Are the QCD MC Models Ready for High Luminosity?

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Outline

How Universal are the QCD MC Model Tunes?
• Do we need a separate tune for each center-of-mass energy? 900 GeV, 1.96 TeV, 7 TeV, etc.
• Do we need a separate tune for each hard QCD subprocess? Jet Production, Drell-Yan Production, etc.
• Do we need separate tunes for “Min-Bias” (MB) and the “underlying event” (UE) in a hard scattering process?

A close look at two PYTHIA tunes:
• PYTHIA 6.2 Tune DW (CDF UE tune).
• PYTHIA 6.4 Tune Z1 (CMS UE tune).

Pile-Up: A quick look at the fluctuations in pile-up.

New CDF UE Data: The Tevatron Energy Scan (300 GeV, 900 GeV, 1.96 TeV).
QCD Monte-Carlo Models: High Transverse Momentum Jets

- Start with the perturbative 2-to-2 (or sometimes 2-to-3) parton-parton scattering and add initial and final-state gluon radiation (in the leading log approximation or modified leading log approximation).

- The “underlying event” consists of the “beam-beam remnants” and additional particles arising from soft or semi-soft multiple parton interactions (MPI).

- Of course the outgoing colored partons fragment into hadron “jet” and inevitably “underlying event” observables receive contributions from the latter.

The “underlying event” is an unavoidable background to most collider observables and having a good understand of it leads to more precise collider measurements!
Start with the perturbative Drell-Yan muon pair production and add initial-state gluon radiation (in the leading log approximation or modified leading log approximation).

The “underlying event” consists of the “beam-beam remnants” and from particles arising from soft or semi-soft multiple parton interactions (MPI).

Of course the outgoing colored partons fragment into hadron “jet” and inevitably “underlying event” observables receive contributions from initial-state radiation.
Look at charged particle correlations in the azimuthal angle $\Delta \phi$ relative to a leading object (i.e. CaloJet#1, ChgJet#1, PTmax, Z-boson). For CDF PTmin = 0.5 GeV/c $\eta_{cut} = 1$.

Define $|\Delta \phi| < 60^\circ$ as “Toward”, $60^\circ < |\Delta \phi| < 120^\circ$ as “Transverse”, and $|\Delta \phi| > 120^\circ$ as “Away”.

All three regions have the same area in $\eta$-$\phi$ space, $\Delta \eta \times \Delta \phi = 2\eta_{cut} \times 120^\circ = 2\eta_{cut} \times 2\pi/3$. Construct densities by dividing by the area in $\eta$-$\phi$ space.
Shows the charged particle density in the “transverse” region for charged particles ($p_T > 0.5$ GeV/c, $|\eta| < 1$) at 7 TeV as defined by $PT_{\text{max}}$, $PT(chg\text{jet#1})$, and $PT(\muon-pair)$ from PYTHIA Tune DW at the particle level (i.e. generator level). Charged particle jets are constructed using the Anti-KT algorithm with $d = 0.5$. 

"Transverse" Charged Particle Density: $dN/d\eta d\phi$

- Charged Particles ($|\eta|<1.0$, $PT>0.5$ GeV/c)
- Charged Particle Jets are constructed using the Anti-KT algorithm with $d = 0.5$.
Min-Bias “Associated” Charged Particle Density

"Transverse" Charged Particle Density: dN/dηdφ

PTmax (GeV/c) vs Charged Density

0.2 TeV → 1.96 TeV
(RHIC → Tevatron, UE increase ~2.7 times)

1.96 TeV → 14 TeV
(Tevatron → LHC, UE increase ~1.9 times)

Shows the “associated” charged particle density in the “transverse” region as a function of PTmax for charged particles (pT > 0.5 GeV/c, |η| < 1, not including PTmax) for “min-bias” events at 0.2 TeV, 0.9 TeV, 1.96 TeV, 7 TeV, 10 TeV, 14 TeV predicted by PYTHIA Tune DW at the particle level (i.e. generator level).
Min-Bias “Associated” Charged Particle Density

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

| Energy (TeV) | Charged Particles (\( |\eta|<1.0, p_T>0.5 \text{ GeV/c} \)) |
|-------------|-------------------------------------------------|
| 0.2         | 0.4                                             |
| 0.9         | 0.8                                             |
| 1.96        | 1.2                                             |
| 7           | 2                                               |
| 10          | 4                                               |
| 14          | 6                                               |

PTmax Direction:
- "Toward"
- "Transverse"
- "Away"

RHIC → Tevatron
- 0.2 TeV → 1.96 TeV (UE increase ~2.7 times)

LHC
- 1.96 TeV → 14 TeV (UE increase ~1.9 times)

Shows the “associated” charged particle density in the “transverse” region as a function of PTmax for charged particles (\( p_T > 0.5 \text{ GeV/c}, |\eta| < 1, \text{ not including PTmax} \)) in “min-bias” events at 0.2 TeV, 0.9 TeV, 1.96 TeV, 7 TeV, 10 TeV, 14 TeV predicted by PYTHIA Tune DW at the particle level (i.e. generator level).
CMS preliminary data at 900 GeV and 7 TeV on the “transverse” charged particle density, \(dN/d\eta d\phi\), as defined by the leading charged particle jet (chgjet#1) for charged particles with \(p_T > 0.5 \text{ GeV/c}\) and \(|\eta| < 2.0\). The data are uncorrected and compared with PYTHIA Tune DW after detector simulation.

ATLAS preliminary data at 900 GeV and 7 TeV on the “transverse” charged particle density, \(dN/d\eta d\phi\), as defined by the leading charged particle jet (pt(chgjet#1)) for charged particles with \(p_T > 0.5 \text{ GeV/c}\) and \(|\eta| < 2.5\). The data are corrected and compared with PYTHIA Tune DW at the generator level.
CMS preliminary data at 900 GeV and 7 TeV on the “transverse” charged particle density, dN/dηdφ, as defined by the leading charged particle jet (chgjet#1) for charged particles with pT > 0.5 GeV/c and |η| < 2.5. The data are uncorrected and compared with PYTHIA Tune DW after detector simulation.

ATLAS preliminary data at 900 GeV and 7 TeV on the “transverse” charged particle density, dN/dηdφ, as defined by the leading charged particle (PTmax) for charged particles with pT > 0.5 GeV/c and |η| < 2.5. The data are corrected and compared with PYTHIA Tune DW generator level.
CMS preliminary data at 900 GeV and 7 TeV on the “transverse” charged particle density, \(\frac{dN}{d\eta d\phi}\), as defined by the leading charged particle jet (chgjet\#1) for charged particles with \(p_T > 0.5 \text{ GeV/c}\) and \(|\eta| < 2\). The data are uncorrected and compared with PYTHIA Tune DW after detector simulation.

Ratio of CMS preliminary data at 900 GeV and 7 TeV on the “transverse” charged particle density, \(\frac{dN}{d\eta d\phi}\), as defined by the leading charged particle jet (chgjet\#1) for charged particles with \(p_T > 0.5 \text{ GeV/c}\) and \(|\eta| < 2\). The data are uncorrected and compared with PYTHIA Tune DW after detector simulation.
CDF data at 1.96 TeV on the density of charged particles, dN/dηdΦ, with p_T > 0.5 GeV/c and |η| < 1 for Drell-Yan production as a function of P_T(Z) for the “toward”, “away”, and “transverse” regions compared with PYTHIA Tune DW.

CMS data at 7 TeV on the density of charged particles, dN/dηdΦ, with p_T > 0.5 GeV/c and |η| < 2 for Drell-Yan production as a function of P_T(Z) for the “toward”, “away”, and “transverse” regions compared with PYTHIA Tune DW.
** Charged Particle Density **

** CDF Run 2 **
- Data corrected pyOTW generator level
- Drell-Yan Production
- 70 < M(pair) < 110 GeV

** CMS Preliminary **
- Data corrected pyOTW generator level
- Drell-Yan Production
- 60 < M(pair) < 120 GeV

** CDF: Proton-Antiproton Collisions at 1.96 GeV **
- Lepton Cuts: p_T > 20 GeV |η| < 1.0
- Mass Cut: 70 < M(lepton-pair) < 110 GeV
- Charged Particles: p_T > 0.5 GeV/c |η| < 1.0

** CMS: Proton-Proton Collisions at 7 GeV **
- Lepton Cuts: p_T > 20 GeV |η| < 2.4
- Mass Cut: 60 < M(lepton-pair) < 120 GeV
- Charged Particles: p_T > 0.5 GeV/c |η| < 2.0

- CDF data at 1.96 TeV on the density of charged particles, dN/dηdφ, with p_T > 0.5 GeV/c and |η| < 1 for Drell-Yan production as a function of P_T(Z) for the “toward”, “away”, and “transverse” regions compared with PYTHIA Tune DW.

- CMS data at 7 TeV on the density of charged particles, dN/dηdφ, with p_T > 0.5 GeV/c and |η| < 2 for Drell-Yan production as a function of P_T(Z) for the “toward”, “away”, and “transverse” regions compared with PYTHIA Tune DW.
Large increase in the UE in going from 1.96 TeV to 7 TeV as predicted by PYTHIA Tune DW!

CDF data at 1.96 TeV on the density of charged particles, dN/dηdφ, with p_T > 0.5 GeV/c and |η| < 1 for Drell-Yan production as a function of P_T(Z) for the “toward”, “away”, and “transverse” regions compared with PYTHIA Tune DW.

CMS data at 7 TeV on the density of charged particles, dN/dηdφ, with p_T > 0.5 GeV/c and |η| < 2 for Drell-Yan production as a function of P_T(Z) for the “toward”, “away”, and “transverse” regions compared with PYTHIA Tune DW.

CDF: Proton-Antiproton Collisions at 1.96 GeV
Lepton Cuts: p_T > 20 GeV |η| < 1.0
Mass Cut: 70 < M(lepton-pair) < 110 GeV
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Lepton Cuts: p_T > 20 GeV |η| < 2.4
Mass Cut: 60 < M(lepton-pair) < 120 GeV
Charged Particles: p_T > 0.5 GeV/c |η| < 2.0
PYTHIA Tune DW

Charged Particle Density: $dN/d\eta d\phi$

**CMS**

- **Average Charged Density**
  - CMS Preliminary data corrected pyDW generator level
  - Drell-Yan Production $60 < M_{\text{pair}} < 120$ GeV
  - Charged Particles ($|\eta|<2.0$, $PT>0.5$ GeV/c) excluding the lepton-pair

**"Toward" Charged Particle Density: $dN/d\eta d\phi$**

- Charged Particles (PT>0.5 GeV/c)

**"Transverse" Charged Particle Density: $dN/d\eta d\phi$**

- Charged Particles (PT>0.5 GeV/c)

**"Transverse" Charged Particle Density: $dN/d\eta d\phi$**

- Charged Particles (PT>0.5 GeV/c)
Overall PYTHIA Tune DW is in amazingly good agreement with the Tevatron Jet production and Drell-Yan data and did a very good job in predicting the LHC Jet production and Drell-Yan data! (although not perfect)
CMS preliminary data at 900 GeV and 7 TeV on the “transverse” charged particle density, $dN/d\eta d\phi$, as defined by the leading charged particle jet (chgjet#1) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 2.0$. The data are corrected and compared with PYTHIA Tune Z1 at the generator level.

Very nice agreement!
ATLAS published data at 900 GeV and 7 TeV on the “transverse” charged particle density, $dN/d\eta d\phi$, as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 2.5$. The data are corrected and compared with PYTHIA Tune Z1 at the generator level.

ATLAS published data at 900 GeV and 7 TeV on the “transverse” charged PTsum density, $dPT/d\eta d\phi$, as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 2.5$. The data are corrected and compared with PYTHIA Tune Z1 at the generator level.
**PYTHIA Tune Z1**

**Charged Particle Density: dN/dηdφ**

- **CDF Run 2** data corrected pyZ1 generator level
- **Drell-Yan Production**
  - 70 < M(pair) < 110 GeV

**CMS Preliminary** data corrected pyZ1 generator level
- **Drell-Yan Production**
  - 60 < M(pair) < 120 GeV

- **High p_T Z-Boson Production**
  - **Outgoing Parton**
    - **Z-Boson**
      - **"Toward"**
        - Proton
        - Initial-State Radiation
    - **AntiProton**
      - **"Away"**
        - Initial-State Radiation

**CMS data at 1.96 TeV** on the density of charged particles, dN/dηdφ, with p_T > 0.5 GeV/c and |η| < 1 for Drell-Yan production as a function of P_T(Z) for the “toward”, “away”, and “transverse” regions compared with PYTHIA Tune Z1.

**CMS data at 7 TeV** on the density of charged particles, dN/dηdφ, with p_T > 0.5 GeV/c and |η| < 2 for Drell-Yan production as a function of P_T(Z) for the “toward”, “away”, and “transverse” regions compared with PYTHIA Tune Z1.
CDF data at 1.96 TeV on the density of charged particles, $dN/d\eta d\phi$, with $p_T > 0.5$ GeV/c and $|\eta| < 1$ for Drell-Yan production as a function of $P_T(Z)$ for the “toward”, “away”, and “transverse” regions compared with PYTHIA Tune Z1.

CMS data at 7 TeV on the density of charged particles, $dN/d\eta d\phi$, with $p_T > 0.5$ GeV/c and $|\eta| < 2$ for Drell-Yan production as a function of $P_T(Z)$ for the “toward”, “away”, and “transverse” regions compared with PYTHIA Tune Z1.
CMS data at 900 GeV on the “transverse” charged particle density, $dN/d\eta d\phi$, as defined by the leading charged particle jet (chgjet#1) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 2.0$. The data are corrected and compared with PYTHIA Tune Z1 at the generator level.

CDF data at 1.96 TeV on the “transverse” charged particle density, $dN/d\eta d\phi$, as defined by the leading calorimeter jet (jet#1) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 1.0$. The data are corrected and compared with PYTHIA Tune Z1 at the generator level.
PYTHIA Tune Z1

"Transverse" Charged Particle Density: $dN/d\eta d\phi$

<table>
<thead>
<tr>
<th>CMS 900 GeV</th>
<th>CDF 1.96 TeV</th>
<th>CMS 7 TeV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Charged Particles (PT&gt;0.5 GeV/c)</td>
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<td>Charged Particles (PT&gt;0.5 GeV/c)</td>
</tr>
</tbody>
</table>

"Away" Charged Particle Density: $dN/d\eta d\phi$

<table>
<thead>
<tr>
<th>CMS Preliminary</th>
<th>CDF 1.96 TeV</th>
<th>CMS 7 TeV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Charged Particles ($</td>
<td>\eta</td>
<td>&lt;2.0$, PT&gt;0.5 GeV/c)</td>
</tr>
</tbody>
</table>

What about Min-Bias?
Overall amazingly good agreement with the LHC and Tevatron Jet production and Drell-Yan! (although not perfect yet)

What about Min-Bias?
The Inelastic Non-Diffractive Cross-Section

Occasionally one of the parton-parton collisions is hard ($p_T \approx 2$ GeV/c)

Majority of “min-bias” events!

“Semi-hard” parton-parton collision ($p_T < 2$ GeV/c)

Multiple-parton interactions (MPI)!
The “Underlying Event”

Select inelastic non-diffractive events that contain a hard scattering

1/(p_T)^4 → 1/(p_T^2 + p_T0^2)^2

Hard parton-parton collisions is hard (p_T > ≈ 2 GeV/c)

The “underlying-event” (UE)!

“Semi-hard” parton-parton collision (p_T < ≈ 2 GeV/c)

Multiple-parton interactions (MPI)!

Given that you have one hard scattering it is more probable to have MPI! Hence, the UE has more activity than “min-bias”.
Model of $\sigma_{ND}$

- Allow leading hard scattering to go to zero $p_T$ with same cut-off as the MPI!

- Model of the inelastic non-diffractive cross section!

- Multiple-parton interactions (MPI)!

- "Semi-hard" parton-parton collision ($p_T \approx 2$ GeV/c)

\[
\frac{1}{(p_T)^4} \rightarrow \frac{1}{(p_T^2 + p_T^0)^2}
\]
Fit the “underlying event” in a hard scattering process.

“Underlying Event”

1/(p_T)^4 \rightarrow 1/(p_T^2 + p_{T0}^2)^2

Allow primary hard-scattering to go to p_T = 0 with same cut-off!

“Min-Bias” (add single & double diffraction)

Predict MB (ND)!

Predict MB (IN)!

Single Diffraction

Double Diffraction
CMS NSD data on the charged particle rapidity distribution at 7 TeV compared with PYTHIA Tune Z1. The plot shows the average number of particles per NSD collision per unit $\eta$, $(1/N_{NSD}) \frac{dN}{d\eta}$.

ALICE NSD data on the charged particle rapidity distribution at 900 GeV compared with PYTHIA Tune Z1. The plot shows the average number of particles per INEL collision per unit $\eta$, $(1/N_{INEL}) \frac{dN}{d\eta}$.

"Minimum Bias" Collisions
CMS NSD data on the charged particle rapidity distribution at 7 TeV compared with PYTHIA Tune Z1. The plot shows the average number of particles per NSD collision per unit $\eta$, $(1/N_{NSD}) \, dN/d\eta$.

ALICE NSD data on the charged particle rapidity distribution at 900 GeV compared with PYTHIA Tune Z1. The plot shows the average number of particles per INEL collision per unit $\eta$, $(1/N_{INEL}) \, dN/d\eta$.

“Minimum Bias” Collisions

Okay not perfect, but remember we know that SD and DD are not modeled well!
CMS NSD data on the charged particle rapidity distribution at 7 TeV compared with PYTHIA Tune Z1. The plot shows the average number of charged particles per NSD collision per unit $\eta$, $(1/N_{NSD}) \, dN/d\eta$.

“Minimum Bias” Collisions

CMS NSD data on the charged particle rapidity distribution at 7 TeV compared with PYTHIA Tune Z1. The plot shows the average number of charged particles per NSD collision per unit $\eta-\phi$, $(1/N_{NSD}) \, dN/d\eta d\phi$. 

Proton

Proton
MB versus UE

Shows the density of charged particles in the “transverse” region as a function of PTmax for charged particles (All p_T, |η| < 2) at 7 TeV from PYTHIA Tune Z1.

CMS NSD data on the charged particle rapidity distribution at 7 TeV compared with PYTHIA Tune Z1. The plot shows the average number of charged particles per NSD collision per unit η−Φ, (1/N_{NSD}) dN/dηdΦ.

Charged Particle Density: dN/dηdΦ

CMS

Tune Z1

NSD = ND + DD

CMS Data

PYTHIA Tune Z1

RDF Preliminary

PYTHIA Tune Z1

Factor of 2!
**CMS High Luminosity Workshop**

**Alushta, Ukraine, May 29, 2012**

**Rick Field – Florida/CDF/CMS**

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**MB versus UE**

**ATLAS data** on the density of charged particles in the “transverse” region as a function of PTmax for charged particles (p_T > 0.1 GeV/c, |η| < 2.5) at 7 TeV compared with PYTHIA **Tune Z1**.

**CMS NSD data** on the charged particle rapidity distribution at 7 TeV compared with PYTHIA **Tune Z1**. The plot shows the average number of charged particles per NSD collision per unit η−φ, (1/N_{NSD}) dN/dηdφ.

![Graphs showing charged particle density distributions](image-url)
NSD Multiplicity Distribution

Generator level charged multiplicity distribution (all pT, |\(\eta\)| < 2) at 900 GeV and 7 TeV. Shows the NSD = HC + DD prediction for Tune Z1. Also shows the CMS NSD data.

Difficult to produce enough events with large multiplicity!

“Minimum Bias” Collisions
Generator level charged multiplicity distribution (all pT, |η| < 2) at 900 GeV and 7 TeV. Shows the NSD = HC + DD prediction for Tune Z1. Also shows the CMS NSD data.

“Minimum Bias” Collisions

Okay not perfect! But not that bad!
Generator level charged multiplicity distribution (all $p_T, |\eta| < 2$) at 900 GeV and 7 TeV. Shows the NSD = HC + DD prediction for Tune Z1. Also shows the CMS NSD data.

CMS corrected data at 900 GeV and 7 TeV on the charged particle multiplicity distribution in the “transverse” region for charged particles ($p_T > 0.5$ GeV/c, $|\eta| < 2$) as defined by the leading charged particle jet with $PT(chgjet#1) > 3$ GeV/c compared with PYTHIA Tune Z1 at the generator level.
Generator level charged multiplicity distribution (all \( p_T, |\eta| < 2 \)) at 900 GeV and 7 TeV. Shows the NSD = HC + DD prediction for Tune Z1. Also shows the CMS NSD data.

Difficult to produce enough events with large multiplicity!

CMS initial level data corrected Tune Z1 generator level

CMS Preliminary
Charged Particles (|\( \eta \)| < 2.0, \( p_T > 0.5 \) GeV/c)

"Transverse" Charged Particle Multiplicity

CMS Preliminary
Data Corrected
Tune Z1 generator level

"Underlying Event"

Difficult to produce enough events with large "transverse" multiplicity at low hard scale!

CMS corrected data at 900 GeV and 7 TeV on the charged particle multiplicity distribution in the "transverse" region for charged particles (\( p_T > 0.5 \) GeV/c, \( |\eta| < 2 \)) as defined by the leading charged particle jet with \( p_T(chgjet#1) > 3 \) GeV/c compared with PYTHIA Tune Z1 at the generator level.
Shows the charged multiplicity distribution (|η| < 2, all p_T) for Npile = 1 (i.e. shows, on the average, what one event looks like). The plot shows the probability of finding 0, 1, 2, ... etc. charged particles. The sum of the points is equal to one. The mean is 24.39 charged particles and σ = 19.7.

Shows the charged particle pseudo-rapidity distribution (all p_T) for Npile = 1 (i.e. shows, on the average, what one event looks like). The plot shows the <Nchg> in a 0.4 bin (i.e. not divided by bin size). The sum of the points with |η| < 2 is 24.39.
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 Shows the charged multiplicity distribution ($|\eta| < 2$, all $p_T$) for $N_{\text{pile}} = 10$ (i.e. shows, on the average, what 10 events looks like). The plot shows the probability of finding 0, 10, 20, … etc. charged particles. The sum of the points is equal to one. The mean is 243.9 charged particles and $\sigma = 62.3$. Also shown is the $N_{\text{pile}} = 1$ distribution scaled by a factor of 10 (i.e. $N_{\text{chg}} \rightarrow 10 \times N_{\text{chg}}$).

 Shows the charged multiplicity distribution ($|\eta| < 2$, all $p_T$) for $N_{\text{pile}} = 50$ (i.e. shows, on the average, what 50 events looks like). The plot shows the probability of finding 0, 50, 100, … etc. charged particles. The sum of the points is equal to one. The mean is 1219.5 charged particles and $\sigma = 138.9$. Also shown is the $N_{\text{pile}} = 1$ distribution scaled by a factor of 50 (i.e. $N_{\text{chg}} \rightarrow 50 \times N_{\text{chg}}$) and the $N_{\text{pile}} = 10$ distribution scaled by a factor of 5 (i.e. $N_{\text{chg}} \rightarrow 5 \times N_{\text{chg}}$).
Pile-Up at the LHC

"Central Limit Theorem": $\langle N_{\text{chg}} \rangle \sim N_{\text{pile}}$, $\sigma \sim \sqrt{N_{\text{pile}}}$!

- Shows the charged multiplicity distribution ($|\eta| < 2$, all $p_T$) for $N_{\text{pile}} = 10$ (i.e. shows, on the average, what 10 events looks like). The plot shows the probability of finding 0, 10, 20, … etc. charged particles. The sum of the points is equal to one. The mean is 243.9 charged particles and $\sigma = 62.3$. Also shown is the $N_{\text{pile}} = 1$ distribution scaled by a factor of 10 (i.e. $N_{\text{chg}} \rightarrow 10 \times N_{\text{chg}}$).

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Just before the shutdown of the Tevatron CDF has collected more than 10M “min-bias” events at several center-of-mass energies!

300 GeV 12.1M MB Events
900 GeV 54.3M MB Events
**New CDF Energies**

- **ATLAS preliminary data at 900 GeV and 7 TeV** on the “transverse” charged particle density, dN/dηdφ, as defined by the leading charged particle (PTmax) for charged particles with p_T > 0.5 GeV/c and |η| < 0.8. The data are corrected and compared with PYTHIA Tune Z1 at the generator level.

- **Predictions for CDF** on the “transverse” charged particle density, dN/dηdφ, as defined by the leading charged particle (PTmax) for charged particles with p_T > 0.5 GeV/c and |η| < 0.8 from PYTHIA Tune Z1 at the generator level.
ATLAS preliminary data at 900 GeV and 7 TeV on the “transverse” charged particle density, $dN/d\eta d\phi$, as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$. The data are corrected and compared with PYTHIA Tune Z1 at the generator level.

Predictions for CDF on the “transverse” charged particle density, $dN/d\eta d\phi$, as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$ from PYTHIA Tune Z1 at the generator level.
Files = 273  Events = 66,374,130
Size = 803,837,367 KB

Raw CDF data at 300 GeV, 900 GeV, and 1.96 TeV on the “transverse” charged particle density, \( \frac{dN}{d\eta d\phi} \), as defined by the leading charged particle (PTmax) for charged particles with \( p_T > 0.5 \) GeV/c and \( |\eta| < 1.0 \).
Files = 273 Events = 66,374,130
Size = 803,837,367 KB

<table>
<thead>
<tr>
<th>Runs</th>
<th>Events</th>
<th>Energy</th>
</tr>
</thead>
<tbody>
<tr>
<td>311581</td>
<td>801,635</td>
<td>300 GeV</td>
</tr>
<tr>
<td>311583</td>
<td>579,395</td>
<td>300 GeV</td>
</tr>
<tr>
<td>311597</td>
<td>140,241</td>
<td>300 GeV</td>
</tr>
<tr>
<td>311604</td>
<td>2,456,067</td>
<td>300 GeV</td>
</tr>
<tr>
<td>311610</td>
<td>2,608,939</td>
<td>300 GeV</td>
</tr>
<tr>
<td>311620</td>
<td>2,351,053</td>
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</tr>
<tr>
<td>311629</td>
<td>3,062,960</td>
<td>300 GeV</td>
</tr>
<tr>
<td>Total</td>
<td>12,000,290</td>
<td>300 GeV</td>
</tr>
</tbody>
</table>

1.96 TeV
1 and only 1 Q12 Vertex
P0-5 19,420,876 Events

900 GeV
0 or 1 Q12 Vertex
38,306,169 Events

Raw CDF data at 300 GeV, 900 GeV, and 1.96 TeV on the “transverse” charged particle density $dN/d\eta d\phi$, as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 1.0$.
How Universal are the Tunes?

Do we need a separate tune for each center-of-mass energy?
900 GeV, 1.96 TeV, 7 TeV, etc.

PYTHIA Tune DW did a nice (although not perfect) job predicting the LHC Jet Production and Drell-Yan UE data. I am still hoping for a single tune that will describe all energies! Tune Z1 also very good!

Soon we will have UE data at 300 GeV, 900 GeV, 1.96 TeV, 7 TeV, & 8 TeV and can map out the energy dependence!

Do we need a separate tune for each hard QCD subprocess? Jet Production, Drell-Yan Production, etc.

The same tune can describe both Jet Production and Drell-Yan.

Do we need separate tunes for “Min-Bias” (MB) and the “underlying event” (UE) in a hard scattering process?

PHTHIA Tune Z1 does fairly well at both the UE and MB, but you cannot expect such a naïve approach to be perfect!
How **Universal** are the Tunes?

- Do we need a separate tune for each center-of-mass energy: 900 GeV, 1.96 TeV, 7 TeV, etc.

PYTHIA Tune DW did a nice (although not perfect) job predicting the LHC Jet Production and Drell-Yan UE data. I am still hoping for a single tune that will describe all energies!

Soon we will have data at 7 TeV, & 8 TeV. What we are learning should allow for more precise predictions at future LHC energies (10 TeV, 13 TeV)!

- Do we need a separate tune for each hard QCD subprocess? Jet Production, Drell-Yan Production, etc.

The same tune can describe both Jet Production and Drell-Yan!

- Do we need separate tunes for “Min-Bias” (MB) and the “underlying event” (UE) in a hard scattering process?

PHTHIA Tune Z1 does fairly well at both the UE and MB, but you cannot expect such a naïve approach to be perfect!