Outline of Talk

→ Review the CDF Run 2 “minimum bias” tune (i.e. PYTHIA Tune A).

→ Show the “minimum bias” predictions for PYTHIA Tune A, Tune DW, Tune DWT, and the ATLAS tune at the LHC.

→ These tunes are discussed in our CMS note on the “underlying event”.

CMS NOTE-2006/067
PYTHIA Tune A Min-Bias

PYTHIA regulates the perturbative 2-to-2 parton-parton cross sections with cut-off parameters which allows one to run with $P_T(\text{hard}) > 0$. One can simulate both “hard” and “soft” collisions in one program.

The relative amount of “hard” versus “soft” depends on the cut-off and can be tuned.

This PYTHIA fit predicts that 12% of all “Min-Bias” events are a result of a hard 2-to-2 parton-parton scattering with $P_T(\text{hard}) > 5$ GeV/c (1% with $P_T(\text{hard}) > 10$ GeV/c)!
PYTHIA Tune A
LHC Min-Bias Predictions

- Shows the center-of-mass energy dependence of the charged particle density, $dN_{\text{chg}}/d\eta d\phi$, for “Min-Bias” collisions compared with PYTHIA Tune A with $P_T(\text{hard}) > 0$.

- PYTHIA was tuned to fit the “underlying event” in hard-scattering processes at 1.8 TeV and 630 GeV.

- PYTHIA Tune A predicts a 42% rise in $dN_{\text{chg}}/d\eta d\phi$ at $\eta = 0$ in going from the Tevatron (1.8 TeV) to the LHC (14 TeV). Similar to HERWIG “soft” min-bias, 4 charged particles per unit $\eta$ becomes 6.
 Shows the Run 1 Z-boson $p_T$ distribution ($<p_T(Z)> \approx 11.5$ GeV/c) compared with PYTHIA Tune A ($<p_T(Z)> = 9.7$ GeV/c), and PYTHIA Tune AW ($<p_T(Z)> = 11.7$ GeV/c).

Effective Q cut-off, below which space-like showers are not evolved.

The $Q^2 = k_T^2$ in $\alpha_s$ for space-like showers is scaled by PARP(64)!
Jet1-Jet2 $\Delta \phi$ Distribution

- MidPoint Cone Algorithm (R = 0.7, f_merge = 0.5)
- $\mathcal{L}$ = 150 pb$^{-1}$ (Phys. Rev. Lett. 94 221801 (2005))
- Data/NLO agreement good. Data/HERWIG agreement good.
- Data/PYTHIA agreement good provided PARP(67) = 1.0 → 4.0 (i.e. like Tune A, best fit 2.5).
PYTHIA Tune DW

PYTHIA 6.2 CTEQ5L

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Tune DW</th>
<th>Tune AW</th>
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<tbody>
<tr>
<td>MSTP(81)</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>MSTP(82)</td>
<td>4</td>
<td>4</td>
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<tr>
<td>PARP(82)</td>
<td>1.9 GeV</td>
<td>2.0 GeV</td>
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<td>PARP(83)</td>
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<td>0.5</td>
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<td>PARP(84)</td>
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<td>PARP(85)</td>
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<td>PARP(86)</td>
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<td>PARP(89)</td>
<td>1.8 TeV</td>
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<td>PARP(90)</td>
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<td>PARP(62)</td>
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</tr>
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<td>PARP(64)</td>
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<td>2.5</td>
<td>4.0</td>
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<td>MSTP(91)</td>
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<td>PARP(91)</td>
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<td>2.1</td>
</tr>
<tr>
<td>PARP(93)</td>
<td>15.0</td>
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Shows the Run 1 Z-boson pT distribution ($<p_T(Z)> \approx 11.5$ GeV/c) compared with PYTHIA Tune DW, and HERWIG.

Pythia Tune DW uses DØ's preferred value of PARP(67)!

Tune DW has a lower value of PARP(67) and slightly more MPI!
Show the “transverse” charged particle density, \(dN/d\eta d\phi\), versus \(P_T(\text{jet}#1)\) for “leading jet” events at 1.96 TeV for \text{Tune DW}, \text{ATLAS}, and \text{HERWIG} (without MPI).
Shows the predictions of **PYTHIA Tune A**, Tune DW, Tune DWT, and the ATLAS tune for the charged particle density $dN/d\eta$ and $dN/dY$ for “hard core” (HC) Min-Bias at 14 TeV (all $p_T$).

- **PYTHIA Tune A** and Tune DW predict about 6 charged particles per unit $\eta$ at $\eta = 0$, while the ATLAS tune predicts around 9.

- **PYTHIA Tune DWT** is identical to Tune DW at 1.96 TeV, but extrapolates to the LHC using the ATLAS energy dependence.
The ATLAS tune has many more “soft” particles than does any of the CDF Tunes. The ATLAS tune has \( <p_T> = 548 \text{ MeV/c} \) while Tune A has \( <p_T> = 641 \text{ MeV/c} \) (100 MeV/c more per particle)!
Shows the predictions of PYTHIA Tune A, Tune DW, Tune DWT, and the ATLAS tune for the charged particle multiplicity distribution for “hard core” (HC) Min-Bias at 14 TeV (|\eta| < 1) and the average number of charged particles with p_T > p_T^{\text{min}} (|\eta| < 1).

The ATLAS tune has many more “soft” particles than does any of the CDF Tunes. The ATLAS tune has <N_{\text{chg}} > = 18.14 (|\eta| < 1) while Tune A has <N_{\text{chg}} > = 11.93 (|\eta| < 1).
Shows the predictions of PYTHIA Tune DWT for the charged particle density \( \frac{dN}{d\eta} \) (all \( p_T \)) and the average number of charged particles with \( p_T > p_T^{\text{min}} \) (\(|\eta| < 1\)) for Min-Bias at 14 TeV.

Shows the contributions from the “hard core” (HC), Single-Diffraction (SD), and double-diffraction (DD) components of Min-Bias collisions. Also shows the sum (HC + SD + DD). Note the sum is actually \( (\text{MB} = 0.697\text{HC} + 0.181\text{SD} + 0.122\text{DD}) \)

For \( p_T > 0.5 \text{ GeV/c} \) and \(|\eta| < 1\) one is simply adding in zero \( N_{\text{chg}} \) for SD and DD.
PYTHIA Tune DWT
LHC Min-Bias Predictions

<table>
<thead>
<tr>
<th>Components</th>
<th>Cross-Section (14 TeV)</th>
<th>% Total</th>
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<tbody>
<tr>
<td>HC</td>
<td>55.22 mb</td>
<td>69.7%</td>
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<tr>
<td>SD</td>
<td>14.30 mb</td>
<td>18.1%</td>
</tr>
<tr>
<td>DD</td>
<td>9.69 mb</td>
<td>12.2%</td>
</tr>
<tr>
<td>Total</td>
<td>79.21 mb</td>
<td>100%</td>
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</table>

Shows the cross-sections (in mb) the “hard core” (HC), Single-Diffraction (SD), and double-diffraction (DD) components of Min-Bias collisions from PYTHIA.

Average Number of charged particles with $p_T > p_T^{\text{min}}$ and $|\eta| < 1$

<table>
<thead>
<tr>
<th>$p_T^{\text{min}}$</th>
<th>HC (pyDWT)</th>
<th>SD</th>
<th>DD</th>
<th>Total</th>
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</thead>
<tbody>
<tr>
<td>0.0</td>
<td>12.95</td>
<td>1.57</td>
<td>1.60</td>
<td>9.50</td>
</tr>
<tr>
<td>0.1</td>
<td>12.45</td>
<td>1.48</td>
<td>1.50</td>
<td>9.13</td>
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<td>0.2</td>
<td>10.90</td>
<td>1.17</td>
<td>1.19</td>
<td>7.94</td>
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<td>0.3</td>
<td>9.09</td>
<td>0.82</td>
<td>0.83</td>
<td>6.58</td>
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<tr>
<td>0.4</td>
<td>7.48</td>
<td>0.54</td>
<td>0.54</td>
<td>5.37</td>
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<tr>
<td>0.5</td>
<td>6.16</td>
<td>0.33</td>
<td>0.33</td>
<td>4.38</td>
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<tr>
<td>0.6</td>
<td>5.09</td>
<td>0.19</td>
<td>0.19</td>
<td>3.60</td>
</tr>
<tr>
<td>0.7</td>
<td>4.24</td>
<td>0.10</td>
<td>0.10</td>
<td>2.98</td>
</tr>
<tr>
<td>0.8</td>
<td>3.56</td>
<td>0.05</td>
<td>0.05</td>
<td>2.49</td>
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<tr>
<td>0.9</td>
<td>3.01</td>
<td>0.03</td>
<td>0.03</td>
<td>2.10</td>
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<tr>
<td>1.0</td>
<td>2.57</td>
<td>0.01</td>
<td>0.01</td>
<td>1.79</td>
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</tbody>
</table>

Shows the predictions of PYTHIA Tune DWT for the average number of charged particles with $p_T > p_T^{\text{min}}$ ($|\eta| < 1$) for Min-Bias at 14 TeV.
We cannot use the new underlying event model in PYTHIA 6.3. It has not been studied (and tuned) well enough yet!

The ATLAS tune is “goofy”! It produces too many “soft” particles. The charged particle $<p_T>$ is too low and does not agree with the CDF Run 2 data. The ATLAS tune agrees with $<N_{ch}>$ but not with $<P_T_{sum}>$ at the Tevatron.

PYTHIA Tune DW is very similar to Tune A except that it fits the CDF $P_T(Z)$ distribution and it uses the DØ preferred value of PARP(67) = 2.5 (determined from the dijet $\Delta \phi$ distribution).

PYTHIA Tune DWT is identical to Tune DW at 1.96 TeV but uses the ATLAS energy extrapolation to the LHC (i.e. PARP(90) = 0.16).
Conclusions

We cannot use the new underlying event model in PYTHIA 6.3. It has not been studied (and tuned) well enough yet!

The ATLAS tune is "goofy"! It produces too many "soft" particles. The charged particle $<p_T>$ is too low and does not agree with the CDF Run 2 data. The ATLAS tune agrees with $<N_{ch}>$ but not with $<p_T^{sum}>$ at the Tevatron.

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PYTHIA Tune DWT is identical to Tune DW at 1.96 TeV but uses the ATLAS energy extrapolation to the LHC (i.e. PARP(90) = 0.16).

I think more work needs to be done in comparing the various tunes. The ATLAS tune cannot be right because it does not fit the Tevatron data. Right now I like Tune DW. Probably no tune will fit the CMS data. That is why we want to measure MB&UE at CMS and retune the Monte-Carlo models!