Physics of the **Underlying Event**

**Outline**

- How well did we do at predicting the behavior of the “underlying event” at the LHC (900 GeV and 7 TeV)?
- How universal are the QCD Monte-Carlo model tunes?
- Examine the connection between the “underlying event” in a hard scattering process (UE) and “min-bias” collisions (MB).
- How well can we predict “min-bias” collisions at the LHC?
- Strange particle and baryon production at the LHC.

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**K^+**

| u̅ | s |

**K^-**

| āu | s |

**K_{short}**

| d̅ | s + d̅ |

**p**

| uud |

**Λ**

| ud s |

**Ξ^-**

| dd s |

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*GGI Florence, Italy*

*September 14, 2011*

*Rick Field – Florida/CDF/CMS*
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 the 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 it.

The “underlying event” is an unavoidable background to most collider observables and having 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.
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 “leading jet” events as a function of the leading jet p_T for the “toward”, “away”, and “transverse” regions. The data are corrected to the particle level (with errors that include both the statistical error and the systematic uncertainty) and are compared with PYTHIA Tune A at the particle level (i.e. generator level).
CDF data at 1.96 TeV on the charged particle scalar $p_T$ sum density, $dP_T/d\eta d\phi$, with $p_T > 0.5$ GeV/c and $|\eta| < 1$ for “leading jet” events as a function of the leading jet $p_T$ for the “toward”, “away”, and “transverse” regions. The data are corrected to the particle level (with errors that include both the statistical error and the systematic uncertainty) and are compared with PYTHIA Tune A at the particle level (i.e. generator level).
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 “Z-Boson” and “Leading Jet” events as a function of the leading jet p_T or P_T(Z) for the “toward”, “away”, and “transverse” regions. The data are corrected to the particle level and are compared with PYTHIA Tune AW and Tune A, respectively, at the particle level (i.e. generator level).
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 “Z-Boson” and “Leading Jet” events as a function of the leading jet $p_T$ or $P_T(Z)$ for the “toward”, “away”, and “transverse” regions. The data are corrected to the particle level and are compared with PYTHIA Tune AW and Tune A, respectively, at the particle level (i.e. generator level).
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CDF data at 1.96 TeV on the charged scalar PTsum density, dPT/dηdφ, with p_T > 0.5 GeV/c and |η| < 1 for “Z-Boson” and “Leading Jet” events as a function of the leading jet p_T or P_T(Z) for the “toward”, “away”, and “transverse” regions. The data are corrected to the particle level and are compared with PYTHIA Tune AW and Tune A, respectively, at the particle level (i.e. generator level).
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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 “Z-Boson” events as a function of P\(_T\)(Z) for the “toward” and “transverse” regions. The data are corrected to the particle level (with errors that include both the statistical error and the systematic uncertainty) and are compared with PYTHIA Tune AW and HERWIG (without MPI) at the particle level (i.e. generator level).
Data at 1.96 TeV on the density of charged particles, dN/dηdφ, with p_T > 0.5 GeV/c and |η| < 1 for "Z-Boson" events as a function of P_T(Z) for the "toward" and "transverse" regions. The data are corrected to the particle level (with errors that include both the statistical error and the systematic uncertainty) and are compared with PYTHIA Tune AW and HERWIG (without MPI) at the particle level (i.e. generator level).
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Data at 1.96 TeV on the charged scalar PTsum density, \( dP_T/d\eta d\phi \), with \( p_T > 0.5 \text{ GeV/c} \) and \(|\eta| < 1\) for “Z-Boson” events as a function of \( P_T(Z) \) for the “toward” and “transverse” regions. The data are corrected to the particle level (with errors that include both the statistical error and the systematic uncertainty) and are compared with PYTHIA Tune AW and HERWIG (without MPI) at the particle level (i.e. generator level).

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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 “Z-Boson” events as a function of $P_T(Z)$ for the “toward” region. The data are corrected to the particle level (with errors that include both the statistical error and the systematic uncertainty) and are compared with PYTHIA Tune AW, Tune DW, PYTHIA ATLAS Tune, HERWIG (without MPI), and HERWIG (with JIMMY MPI) at the particle level (i.e. generator level).
Z-Boson: “Towards” Region

- Data at 1.96 TeV on the density of charged particles, dN/dηdφ, with p_T > 0.5 GeV/c and |η| < 1 for “Z-Boson” events as a function of P_T(Z) for the “toward” region from PYTHIA Tune AW, Tune DW, Tune S320, and Tune P329 at the particle level (i.e. generator level).

- Extrapolations of PYTHIA Tune AW, Tune DW, Tune DWT, Tune S320, and Tune P329, and pyATLAS to the LHC.
Z-Boson: “Towards” Region

If the LHC data are not in the range shown here then we learn new (QCD) physics!

- 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 “Z-Boson” events as a function of P_T(Z) for the “toward” region from PYTHIA Tune AW, Tune DW, Tune S320, and Tune P329 at the particle level to the generator level.

- Extrapolations of PYTHIA Tune AW, Tune DW, Tune DWT, Tune S320, and Tune P329, and pyATLAS to the LHC.

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Fake data (from MC) at 900 GeV on the “transverse” charged particle density, \(dN/d\eta d\phi\), as defined by the leading charged particle (PTmax) and the leading charged particle jet (chgjet#1) for charged particles with \(p_T > 0.5\) GeV/c and \(|\eta| < 2\). The fake data (from PYTHIA Tune DW) are generated at the particle level (i.e. generator level) assuming 0.5 M min-bias events at 900 GeV (361,595 events in the plot).
Fake data (from MC) at 900 GeV on the “transverse” charged particle density, dN/dηdϕ, as defined by the leading charged particle (PTmax) and the leading charged particle jet (chgjet#1) for charged particles with p_T > 0.5 GeV/c and |η| < 2. The fake data (from PYTHIA Tune DW) are generated at the particle level (i.e. generator level) assuming 0.5 M min-bias events at 900 GeV (361,595 events in the plot).

CMS preliminary data at 900 GeV on the “transverse” charged particle density, dN/dηdϕ, as defined by the leading charged particle (PTmax) and the leading charged particle jet (chgjet#1) for charged particles with p_T > 0.5 GeV/c and |η| < 2. The data are uncorrected and compared with PYTHIA Tune DW after detector simulation (216,215 events in the plot).
**“Transverse” Charged PTsum Density**

- Fake data (from MC) at 900 GeV on the “transverse” charged PTsum density, \( dPT/d\eta d\phi \), as defined by the leading charged particle (PTmax) and the leading charged particle jet (chgjet#1) for charged particles with \( p_T > 0.5 \) GeV/c and \( |\eta| < 2 \). The fake data (from PYTHIA Tune DW) are generated at the particle level (i.e. generator level) assuming 0.5 M min-bias events at 900 GeV (361,595 events in the plot).

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“Transverse” Charge Density

RDF Preliminary
by Tune DW generator level

900 GeV

7 TeV

factor of 2!

Prediction!

LHC
900 GeV

900 GeV → 7 TeV
(UE increase ~ factor of 2)

~0.4 → ~0.8

LHC
7 TeV

Shows the charged particle density in the “transverse” region for charged particles ($p_T > 0.5$ GeV/c, $|\eta| < 2$) at 900 GeV and 7 TeV as defined by PTmax from PYTHIA Tune DW and 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 \(p_T > 0.5\) 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, \(dN/d\eta d\phi\), as defined by the leading charged particle jet (chgjet#1) for charged particles with \(p_T > 0.5\) GeV/c and \(|\eta| < 2\). 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, $dN/d\eta d\phi$, as defined by the leading charged particle jet (chgjet#1) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 2$. The data are uncorrected and compared with PYTHIA Tune DW after detector simulation.

Ratio of the 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 $|\eta| < 2.5$. The data are corrected and compared with PYTHIA Tune DW at the generator level.
Ratio of the CMS preliminary 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 jet (chgjet#1) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 2$. The data are uncorrected and compared with PYTHIA Tune DW after detector simulation.

Ratio of the ATLAS preliminary 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 DW at the generator level.
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ATLAS preliminary data at 900 GeV and 7 TeV on the “transverse” charged particle density, dN/dηdφ, as defined by the leading charged particle jet (PTmax) for charged particles with p_T > 0.5 GeV/c and |η| < 2.5. The data are corrected and compared with PYTHIA Tune DW at the generator level.
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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 DW.

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 DW.
**charged particle density**

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

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

- **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 DW.

- **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 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, $dN/d\eta d\phi$, 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 DW.

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 DW.

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CDF data at 1.96 TeV on the charged PTsum density, $dP_T/d\eta d\phi$, with $p_T > 0.5$ GeV/c and $|\eta| < 1$ for Drell-Yan production as a function of PT(Z) for the “toward”, “away”, and “transverse” regions compared with PYTHIA Tune DW.

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

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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**

**"Away"**

**"Transverse"**

**"Toward"**

**Charged Particles Density**

- **"Toward" Charged Particle Density: $dN/d\eta d\phi$**
  - **CMS 7 TeV**
  - **CDF 1.96 TeV**
  - **CMS 900 GeV**

- **"Transverse" Charged Particle Density: $dN/d\eta d\phi$**
  - **CDF 1.96 TeV**
  - **CMS 7 TeV**
  - **CMS 900 GeV**

**Drell-Yan Production**

**Charged Particles (PT>0.5 GeV/c)**

**Charged Particles Density**

- **"Transverse" Charged Particle Density: $dN/d\eta d\phi$**
  - **CDF 1.96 TeV**
  - **CMS 7 TeV**
  - **CMS 900 GeV**

**Charged Particles (PT>0.5 GeV/c)**

- **RDF Preliminary**
  - Data corrected pyDW generator level

**Charged Particles Density**

- **"Transverse" Charged Particle Density: $dN/d\eta d\phi$**
  - **CDF 1.96 TeV**
  - **CMS 7 TeV**
  - **CMS 900 GeV**

**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)
All my previous tunes (A, DW, DWT, D6, D6T, CW, X1, and X2) were PYTHIA 6.4 tunes using the old $Q^2$-ordered parton showers and the old MPI model (really 6.2 tunes)!

I believe that it is time to move to PYTHIA 6.4 ($p_T$-ordered parton showers and new MPI model)!

**Tune Z1:** I started with the parameters of ATLAS Tune AMBT1, but I changed LO* to CTEQ5L and I varied PARP(82) and PARP(90) to get a very good fit of the CMS UE data at 900 GeV and 7 TeV.

The ATLAS Tune AMBT1 was designed to fit the inelastic data for $N\text{chg} \geq 6$ and to fit the $P_T\text{max}$ UE data with $P_T\text{max} > 10$ GeV/c. Tune AMBT1 is primarily a min-bias tune, while Tune Z1 is a UE tune!
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Tune Z1 (R. Field CMS)</th>
<th>Tune AMBT1 (ATLAS)</th>
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<tbody>
<tr>
<td>Parton Distribution Function</td>
<td>CTEQ5L</td>
<td>LO*</td>
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<td>PARP(82) – MPI Cut-off</td>
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<td>PARP(89) – Reference energy, E0</td>
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<td>1800.0</td>
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<td>PARP(90) – MPI Energy Extrapolation</td>
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<td>PARP(77) – CR Suppression</td>
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<tr>
<td>PARP(78) – CR Strength</td>
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<td>PARP(80) – Probability colored parton from BBR</td>
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<tr>
<td>PARP(83) – Matter fraction in core</td>
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<td>PARP(84) – Core of matter overlap</td>
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<td>PARP(62) – ISR Cut-off</td>
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<tr>
<td>PARP(93) – primordial kT-max</td>
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<tr>
<td>MSTP(81) – MPI, ISR, FSR, BBR model</td>
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<tr>
<td>MSTP(82) – Double gaussian matter distribution</td>
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<td>MSTP(91) – Gaussian primordial kT</td>
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<tr>
<td>MSTP(95) – strategy for color reconnection</td>
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</table>

Parameters not shown are the PYTHIA 6.4 defaults!
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!

CMS corrected data!
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 ($PT_{\text{max}}$) 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 publication – arXiv:1012.0791

December 3, 2010
CMS preliminary data at 7 TeV on the “transverse” charged particle density, dN/dηdφ, as defined by the leading charged particle jet (chgjet#1) for charged particles with p_T > 0.5 GeV/c and |η| < 2.0 together with the ATLAS published data at 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| < 2.5 The data are corrected and compared with PYTHIA Tune Z1 at the generator level.

Amazing agreement!
The charged particle density in the “transverse” region as defined by the leading charged particle jet from PYTHIA Tune Z1. The charged particles are in the region $p_T > 0.5$ GeV/c and $|\eta| < 2.5$. Charged particle jets are constructed using the Anti-KT algorithm with $d = 0.2$, 0.5, and 1.0 from charged particles in the region $p_T > 0.5$ GeV/c and $|\eta| < 2.5$, however, the leading charged particle jet is required to have $|\eta(chgjet#1)| < 1.5$.

It appears that large jet radius “biases” the UE to be more active!
ATLAS preliminary data at 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. Also shows the prediction of Tune Z1 for the “transverse” charged particle density with \(p_T > 0.1\) GeV/c and \(|\eta| < 2.5\).
ATLAS preliminary data at 7 TeV on the “transverse” charged particle density, \( dN/d\eta d\phi \), as defined by the leading charged particle (\( PT_{\text{max}} \)) for charged particles with \( p_T > 0.5 \) GeV/c and \( |\eta| < 2.5 \). The data are corrected and compared with \textsc{Pythia} Tune Z1 at the generator level. Also shows the prediction of Tune Z1 for the “transverse” charged particle density with \( p_T > 0.1 \) GeV/c and \( |\eta| < 2.5 \).

\textbf{Transverse} Charged Density
\textbf{RDF Preliminary}
\textbf{ATLAS corrected data}
\textbf{Tune Z1 generator level}

\textbf{Charge Particle Density}
\textbf{Charge PTsum Density}

\( PT_{\text{max}} \) (GeV/c)
\( 0.0 \quad 0.5 \quad 1.0 \quad 1.5 \quad 2.0 \quad 2.5 \quad 0 \quad 2 \quad 4 \quad 6 \quad 8 \quad 10 \quad 12 \quad 14 \quad 16 \quad 18 \quad 20 \)

\( dN/d\eta d\phi \)

\( PT > 0.1 \text{ GeV/c} \)
\( PT > 0.5 \text{ GeV/c} \)

Rick Field
MPI@LHC 2010 Glasgow, Scotland
December 2, 2010
ATLAS preliminary data at 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 $p_T > 0.1$ GeV/c ($|\eta| < 2.5$). The data are corrected and compared with PYTHIA Tune Z1 at the generator level.

ATLAS publication – arXiv:1012.0791

December 3, 2010
ATLAS preliminary data at 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 \( p_T > 0.1 \text{ GeV/c} \) and \( p_T > 0.5 \text{ GeV/c} \) (\(|\eta| < 2.5\)). The data are corrected and compared with PYTHIA Tune Z1 at the generator level.

**Charge Particle Density**

**Charge PTsum Density**

**"Transverse" Ratio: PT > 0.1 and > 0.5 GeV/c**

**"Transverse" Charged Density**

**"Transverse" Charged PTsum Density**

**ATLAS**

**7 TeV**

**Charged Particles (|\(\eta| < 2.5\))**

**RDF Preliminary**

**ATLAS corrected data Tune Z1 generator level**

**ATLAS publication – arXiv:1012.0791**

*December 3, 2010*
ALICE 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 (\( PT_{\text{max}} \)) for charged particles with \( p_T > 0.5 \text{ GeV/c} \) and \( \eta < 0.8 \). The data are corrected and compared with PYTHIA Tune Z1 at the generator level.

ALICE preliminary data at 900 GeV and 7 TeV on the “transverse” charged \( PT_{\text{sum}} \) density, \( dPT/d\eta d\phi \), as defined by the leading charged particle (\( PT_{\text{max}} \)) for charged particles with \( p_T > 0.5 \text{ GeV/c} \) and \( \eta < 0.8 \). The data are corrected and compared with PYTHIA Tune Z1 at the generator level.
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.

ATLAS preliminary data at 900 GeV and 7 TeV on the “transverse” charged PTsum density, dPT/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.
The LPCC MB&UE Working Group has suggested several MB&UE “Common Plots” the all the LHC groups can produce and compare with each other.
ALICE 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.

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.
ALICE 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.

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.
Over the past few days CDF has collected more than 10M “min-bias” events at several center-of-mass energies!

- 300 GeV 12M MB Events
- 900 GeV 17M MB Events
CMS data at 900 GeV on the “transverse” charged particle density, dN/dηdφ, as defined by the leading charged particle jet (chgjet#1) for charged particles with p_T > 0.5 GeV/c and |η| < 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/dηdφ, as defined by the leading calorimeter jet (jet#1) for charged particles with p_T > 0.5 GeV/c and |η| < 1.0. The data are corrected and compared with PYTHIA Tune Z1 at the generator level.
CMS 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 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 PTsum density, \(dPT/d\eta d\phi\), 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.
- 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 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.
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CMS data at 7 TeV on the charged PTsum density, dPT/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 charged PTsum density, \( \text{dPT}/\text{d}\eta\text{d}\phi \), with \( p_T > 0.5 \text{ GeV/c} \) 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 charged PTsum density, \( \text{dPT}/\text{d}\eta\text{d}\phi \), with \( p_T > 0.5 \text{ GeV/c} \) 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.
PYTHIA Tune Z1

"Transverse" Charged PTsum Density: $dP_T/d\eta d\phi$

- RDF Preliminary data corrected pyZ1 generator level
- CMS 7 TeV
- CDF 1.96 TeV
- CMS 900 GeV

"Away" Charged PTsum Density: $dP_T/d\eta d\phi$

- RDF Preliminary data corrected pyZ1 generator level
- CMS 7 TeV
- CDF 1.96 TeV
- CMS Preliminary data corrected pyZ1 generator level

Drell-Yan Production

Charged Particles ($|\eta|<2.0$, $P_T>0.5$ GeV/c)
PYTHIA Tune Z1

"Transverse" Charged PTsum Density: $d\mathit{PT}/d\eta\phi$

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

What about Min-Bias?

Tune Z1

CDF 1.96 TeV
CMS 7 TeV
RDF Preliminary data corrected pyZ1 generator level

"Transverse" Charged PTsum Density: $d\mathit{PT}/d\eta\phi$

Charged PTsum Density (GeV/c)
Drell-Yan Production
Charged Particles ($|\eta|<2.0$, PT>0.5 GeV/c)
The Inelastic Non-Diffractive Cross-Section

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

Majority of “min-bias” events!

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

Multiple-parton interactions (MPI)!
Select inelastic non-diffractive events that contain a hard scattering

Hard parton-parton collisions is hard ($p_T \approx 2$ GeV/c)

The “underlying-event” (UE)!

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

“Semi-hard” parton-parton collision ($p_T < \approx 2$ 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”.

The “Underlying Event”
Model of $\sigma_{\text{ND}}$

All 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!

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

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

Multiple-parton interactions (MPI)!
Fit the “underlying event” in a hard scattering process.

“Underlying Event”

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

$1/(p_T^4) \rightarrow 1/(p_T^2 + p_0^2)^2$

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

Predict MB (ND)!

Predict MB (IN)!

Single Diffraction

Double Diffraction

GGI Florence, Italy
September 14, 2011

Rick Field – Florida/CDF/CMS
Compares the 900 GeV ALICE data with PYTHIA Tune DW and Tune S320 Perugia 0. Tune DW uses the old $Q^2$-ordered parton shower and the old MPI model. Tune S320 uses the new $p_T$-ordered parton shower and the new MPI model. The numbers in parentheses are the average value of $dN/d\eta$ for the region $|\eta| < 0.6$. 

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

- ALICE INEL
- UA5 INEL
- pyDW INEL (2.67)
- pyS320 INEL (2.70)

**PseudoRapidity $\eta$**

- ALICE INEL
- UA5 INEL
- pyDW INEL (2.67)
- pyS320 INEL (2.70)

**Proton Proton “Minimum Bias” Collisions**
LHC MB Predictions: 900 GeV

Compares the 900 GeV Proton Proton "Minimum Bias" Collisions with ALICE data and PYTHIA Tune DW and Tune S320 Perugia 0. Tune DW uses the old $Q^2$-ordered parton shower and the old MPI model. Tune S320 uses the new $p_T$-ordered parton shower and the new MPI model. The numbers in parentheses are the average value of $dN/d\eta$ for the region $|\eta| < 0.6$. Off by 11%!
ALICE inelastic data at 900 GeV on the dN/d\eta distribution for charged particles (p_T > PTmin) for events with at least one charged particle with p_T > PTmin and |\eta| < 0.8 for PTmin = 0.15 GeV/c, 0.5 GeV/c, and 1.0 GeV/c compared with PYTHIA Tune DW at the generator level.

If one increases the p_T, the agreement improves!

<table>
<thead>
<tr>
<th>Charged Particle Density: dN/d\eta</th>
<th>RDF Preliminary</th>
<th>900 GeV</th>
<th>At Least 1 Charged Particle</th>
<th>p_T &gt; 0.15 GeV/c</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALICE INEL data at generator level</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

“Minimum Bias” Collisions
ALICE inelastic data at 900 GeV on the dN/d\(\eta\) distribution for charged particles (p_T > PTmin) for events with at least one charged particle with p_T > PTmin and |\(\eta\)| < 0.8 for PTmin = 0.15 GeV/c, 0.5 GeV/c, and 1.0 GeV/c compared with PYTHIA Tune Z1 at the generator level (dashed = ND, solid = INEL).

“Minimum Bias” Collisions

Cannot trust PYTHIA 6.2 modeling of diffraction!

Diffraction contributes less at harder scales!
Generator level $dN/d\eta$ (all $p_T$). Shows the NSD = HC + DD and the HC = ND contributions for Tune DW. Also shows the CMS NSD data.

"Minimum Bias" Collisions

Off by 30%!
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!
ALICE inelastic data at 900 GeV on the dN/d\(\eta\) distribution for charged particles (\(p_T > P_T\text{min}\)) for events with at least one charged particle with \(p_T > P_T\text{min}\) and |\(\eta\)| < 0.8 for \(P_T\text{min} = 0.15\) GeV/c, 0.5 GeV/c, and 1.0 GeV/c compared with PYTHIA Tune Z1 at the generator level.

“Minimum Bias” Collisions

Okay not perfect, but remember we do not know if the SD & DD are correct!
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 $\eta$, $(1/N_{NSD}) \, dN/d\eta$.

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 $\eta-\phi$, $(1/N_{NSD}) \, dN/d\eta d\phi$.

“Minimum Bias” Collisions

Proton

Proton
**MB versus UE**

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\(_{NSD}\)) \( dN/d\eta d\phi \).

Shows the density of charged particles in the “transverse” region as a function of PT\(_{\text{max}}\) for charged particles (All \( p_T \), \( |\eta| < 2 \)) at 7 TeV from PYTHIA Tune Z1.
**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.
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.

“Minimum Bias” Collisions

Okay not perfect! But not that bad!

Difficult to produce enough events with large multiplicity!
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.

Difficult to produce enough events with large multiplicity!

CMS corrected data at 900 GeV and 7 TeV on the charged particle multiplicity distribution in the region for charged particles (all pT, |η| < 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.

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

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!
CMS NSD data on the $K_{\text{short}}$ rapidity distribution at 7 TeV and 900 GeV compared with PYTHIA Tune Z1. The plot shows the average number of $K_{\text{short}}$ per NSD collision per unit $Y$, ($1/N_{\text{NSD}}$) $dN/dY$.

CMS NSD data on the $K_{\text{short}}$ rapidity distribution at 900 GeV and the ALICE point at $Y = 0$ (INEL) compared with PYTHIA Tune Z1. The ALICE point is the average number of $K_{\text{short}}$ per INEL collision per unit $Y$ at $Y = 0$, ($1/N_{\text{INEL}}$) $dN/dY$.

“Minimum Bias” Collisions

No overall shortage of Kaons in PYTHIA Tune Z1!
ALICE INEL data on the charged kaon rapidity distribution at 900 GeV compared with PYTHIA Tune Z1. The plot shows the average number of charged kaons per INEL collision per unit Y at Y = 0, \(\frac{1}{N_{\text{INEL}}} dN/dY\).

ALICE INEL data on the charged kaon to charged pion rapidity ratio at 900 GeV compared with PYTHIA Tune Z1.

\[
\frac{(K^+ + K^-)}{(\pi^+ + \pi^-)} = \frac{\text{Strange Meson}}{\text{Non-strange Meson}}
\]

“Minimum Bias” Collisions

No overall shortage of Kaons in PYTHIA Tune Z1!
ALICE INEL data on the charged kaon rapidity distribution at 900 GeV compared with PYTHIA Tune Z1. The plot shows the average number of charged kaons per INEL collision per unit Y at Y = 0, \(\frac{1}{N_{INEL}} dN/dY\).

No overall shortage of Kaons in PYTHIA Tune Z1!
ALICE INEL data on the charged kaon to charged pions ratio versus $p_T$ at 900 GeV ($|Y| < 0.75$) compared with PYTHIA Tune Z1 & Z1C.

PYTHIA $p_T$ dependence off on Kaons!

ALICE INEL data on the charged kaon to charged pion rapidity ratio at 900 GeV compared with PYTHIA Tune Z1.

$\frac{dN/dY}{dN/dY}$ Particle Ratio

ALICE Data
PYTHIA Tune Z1 & Z1C

$900 \text{ GeV}$

INEL (all $p_T$)

qq/q: 0.1 $\rightarrow$ 0.12
us/s: 0.4 $\rightarrow$ 0.8

Strange Meson
Non-strange Meson

$\frac{(K^+ + K^-)}{(\pi^+ + \pi^-)}$

$u \bar{u}$
$K^+$
$\bar{u} \bar{s}$
$K^-$
<table>
<thead>
<tr>
<th>Tune</th>
<th>Description</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Z1</td>
<td>1st ATLAS tune incl 7 TeV, w. LO* PDFs</td>
<td>2010</td>
</tr>
<tr>
<td>Z1</td>
<td>Retune of AMBT1 by Field w CTEQ5L PDFs</td>
<td>2010</td>
</tr>
<tr>
<td>Z2</td>
<td>Retune of Z1 by Skands w CTEQ5L PDFs</td>
<td>2010</td>
</tr>
<tr>
<td>Z2</td>
<td>Retune of Z1 by Field w CTEQ6L1 PDFs</td>
<td>2010</td>
</tr>
<tr>
<td>Z2-LEP</td>
<td>Retune of Z1 by Skands w CTEQ6L1 PDFs</td>
<td>2010</td>
</tr>
<tr>
<td>350</td>
<td>Retune of Perugia 2010 incl 7-TeV data</td>
<td>2011</td>
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<tr>
<td>S350</td>
<td>Variation with alphaS(pT/2)</td>
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<tr>
<td>S350</td>
<td>Variation with alphaS(2pT)</td>
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<td>S356</td>
<td>Variation with more semi-hard MPI</td>
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<td>S356</td>
<td>Variation without color reconnections</td>
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<td>S356</td>
<td>Perugia 2011 using MSTW LO** PDFs</td>
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<td>S356</td>
<td>Perugia 2011 using CTEQ6L1 PDFs</td>
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<td>T16</td>
<td>Variation with PARP(90)=0.16 away from 7 TeV</td>
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<tr>
<td>T32</td>
<td>Variation with PARP(90)=0.32 away from 7 TeV</td>
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<tr>
<td>TeV</td>
<td>Perugia 2011 optimized for Tevatron</td>
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<tr>
<td>Global</td>
<td>Schulz-Skands Global fit</td>
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<td>7000</td>
<td>Schulz-Skands at 7000 GeV</td>
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<td>Schulz-Skands at 1800 GeV</td>
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<td>900</td>
<td>Schulz-Skands at 900 GeV</td>
<td>2011</td>
</tr>
<tr>
<td>630</td>
<td>Schulz-Skands at 630 GeV</td>
<td>2011</td>
</tr>
</tbody>
</table>
mcplots.cern.ch

(SOINC users, see Test4Theory@Home page)

Rapidity Distribution Ratio: Kaons/Pions

ALICE Data

PYTHIA Tune Z1 & S350

(K^+ + K^-)/(...)

dN/dy Particle Ratio

INEL (all pT) 900 GeV

pyZ1 solid pyS350 dashed

ALEPH_1996_S3486095

Pythia 6.425

91 GeV ee

Z (hadronic)

K^0 Spectrum (particle-level)

- ALEPH
- Pythia 6 (340:AMBT1)
- Pythia 6 (327:P2010)
- Pythia 6 (129:Pro-Q2O)
- Pythia 6 (343:Z2)

91 GeV ee

Z (hadronic)

Rapidity Distribution Ratio: Kaons/Pions

900 GeV

(K^+ + K^-)/(...)

INEL (all pT) 900 GeV

pyZ1 solid pyS350 dashed

ALEPH_1996_S3486095

Pythia 6.425

91 GeV ee

Z (hadronic)

K^0 Spectrum (particle-level)

- ALEPH
- Pythia 6 (340:AMBT1)
- Pythia 6 (327:P2010)
- Pythia 6 (129:Pro-Q2O)
- Pythia 6 (343:Z2)
CMS NSD data on the Lambda+AntiLambda rapidity distribution at 7 TeV and 900 GeV compared with PYTHIA Tune Z1. The plot shows the average number of particles per NSD collision per unit Y, \( \langle 1/N_{\text{NSD}} \rangle \, dN/dY \).

CMS NSD data on the Lambda+AntiLambda to 2Kshort rapidity ratio at 7 TeV compared with PYTHIA Tune Z1.

\[
\frac{\Lambda + \bar{\Lambda}}{2K_{\text{short}}} = \text{Single-strange Baryon Strange Meson}
\]

“Minimum Bias” Collisions

Oops! Not enough Lambda’s in PYTHIA Tune Z1!
CMS NSD data on the Cascade⁻ + AntiCascade⁻ rapidity distribution at 7 TeV and 900 GeV compared with PYTHIA Tune Z1. The plot shows the average number of particles per NSD collision per unit Y, \((1/N_{NSD}) \, dN/dY\).

CMS data on the Cascade⁻+AntiCascade⁻ to 2K_short rapidity ratio at 7 TeV compared with PYTHIA Tune Z1.

\[
\frac{(\Xi^- + \Xi^-)}{2K_{short}} = \text{Double-strange Baryon Strange Meson}
\]

“Minimum Bias” Collisions

Yikes! Way too few Cascade’s in PYTHIA Tune Z1!
LEP: Ξ Spectrum

mcplots.cern.ch

June 2011 - A. Karneyeu, D. Konstantinov, M. Mangano, L. Mijovic, W. Pokorski, S. Prestel, A. Pytel, P. Skands
(BOINC users, see Test4Theory@Home page)

Rapidity Distribution Ratio: (Cas+CasBar)/(2Kshort)

CMS Data
PyTHIA Tune Z1 & S350

PyZf = solid
pyS350 = dashed

NSD (all pT)

Rapidity Y

Arapidity Distribution Ratio: (Cas+CasBar)/(2Kshort)

91 GeV ee Z (hadronic)

1/dx

1

10

10

10

10

10

10

10

ALEPH
Pythia 6 (340:AMBT1)
Pythia 6 (327:P2010)
Pythia 6 (129:Pro-Q2O)
Pythia 6 (343:Z2)

91 GeV ee

Z (hadronic)

1/dx

1

10

10

10

10

10

10

10

ALEPH_1996_S3486095
Pythia 6.425

CMS Data

PYTHIA Tune Z1 & S350

pyZf = solid
pyS350 = dashed

CMS Data

π0

Production

CMS Data

π0

Production
CMS NSD data on the Cascade+AntiCascade transverse momentum distribution at 7 TeV compared with PYTHIA Tune Z1 & Z1C. The plot shows the average number of particles per NSD collision per unit p_T, \((1/N_{NSD})\, dN/dp_T\) for \(|Y| < 2\).

CMS NSD data on the Cascade+AntiCascade transverse momentum distribution at 7 TeV (normalized to 1) compared with PYTHIA Tune Z1 & Z1C.

PYTHIA Tune Z1 & Z1C are a bit off on the p_T dependence!
ALICE INEL data on the Proton+AntiProton to charged pion ratio versus $p_T$ at 900 GeV ($|Y| < 0.75$) compared with PYTHIA Tune Z1 & Z1C. The rapidity distribution ratio at 900 GeV compared with PYTHIA Tune Z1 & Z1C.

PYTHIA way off on the $p_T$ dependence of Protons!
**MB versus UE**

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**Transverse Charged Particle Density: dN/dηdφ**

- **RDF Preliminary**
- **PYTHIA Tune Z1**

**Factor of 2!**

**Tune Z1**

**7 TeV ND**

**Charged Particle Density**

- 0.0
- 0.5
- 1.0
- 1.5
- 2.0
- 2.5

**PT max (GeV/c)**

- 0
- 5
- 10
- 15
- 20
- 25

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**Charged Particle Density: dN/dηdφ**

- **CMS**
- **Tune Z1**
- **NSD = ND + DD**

**CMS Data**

**PYTHIA Tune Z1**

**NSD (all pT)**

**7 TeV**

**pyZ1 ND = dashed**

**pyZ1 NSD = solid**

**Charged Particle Density**

- 0.0
- 0.5
- 1.0
- 1.5
- 2.0
- 2.5

**Pseudo-Rapidity η**

- -4
- -3
- -2
- -1
- 0
- 1
- 2
- 3
- 4

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- **Shows the density of charged particles in the “transverse” region as a function of PTmax for charged particles (All pT, |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.

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*GGI Florence, Italy*
*September 14, 2011*
UE Particle Type

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.

Shows the density of 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.
Shows the density of $K_{\text{short}}$ particles in the “transverse” region as a function of $p_T$ for charged particles ($|\eta| < 2$) at 7 TeV from PYTHIA Tune Z1.

Shows the $K_{\text{short}}$ pseudo-rapidity distribution (all $p_T$) at 7 TeV from PYTHIA Tune Z1. The plot shows the average number of particles per ND collision per unit $\eta-\phi$, $(1/N_{\text{ND}}) dN/d\eta d\phi$. 
"Transverse" Particle Density: $dN/d\eta d\phi$

Factor of ~2!

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

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

Shows the $P$-anti$P$ pseudo-rapidity distribution (all $p_T$) at 7 TeV from PYTHIA Tune Z1. The plot shows the average number of particles per ND collision per unit $\eta-\phi$, $(1/N_{ND}) dN/d\eta d\phi$. 

"Minimum Bias" Collisions
"Transverse" Particle Density: \( \frac{dN}{d\eta d\phi} \)

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

**Coming soon!** Measurements from CMS, ATLAS, and ALICE on the strange particles and baryons in the “underlying event”.

Shows the density distribution of \((\Lambda + \bar{\Lambda})\) particles from PYTHIA Tune Z1. The PTmax for charged particles (All pT, |\(\eta\)| < 2) at 7 TeV from PYTHIA Tune Z1. The plot shows the average number of particles per the pseudo-rapidity, \((1/N_{ND}) \frac{dN}{d\eta d\phi}\).

**“Minimum Bias” Collisions**

Proton

Underlying Event

Final-State Radiation

Outgoing Parton

PT(hard)

Initial-State Radiation

Proton

Underlying Event

Proton
Fragmentation Summary

Strange Particle & Baryon Yields: PYTHIA is off on the overall yield of Lambda’s and Cascades (MC below the data) and too high on the proton yield. Difficult to fix this without destroying agreement with LEP!

PT Distributions: PYTHIA does not describe correctly the $p_T$ distributions of heavy particles (MC softer than the data). None of the fragmentation parameters I have looked at changes the $p_T$ distributions. Hence, if one looks at particle ratios at large $p_T$ you can see big discrepancies between data and MC (out in the tails of the distributions)!

Factorization: Are we seeing a breakdown in factorization between $e^+e^-$ annihilations and hadron-hadron collisions! Is something happening in hadron-hadron collisions that does not happen in $e^+e^-$ annihilations?

Herwig++ & Sherpa: Before making any conclusions about fragmentation one must check the predictions of Herwig++ and Sherpa carefully!
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Herwig++ & Sherpa: Before making any conclusions about fragmentation one must check the predictions of Herwig++ and Sherpa carefully!
Before making any conclusion about $e^+e^-$ versus pp collisions one must check the predictions of Herwig++ and Sherpa!

Sherpa does better than PYTHIA 8!

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