Simulations of minimum bias and the underlying event, MC tuning and predictions for the LHC

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Outline

• Multi-parton scattering
• Tuning of PYTHIA
• Tuning using Jetweb
• LHC predictions
• Energy extrapolation and comparison with PHOJET
• Application to central jet veto in Higgs searches
• Summary+future work
How to describe low-pt behaviour?

\[ \sigma_{2\rightarrow2} > \sigma_{pp} \text{ at } p_T \sim 5\text{GeV} \]

Different approaches but all many to multi-parton scattering

\[ \bar{n} = \frac{\sigma_{\text{hard}}}{\sigma_{pp}} \]

\[ \sigma_{\text{hard}} = \int_{p_T \sim \text{min}}^{s/4} \frac{d\sigma}{dp_t^2} \text{d}p_t^2 \]

(simple scenario with sharp cut-off)
Evidence for multi-parton interactions

Direct

\[ p\bar{p} \rightarrow \gamma / \pi^0 + 3 \text{jets} + X \]

CDF

Indirect

UA5 KNO distributions

D0 multijet analysis

HERA photoproduction

CDF underlying event

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PYTHIA model

Multiple interactions solve total xsect problem
Need to tame the PT divergence over QCD cross-section

Parameters of the model:
• $p_T$-min → Abrupt vs smooth cut-off
• Energy dependence → $p_{t0} = 1.9 \text{GeV} \left( \frac{\sqrt{s}}{1\text{TeV}} \right)^{0.16}$
• Impact parameter → Matter distribution → Number of interactions and fluctuations

Parameters not looked at: string drawing, effect of ISR (CDF)
Minimum bias data:

<table>
<thead>
<tr>
<th>Experiment</th>
<th>References</th>
<th>Colliding beams</th>
</tr>
</thead>
<tbody>
<tr>
<td>CERN – ISR</td>
<td>Phys. Rev. D 30 528 (1984)</td>
<td>pp at ( \sqrt{s} = 30.4, 44.5, 52.6 ) and 62.2 GeV</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CDF - Tevatron</td>
<td>Phys. Rev. D 41 2330 (1990)</td>
<td>pp at ( \sqrt{s} = 1.8 ) TeV</td>
</tr>
</tbody>
</table>

Set \( \pi^0, K^0_s \) and \( A^0 \) stable

Multiplicity information: \( \langle n_{ch} \rangle, dN/d\eta, \) KNO, FB, etc.
Use ‘complex’ scenario with smooth cut-off

Use ‘double-gaussian’ Matter distribution

Abrupt cut-off generates too few interactions
Pt-min is $\sim 1.9\text{GeV}$ default value
The underlying event requires less activity \( \Rightarrow \) higher pt
Lose ‘unification’ of min-bias and underlying event

CDF Run 1 underlying event analysis

Alternatively increase the core size
This reduces the core density-reducing activity

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The rapidity distributions are insensitive to the matter distribution.

Agreement with KNO improves as it reduces the large fluctuations in multiplicity.
<table>
<thead>
<tr>
<th>minimum bias</th>
<th>underlying event</th>
</tr>
</thead>
</table>
| **MSUB(94) = 1**  
(D=0)  
MSUB(95) = 1  
(D=1) | **MSUB(95) = 1**  
(D=1) |
| **MSTP(51) = 7**  
(D=7) | **MSTP(51) = 7**  
(D=7) |
| **MSTP(81) = 1**  
(D=1) | **MSTP(81) = 1**  
(D=1) |
| **MSTP(82) = 4**  
(D=1) | **MSTP(82) = 4**  
(D=1) |
| **PARP(82) = 1.8**  
(D=1.9) | **PARP(82) = 1.8**  
(D=1.9) |
| **PARP(84) = 0.5**  
(D=0.2) | **PARP(84) = 0.5**  
(D=0.2) |
| **PARP(90) = 0.16**  
(D=0.16) | **PARP(90) = 0.16**  
(D=0.16) |
| $\pi^0$, $K^0_s$, and $\Lambda^0$ stable  
(D=decay’s on!) | MC distributions corrected. |

“D” = PYTHIA’s default

- **Non-diff. + d.diff.**
- **Double Gaussian**
- **Core size**
- **Primary vertex**
- **Minimum bias**
- **Underlying event**
- **CTEQ 5L**
- **Multiple interactions**
- **PT0**
- **PT0 energy dependence**
- **Exclude 8% of chd. tracks**

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Jetweb

Jetweb is a database tool for tuning MCs
J Butterworth and S Butterworth:

http://jetweb.hep.ucl.ac.uk

• Collection of plots from OPAL, H1, ZEUS, CDF, D0, UA5 publications, stored as distributions

• Generates events using (currently PYTHIA or HERWIG) and uses HBOOK to generate histograms to compare to data

• $\chi^2/DF$ calculated for distributions

• Fits are stored for future reference and comparison to different
Jetweb comparison

<table>
<thead>
<tr>
<th>Energy</th>
<th>dN/dη fit $\chi^2$/DF</th>
<th>KNO fit $\chi^2$/DF</th>
</tr>
</thead>
<tbody>
<tr>
<td>200 (UA5)</td>
<td>16.9</td>
<td>17.7</td>
</tr>
<tr>
<td>900 (UA5)</td>
<td>11.3</td>
<td>22.9</td>
</tr>
<tr>
<td>1800 (E735)</td>
<td>27.2</td>
<td>27.2</td>
</tr>
</tbody>
</table>

Jetweb fits generated by B. Waugh, UCL
LHC predictions

\[
\left( \frac{UE(LHC)}{MB(LHC)} \right)_{\rho_{\text{particle}}} = \frac{4.4}{2.6} = 1.7
\]

\[
\left( \frac{UE(CDF)}{MB(CDF)} \right)_{\rho_{\text{particle}}} = \frac{2.3}{7.0} = 0.33
\]

\[
\begin{array}{|c|c|c|}
\hline
\text{LHC prediction} & \text{dN/d}\eta\text{ (}\eta=0\text{)} & \text{N}_{ch}\text{ jet-}\text{p}_t=20\text{GeV} \\
\hline
1.8\text{TeV (pp)} & 4.1 & 2.3 \\
14\text{TeV (pp)} & 7.0 & 7.0 \\
\text{increase} & \sim\times1.8 & \sim\times3 \\
\hline
\end{array}
\]
PYTHIA vs PHOJET: Minimum bias

- PYTHIA6.214 - tuned
- PHOJET1.12

$p\bar{p}$ at $\sqrt{s} = 1.8$ TeV

$p\bar{p}$ at $\sqrt{s} = 200$ GeV

Charged particle multiplicity, $N_{ch}$

NSD interactions

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PYTHIA vs PHOJET: Underlying event

CDF Run 1 underlying event analysis
Extrapolation to the LHC-Comparison with PHOJET

- **PYTHIA** exceeds exp. extrapolation.

### Plots:

- **PYTHIA** and **PHOJET** comparisons across energies.
- Distributions of **dN/d\(\eta\)** at \(\eta = 0\) for LHC.
- Transverse \(<N_{\text{ch}}\>\) values.

### Equations:

\[
0.023 \ln(s) - 0.025 \ln(s) + 2.5
\]

\[
\sqrt{s} \text{ (GeV)}
\]

### LHC Data Points:

- UA5 53, 200, 546 and 900 GeV
- CDF 630 and 1800 GeV

### PYTHIA6.214-tuned PHOJET1.12:

- \(x 3\) increase
- \(x 1.5\) increase
VBF Signal ($H \rightarrow WW \rightarrow l\nu l\nu$)

Prospects for the search for a standard model Higgs boson in ATLAS using VBF, S. Asai et al, SN-ATLAS-2003-024 \(\rightarrow\) EPJ

- forward tagging jets
- correlated leptons
- **low hadronic activity in central region**
- central Higgs production

**Tag jet cuts**
- Candidates are two highest $P_T$ jets in opposite hemispheres: $|\Delta \eta| > 3.8$
- $P_T^1 > 40 \text{GeV}; P_T^2 > 20 \text{GeV}$
- $M_{jj} > 550 \text{GeV}$

**Important discovery channel**
For Higgs in mass range $120-200 \text{GeV}$
Central-jet veto:
Cut non-tag jets in $|\eta|<3.2$
$P_T>20\text{GeV}$

<table>
<thead>
<tr>
<th>Model</th>
<th>CJV efficiency</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Default pythia</td>
<td>82%</td>
<td>8.1</td>
</tr>
<tr>
<td>Default DG</td>
<td>71%</td>
<td>7.5</td>
</tr>
<tr>
<td>AM tuning</td>
<td>76%</td>
<td>7.6</td>
</tr>
<tr>
<td>Paper</td>
<td>86%</td>
<td>8.2</td>
</tr>
</tbody>
</table>

Pythia 6.214
Jetweb comparison
Preliminary

ZEUS precision di-jet
Photoproduction data

<table>
<thead>
<tr>
<th>Jet ET-range</th>
<th>dσ/dxγ</th>
<th>χ²/DF</th>
</tr>
</thead>
<tbody>
<tr>
<td>35-90</td>
<td>1.4</td>
<td>3.1</td>
</tr>
<tr>
<td>25-35</td>
<td>6.8</td>
<td>2.0</td>
</tr>
<tr>
<td>17-25</td>
<td>0.9</td>
<td>1.0</td>
</tr>
<tr>
<td>14-17</td>
<td>4.0</td>
<td>7.5</td>
</tr>
</tbody>
</table>

Increasing sensitivity to Underlying event

Default Pythia

Tuned Pythia
Summary and conclusions

- PYTHIA(+PHOJET) can be ‘tuned’ to give a good description of minimum bias and underlying event data from 200GeV-1800GeV. Main parameters are: $p_T$-min and the proton matter distribution.
- PYTHIA overestimates particle multiplicities predicted by extrapolations of data, and predictions from PHOJET at LHC energies.
- Underlying event activity at the LHC is greater than at Tevatron by $\sim x3$ using tuned PYTHIA.
- Compare to tunings using initial state radiation (suggested by R Field (CDF)).
- Use Jetweb to compare to wider range of data: HERA, other Tevatron data.
**PHOJET**

- Developed mainly for soft and semi-hard particle production.

- Implements ideas of **Dual Parton Model** for low-\(p_T\) processes.

- **Multiple Pomeron** exchanges (sea-quark multi-chains) enhances the event activity.

- Limited to production mechanisms of strong interactions.

- However, useful tool for **MB** and **UE** studies where jets are involved.