaussian matter distribution (governed by $\text{PARP}(83)$ and $\text{PARP}(84)$), with a smooth turn-off $P_T^0=\text{PARP}(82)$
5 | Multiple interactions assuming a varying impact parameter and a hadronic matter overlap consistent with a smooth turn-off $P_T^0=\text{PARP}(82)$

Note that since the same cut-off parameters govern both the primary hard scattering and the secondary MPI interaction, changing the amount of MPI also changes the amount of hard primary scattering in PYTHIA Min-Bias events!
## Tuning PYTHIA: Multiple Parton Interaction Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Default</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>PARP(83)</td>
<td>0.5</td>
<td>Double-Gaussian: Fraction of total hadronic matter within PARP(84)</td>
</tr>
<tr>
<td>PARP(84)</td>
<td>0.2</td>
<td>Double-Gaussian: Fraction of the overall hadron radius containing the fraction PARP(83) of the total hadronic matter.</td>
</tr>
<tr>
<td>PARP(85)</td>
<td>0.33</td>
<td>Probability that the MPI produces two gluons with color connections to the “nearest neighbors.”</td>
</tr>
<tr>
<td>PARP(86)</td>
<td>0.66</td>
<td>Probability that the MPI produces two gluons either as described by PARP(85) or as a closed gluon loop; the remaining fraction consists of quark-antiquark pairs.</td>
</tr>
<tr>
<td>PARP(89)</td>
<td>1 TeV</td>
<td>Determines the reference energy $E_0$.</td>
</tr>
<tr>
<td>PARP(90)</td>
<td>0.16</td>
<td>Determines the energy dependence of the cut-off $P_{T0}$ as follows $P_{T0}(E_{cm}) = P_{T0}(E_{cm}/E_0)^\varepsilon$ with $\varepsilon = PARP(90)$</td>
</tr>
<tr>
<td>PARP(67)</td>
<td>1.0</td>
<td>A scale factor that determines the maximum parton virtuality for space-like showers. The larger the value of PARP(67) the more initial-state radiation.</td>
</tr>
</tbody>
</table>

### $\varepsilon$ Values

- $\varepsilon = 0.16$ (default)
- $\varepsilon = 0.25$ (Set A)

### Additional Information

- **Hard Core**: Affects the amount of initial-state radiation!
- **Multiplies $Q^2$ scale (for some processes)**!
- **Reference point at 1.8 TeV**
- **Determines $E_0$ by comparing with 630 GeV data!**

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**Fermilab MC Workshop**
June 11, 2004

Rick Field - CDF/Florida
Plot shows the “Transverse” charged particle density versus $P_T(chg\text{jet#1})$ compared to the QCD hard scattering predictions of PYTHIA 6.206 ($P_T(\text{hard}) > 0$) using the default parameters for multiple parton interactions and CTEQ3L, CTEQ4L, and CTEQ5L.

Default parameters give very poor description of the “underlying event”!

Note Change
PARP(67) = 4.0 ($< 6.138$)
PARP(67) = 1.0 ($> 6.138$)
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Tune B</th>
<th>Tune A</th>
</tr>
</thead>
<tbody>
<tr>
<td>MSTOP(81)</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>MSTOP(82)</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>PARP(82)</td>
<td>1.9 GeV</td>
<td>2.0 GeV</td>
</tr>
<tr>
<td>PARP(83)</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>PARP(84)</td>
<td>0.4</td>
<td>0.4</td>
</tr>
<tr>
<td>PARP(85)</td>
<td>1.0</td>
<td>0.9</td>
</tr>
<tr>
<td>PARP(86)</td>
<td>1.0</td>
<td>0.95</td>
</tr>
<tr>
<td>PARP(89)</td>
<td>1.8 TeV</td>
<td>1.8 TeV</td>
</tr>
<tr>
<td>PARP(90)</td>
<td>0.25</td>
<td>0.25</td>
</tr>
<tr>
<td>PARP(67)</td>
<td>1.0</td>
<td>4.0</td>
</tr>
</tbody>
</table>

Plot shows the “Transverse” charged particle density versus $P_T$ (charged jet#1) compared to the QCD hard scattering predictions of two tuned versions of PYTHIA 6.206 (CTEQ5L, Set B (PARP(67)=1) and Set A (PARP(67)=4)).

Old PYTHIA default (more initial-state radiation)

New PYTHIA default (less initial-state radiation)
Predictions of PYTHIA 6.206 (CTEQ5L) with PARP(67)=1 (new default) and PARP(67)=4 (old default) for the azimuthal angle, $\Delta \phi$, between a b-quark with $P T_1 > 15$ GeV/c, $|y_1| < 1$ and bbar-quark with $P T_2 > 10$ GeV/c, $|y_2| < 1$ in proton-antiproton collisions at 1.8 TeV. The curves correspond to $d\sigma/d\Delta \phi (\mu b/\circ)$ for flavor creation, flavor excitation, shower/fragmentation, and the resulting total.
Predictions of HERWIG 6.4 (CTEQ5L) for the azimuthal angle, $\Delta \phi$, between a b-quark with $P_T_1 > 15 \text{ GeV/c}$, $|y_1| < 1$ and bbar-quark with $P_T_2 > 10 \text{ GeV/c}$, $|y_2| < 1$ in proton-antiproton collisions at 1.8 TeV. The curves correspond to $d\sigma/d\Delta \phi (\mu b/\text{rad})$ for flavor creation, flavor excitation, shower/fragmentation, and the resulting total.
Predictions of PYTHIA 6.158 (CTEQ5L) with PARP(67)=1 (new default) and PARP(67)=4 (old default) for diphoton system PT and the azimuthal angle, $\Delta \phi$, between a photon with $P_T_1 > 12$ GeV/c, $|y_1| < 0.9$ and photon with $P_T_2 > 12$ GeV/c, $|y_2|< 0.9$ in proton-antiproton collisions at 1.8 TeV compared with CDF data.
Tuned PYTHIA 6.206
“Transverse” $P_T$ Distribution

Compares the average “transverse” charge particle density ($|\eta|<1$, $P_T>0.5$ GeV) versus $P_T$(charged jet#1) and the $P_T$ distribution of the “transverse” density, $dN_{chg}/d\eta d\phi dP_T$ with the QCD Monte-Carlo predictions of two tuned versions of PYTHIA 6.206 ($P_T$(hard) > 0, CTEQ5L, Set B (PARP(67)=1) and Set A (PARP(67)=4)).
**Tuned PYTHIA 6.206 Run 1 Tune A**

**Charged Particle Density**

"Transverse" Charged Particle Density: \( \frac{dN}{d\eta d\phi} \)

CDF Run 1 data uncorrected
theory corrected

PYTHIA 6.206 Set A

- \( 1.8 \text{ TeV} \) | \( |\eta|<1 \text{ PT}>0.5 \text{ GeV} \)

CDF Min-Bias

"Transverse" Charged Particle Density

Describes the rise from "Min-Bias" to "underlying event"!

PYTHIA 6.206 Set A

CDF Run 1 data uncorrected
theory corrected

"Transverse" PT(chrgjet#1) > 5 GeV/c

"Transverse" PT(chrgjet#1) > 30 GeV/c

**Comparisons**

- Compares the average "transverse" charge particle density (|\( \eta \)|<1, \( P_T >0.5 \text{ GeV} \)) versus \( P_T \) (charged jet#1) and the \( P_T \) distribution of the "transverse" and "Min-Bias" densities with the QCD Monte-Carlo predictions of a tuned version of **PYTHIA 6.206** (\( P_T \) (hard) > 0, CTEQ5L, Set A).

- Describes "Min-Bias" collisions! Describes the "underlying event"!
Describes the rise from “Min-Bias” to “underlying event”!

“Transverse” Charged Particle Density: $\frac{dN}{d\eta d\phi}$

Compared the average “transverse” charge particle density ($|\eta|<1, P_T>0.5$ GeV) versus $P_T$(charged jet#1) and the $P_T$ distribution of the “transverse” and “Min-Bias” densities with the QCD Monte-Carlo predictions of a tuned version of PYTHIA 6.206 (P_T(hard) > 0, CTEQ5L, Set A). Describes “Min-Bias” collisions! Describes the “underlying event”!
PYTHIA (tune “A” and “B”) does a good job of describing both “min-bias” collisions and the “underlying event” in hard scattering processes in the Run I data.

PYTHIA (tune “A” or “B”) is the only “min-bias” generator that includes both “soft” and “hard” scattering.

Both ISAJET and HERWIG have the too steep of a $P_T$ dependence of the “beam-beam remnant” component of the “underlying event” and hence do not have enough beam-beam remnants with $P_T > 0.5$ GeV/c.

PYTHIA tune “A” is slightly favored over tune “B”, but eventually the best fit may be somewhere in between. The initial-state radiation in tune “A” with PARP(67) = 4 (used in all Run I simulations) looks more like HERWIG’s initial-state radiation.
Run 1 Summary

"Min-Bias" and the "Underlying Event"

PYTHIA (tune "A" and "B") does a good job of describing both "min-bias" collisions and the "underlying event" in hard scattering processes in the Run I data.

PYTHIA (tune "A" or "B") is the only "min-bias" generator that includes both "soft" and "hard" scattering.

Both ISAJET and HERWIG have the too steep of a PT dependence of the "beam-beam remnant" component of the "underlying event" and hence do not have enough beam-beam remnants with PT > 0.5 GeV.

PYTHIA tune "A" is slightly favored over tune "B", but eventually the best fit may be somewhere in between. The initial-state radiation in tune "A" with PARP(67) = 4 (used in all Run I simulations) looks more like HERWIG's initial-state radiation.

But does it work for all processes!

Upon my recommendation PYTHIA Tune A was chosen as the default parameterization in Run 2 at CDF!

But does it work for all processes!
Study the \( \Delta \phi \) distribution of the charged particle density, \( \frac{dN_{\text{chg}}}{d\eta d\phi} \), and the charged scalar \( p_T \) sum density, \( \frac{dP_T\text{sum}}{d\eta d\phi} \), for charged particles in the region \( p_T > 0.5 \text{ GeV/c}, |\eta| < 1 \).

Study the average charged particle and PTsum density in the “toward”, “transverse”, and “away” regions versus \( E_T(jet\#1) \).
Look at the “transverse” region as defined by the leading jet (JetClu R = 0.7, |η| < 2) or by the leading two jets (JetClu R = 0.7, |η| < 2). “Back-to-Back” events are selected to have at least two jets with Jet#1 and Jet#2 nearly “back-to-back” (Δφ_{12} > 150°) with almost equal transverse energies (E_T(jet#2)/E_T(jet#1) > 0.8).

Shows the Δφ dependence of the charged particle density, dN_{chg}/dηdφ, for charged particles in the range p_T > 0.5 GeV/c and |η| < 1 relative to jet#1 (rotated to 270°) for 30 < E_T(jet#1) < 70 GeV for “Leading Jet” and “Back-to-Back” events.
Shows the average charged particle density, $dN_{\text{chg}}/d\eta d\phi$, in the “transverse” region ($p_T > 0.5$ GeV/c, $|\eta| < 1$) versus $E_T(\text{jet#1})$ for “Leading Jet” and “Back-to-Back” events.

Compares the (uncorrected) data with PYTHIA Tune A and HERWIG after CDFSIM.
Charged Particle Density
PYTHIA Tune A vs HERWIG

HERWIG (without multiple parton interactions) produces too few charged particles in the “transverse” region for $30 < E_T(\text{jet#1}) < 70$ GeV!
“Transverse” PTsum Density
PYTHIA Tune A vs HERWIG

Now look in detail at “back-to-back” events in the region 30 < ET(jet#1) < 70 GeV!

- Shows the average charged PTsum density, dPTsum/dηdφ, in the “transverse” region (pT > 0.5 GeV/c, |η| < 1) versus ET(jet#1) for “Leading Jet” and “Back-to-Back” events.
- Compares the (uncorrected) data with PYTHIA Tune A and HERWIG after CDFSIM.
Charged PTsum Density
PYTHIA Tune A vs HERWIG

- HERWIG (without multiple parton interactions) does not produce enough PTsum in the “transverse” region for 30 < E_{T}(jet#1) < 70 GeV!
Study the $\Delta \phi$ distribution of the charged particle density, $dN_{\text{chg}}/d\eta d\phi$, and the charged scalar $p_T$ sum density, $dP_{T\text{sum}}/d\eta d\phi$, for charged particles in the region $p_T > 0.5$ GeV/c, $|\eta| < 1$) in “leading jet” events and “leading photon” events and “Z-boson” events!

Study the average charged particle and PTsum density in the “toward”, “transverse”, and “away” regions versus $E_T(\text{jet}\#1)$ in “leading jet” events and “leading photon” events and “Z-boson” events!
Charged Particle Density

\[ \Delta \phi \] Dependence

Shows the \( \Delta \phi \) dependence of the density, \( dN_{\text{chg}}/d\eta d\phi \), for charged particles in the range \( p_T > 0.5 \text{ GeV}/c \) and \( |\eta| < 1 \) relative to jet#1 (rotated to 270°) for \( E_T(\text{jet#1}) > 30 \text{ GeV} \) for “Leading Jet” events from PYTHIA Tune A.

Shows the \( \Delta \phi \) dependence of the density, \( dN_{\text{chg}}/d\eta d\phi \), for charged particles in the range \( p_T > 0.5 \text{ GeV}/c \) and \( |\eta| < 1 \) relative to pho#1 (rotated to 270°) for \( P_T(\text{pho#1}) > 30 \text{ GeV} \) for “Leading Photon” events from PYTHIA Tune A.

Shows the \( \Delta \phi \) dependence of the density, \( dN_{\text{chg}}/d\eta d\phi \), for charged particles in the range \( p_T > 0.5 \text{ GeV}/c \) and \( |\eta| < 1 \) relative to the Z (rotated to 270°) for \( P_T(Z) > 30 \text{ GeV} \) for “Z-boson” events from PYTHIA Tune A.
"Towards" and "Transverse" Particle Densities

Shows the average charged particle density, $dN_{chg}/d\eta d\phi$, in the "toward" and "transverse" region ($p_T > 0.5$ GeV/c, $|\eta| < 1$) versus $P_T$ (pho#1) for "Leading Photon" events (solid) and versus $P_T$ (Z) for "Z-boson" events (dashed) at 1.96 TeV from PYTHIA Tune A.

Shows the average charged particle density, $dN_{chg}/d\eta d\phi$, in the "transverse" region ($p_T > 0.5$ GeV/c, $|\eta| < 1$) versus $P_T$ (pho#1) for "Leading Photon" events (solid) and versus $P_T$ (Z) for "Z-boson" events (dashed) and versus $E_T$ (jet#1) for "Leading Jet" events (dots) at 1.96 TeV from PYTHIA Tune A.
I am working on a “universal” PYTHIA Run 2 tune: QCD jets, direct photons, Z and W bosons, Drell-Yan, heavy flavor production, etc..

I am just getting started, but so far I have seen no major problems with PYTHIA Tune A except that I should have included a larger intrinsic k_T (I used the default).

In addition to specifying the PDF and the MPI parameters, one will have to specify the Q^2 scale for each process. For Tune A Q^2 = 4p_T^2 for QCD jets and direct photons and Q^2 = M_Z^2 for Z-boson production.