Outline of Talk

- How well did we do at predicting the LHC UE data at 900 GeV and 7 TeV? A careful look.

- How well did we do at predicting the LHC MB data at 900 GeV and 7 TeV? A careful look.

- PYTHIA 6.4 Tune Z1: New CMS 6.4 tune (pT-ordered parton showers and new MPI).

- Strange particle production: A problem for the models?

- New physics in min-bias??: Observation of long-range same-side correlations at 7 TeV.
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 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 and final-state radiation.
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 other 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!
Look at charged particle correlations in the azimuthal angle $\Delta \phi$ relative to the leading charged particle jet.

- 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, $\Delta \eta \times \Delta \phi = 2\eta_{\text{cut}} \times 120^\circ = 2\eta_{\text{cut}} \times 2\pi/3$.
- Construct densities by dividing by the area in $\eta-\phi$ space.
Look at charged particle correlations in the azimuthal angle $\Delta \phi$ relative to the leading charged particle jet.

- 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.
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, $dN/d\eta d\phi$, 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).

CMS preliminary data 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 data are uncorrected and compared with PYTHIA Tune DW after detector simulation (216,215 events in the plot).
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).

CMS preliminary data 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 data are uncorrected and compared with PYTHIA Tune DW after detector simulation (216,215 events in the plot).
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.
**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| < 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, \(dN/d\eta d\phi\), 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.

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.
CMS preliminary data at 900 GeV and 7 TeV on the “transverse” charged PTsum density, dPT/dηdφ, 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.

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 \( p_T > 0.5 \text{ GeV/c} \) and \( |\eta| < 2.5 \). The data are corrected and compared with PYTHIA Tune DW at the generator level.
"Transverse" Charge Density

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).

$LHC\ 900\ GeV \rightarrow 7\ TeV$ (UE increase ~ factor of 2) $\sim 0.4 \rightarrow \sim 0.8$
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.

Ratio of the ATLAS 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 (PTmax) 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.
**PYTHIA Tune DW**

**Southeastern APS Meeting**
Baton Rouge, LA  October 23, 2010

**Rick Field – Florida/CDF/CMS**

---

Ratio of the CMS preliminary data at 900 GeV and 7 TeV on the “transverse” charged PTsum density, dPT/dηdφ, as defined by 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.

**CMS**

- Ratio: 7 TeV/900 GeV
- Charged Particles (|η|<2.0, PT>0.5 GeV/c)

**ATLAS**

- Ratio of the 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| < 2.5. The data are corrected and compared with PYTHIA Tune DW at the generator level.

**Ratio:** 7 TeV/900 GeV

- Charged Particles (|η|<2.5, PT>0.5 GeV/c)

---

**Sudbury**

- **Ratio:** 7 TeV/900 GeV
- Charged Particles (|η|<2.0, PT>0.5 GeV/c)

**ATLAS**

- **Ratio:** 8 TeV/900 GeV
- Charged Particles (|η|<2.5, PT>0.5 GeV/c)

---

**CMS**

- **Ratio:** 8 TeV/900 GeV
- Charged Particles (|η|<2.0, PT>0.5 GeV/c)

**ATLAS**

- **Ratio:** 8 TeV/900 GeV
- Charged Particles (|η|<2.5, PT>0.5 GeV/c)

---

**Sudbury**

- **Ratio:** 8 TeV/900 GeV
- Charged Particles (|η|<2.0, PT>0.5 GeV/c)

**ATLAS**

- **Ratio:** 9 TeV/900 GeV
- Charged Particles (|η|<2.5, PT>0.5 GeV/c)

---

**CMS**

- **Ratio:** 9 TeV/900 GeV
- Charged Particles (|η|<2.0, PT>0.5 GeV/c)

**ATLAS**

- **Ratio:** 9 TeV/900 GeV
- Charged Particles (|η|<2.5, PT>0.5 GeV/c)

---

**Sudbury**

- **Ratio:** 9 TeV/900 GeV
- Charged Particles (|η|<2.0, PT>0.5 GeV/c)

**ATLAS**

- **Ratio:** 9 TeV/900 GeV
- Charged Particles (|η|<2.5, PT>0.5 GeV/c)
CMS uncorrected 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, chgjet#1, with PT(chgjet#1) > 3 GeV/c compared with PYTHIA Tune DW at the detector level (i.e. Theory + SIM).

Shows the growth of the “underlying event” as the center-of-mass energy increases.
CMS uncorrected data at 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, chgjet#1, with $PT(chgjet#1) > 3$ GeV/c and $PT(chgjet#1) > 20$ GeV/c compared with PYTHIA Tune DW at the detector level (i.e. Theory + SIM).

- Shows the growth of the "underlying event" as the hard scale increases.
I am surprised that the Tunes did not do a better job of predicting the behavior of the “underlying event” at 900 GeV and 7 TeV!
How well did we do at predicting the “underlying event” at 900 GeV and 7 TeV?

I am surprised that the Tunes did as well as they did at predicting the behavior of the “underlying event” at 900 GeV and 7 TeV!
The “underlying event” at 7 TeV and 900 GeV is almost what we expected! With a little tuning we should be able to describe the data very well (see Tune Z1 later in this talk).

I am surprised that the Tunes did as well as they did at predicting the behavior of the “underlying event” at 900 GeV and 7 TeV! Remember this is “soft” QCD!

“Min-Bias” is a whole different story! Much more complicated due to diffraction!
The “underlying event” at 7 TeV and 900 GeV is almost what we expected! With a little tuning, we should be able to describe it very well.

I am surprised that the Tunes did as well as they did at predicting the behavior of the “underlying event”!

Remember this is “soft” QCD!

Warning! All the UE studies look at charged particles with $p_T > 0.5$ GeV/c. We do not know if the models correctly describe the UE at lower $p_T$ values!

“Min-Bias” is a whole different story! Much more complicated due to diffraction!
Proton-Proton Collisions

Elastic Scattering

Single Diffraction

Double Diffraction

\[ \sigma_{tot} = \sigma_{EL} + \sigma_{SD} + \sigma_{DD} + \sigma_{ND} \]

“Inelastic Non-Diffractive Component”

The “hard core” component contains both “hard” and “soft” collisions.

“Soft” Hard Core (no hard scattering)

“Hard” Hard Core (hard scattering)
The Inelastic Non-Diffractive Cross-Section

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

Multiple-parton interactions (MPI)!
The Inelastic Non-Diffractive Cross-Section

Majority of “min-bias” events!

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

Multiple-parton interactions (MPI)!

+ + + + +
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 ($p_T < \approx 2$ GeV/c)

Multiple-parton interactions (MPI)!

"Semi-hard" parton-parton collision (p$_T$ > 2 GeV/c)
The “Underlying Event”

Select inelastic non-diffractive events that contain a hard scattering

- Proton

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)

Given that you have one hard scattering it is more probable to have MPI! Hence, the UE has more activity than “min-bias”.

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

“Underlying Event”

“Min-Bias” (ND)

Predict MB (ND)!

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

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

Fit the “underlying event” in a hard scattering process.

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

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

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

Predict MB (ND)!

Southeastern APS Meeting
Baton Rouge, LA  October 23, 2010

Rick Field – Florida/CDF/CMS  Page 28
LHC MB Predictions: 900 GeV

Compared 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 $|\eta| < 0.6$. 

Southeastern APS Meeting
Baton Rouge, LA  October 23, 2010
Rick Field – Florida/CDF/CMS
Page 29
LHC MB Predictions: 900 GeV

- Compares the 900 GeV 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/dη for the region |η| < 0.6.
None of the tunes fit the ATLAS INEL $dN/d\eta$ data with $p_T > 100$ MeV! They all predict too few particles.

The ATLAS Tune AMBT1 was designed to fit the inelastic data for $N_{ch}g \geq 6$ with $p_T > 0.5$ GeV/c!
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 $PTmin = 0.15 \text{ GeV/c}$, $0.5 \text{ GeV/c}$, and $1.0 \text{ GeV/c}$ compared with PYTHIA Tune DW at the generator level.

The same thing occurs at 7 TeV! ALICE, ATLAS, and CMS data coming soon.
ALICE inelastic data at 900 GeV on the $dN/d\eta$ distribution for charged particles ($p_T > PT_{min}$) for events with at least one charged particle with $p_T > PT_{min}$ and $|\eta| < 0.8$ for $PT_{min} = 0.15\text{ GeV}/c$, $0.5\text{ GeV}/c$, and $1.0\text{ GeV}/c$ compared with PYTHIA Tune Z1 at the generator level (dashed = ND, solid = INEL).

Diffraction contributes less at harder scales!

Cannot trust PYTHIA 6.2 modeling of diffraction!
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.

Off by 50%!
Okay if the Monte-Carlo does not fit the data what do we do?
We tune the Monte-Carlo to fit the data!

- Generator level dN/dη 7 TeV

RDF Preliminary
CMS NSD data pyDW generator level
Dashed = ND  solid = NSD
CMS

Off by 50%!
Okay if the Monte-Carlo does not fit the data what do we do?

We tune the Monte-Carlo to fit the data!

Be careful not to tune away new physics!
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 Nchge ≥ 6 and to fit the PTmax UE data with PTmax > 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>
</tr>
</thead>
<tbody>
<tr>
<td>Parton Distribution Function</td>
<td>CTEQ5L</td>
<td>LO*</td>
</tr>
<tr>
<td>PARP(82) – MPI Cut-off</td>
<td>1.932</td>
<td>2.292</td>
</tr>
<tr>
<td>PARP(89) – Reference energy, E0</td>
<td>1800.0</td>
<td>1800.0</td>
</tr>
<tr>
<td>PARP(90) – MPI Energy Extrapolation</td>
<td>0.275</td>
<td>0.25</td>
</tr>
<tr>
<td>PARP(77) – CR Suppression</td>
<td>1.016</td>
<td>1.016</td>
</tr>
<tr>
<td>PARP(78) – CR Strength</td>
<td>0.538</td>
<td>0.538</td>
</tr>
<tr>
<td>PARP(80) – Probability colored parton from BBR</td>
<td>0.1</td>
<td>0.1</td>
</tr>
<tr>
<td>PARP(83) – Matter fraction in core</td>
<td>0.356</td>
<td>0.356</td>
</tr>
<tr>
<td>PARP(84) – Core of matter overlap</td>
<td>0.651</td>
<td>0.651</td>
</tr>
<tr>
<td>PARP(62) – ISR Cut-off</td>
<td>1.025</td>
<td>1.025</td>
</tr>
<tr>
<td>PARP(93) – primordial kT-max</td>
<td>10.0</td>
<td>10.0</td>
</tr>
<tr>
<td>MSTP(81) – MPI, ISR, FSR, BBR model</td>
<td>21</td>
<td>21</td>
</tr>
<tr>
<td>MSTP(82) – Double gaussian matter distribution</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>MSTP(91) – Gaussian primordial kT</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>MSTP(95) – strategy for color reconnection</td>
<td>6</td>
<td>6</td>
</tr>
</tbody>
</table>
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 uncorrected and compared with PYTHIA Tune DW and D6T after detector simulation (SIM).

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 uncorrected and compared with PYTHIA Tune Z1 after detector simulation (SIM).

**Tune Z1 (CTEQ5L)**
- \( \text{PARP}(82) = 1.932 \)
- \( \text{PARP}(90) = 0.275 \)
- \( \text{PARP}(77) = 1.016 \)
- \( \text{PARP}(78) = 0.538 \)

Tune Z1 is a PYTHIA 6.4 using \( p_T \)-ordered parton showers and the new MPI model!
CMS preliminary data at 900 GeV and 7 TeV on the “transverse” charged PTsum density, dPT/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 uncorrected and compared with PYTHIA Tune DW and D6T after detector simulation (SIM).

PYTHIA Tune Z1

Color reconnection suppression. Color reconnection strength.

Tune Z1 (CTEQ5L)
PARP(82) = 1.932
PARP(90) = 0.275
PARP(77) = 1.016
PARP(78) = 0.538

Tune Z1 is a PYTHIA 6.4 using p_T-ordered parton showers and the new MPI model!
**SEAS Southeastern APS Meeting**
**Baton Rouge, LA October 23, 2010**

**Rick Field – Florida/CDF/CMS**

Page 41

#### 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| < 2.5. 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| < 2.5. The data are corrected and compared with PYTHIA Tune Z1 at the generator level.

---

**Tune Z1 (CTEQ5L)**
- PARP(82) = 1.932
- PARP(90) = 0.275
- PARP(77) = 1.016
- PARP(78) = 0.538

**Color reconnection suppression. Color reconnection strength.**

**Tune Z1 is a PYTHIA 6.4 using p_T-ordered parton showers and the new MPI model!**
Ratio of CMS preliminary data at 900 GeV and 7 TeV (7 TeV divided by 900 GeV) on the “transverse” charged particle density 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 uncorrected and compared with PYTHIA Tune DW, D6T, CW, and P0 after detector simulation (SIM).
**Ratio of CMS preliminary data at 900 GeV and 7 TeV (7 TeV divided by 900 GeV) on the “transverse” charged PTsum density 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 uncorrected and compared with PYTHIA Tune DW, D6T, CW, and P0 after detector simulation (SIM).**

**Ratio of CMS preliminary data at 900 GeV and 7 TeV (7 TeV divided by 900 GeV) on the “transverse” charged PTsum density 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 uncorrected and compared with PYTHIA Tune Z1 after detector simulation (SIM).**
Ratio of the ATLAS preliminary data on the charged particle density in the “transverse” region for charged particles (p_T > 0.5 GeV/c, |η| < 2.5) at 900 GeV and 7 TeV as defined by PTmax compared with PYTHIA Tune Z1 at the generator level.

Ratio of the ATLAS preliminary data on the charged PTsum density in the “transverse” region for charged particles (p_T > 0.5 GeV/c, |η| < 2.5) at 900 GeV and 7 TeV as defined by PTmax compared with PYTHIA Tune Z1 at the generator level.
CMS uncorrected 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 DW and Tune D6T at the detector level (i.e. Theory + SIM).

CMS uncorrected 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 detector level (i.e. Theory + SIM).
CMS uncorrected data at 900 GeV and 7 TeV on the charged scalar PTsum 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 $PT(\text{chgjet#1}) > 3$ GeV/c compared with PYTHIA Tune DW, and Tune D6T at the detector level (i.e. Theory + SIM).

CMS uncorrected data at 900 GeV and 7 TeV on the charged scalar PTsum 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 $PT(\text{chgjet#1}) > 3$ GeV/c compared with PYTHIA Tune Z1, at the detector level (i.e. Theory + SIM).
CMS uncorrected data at 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 and $p_T(chgjet#1) > 20$ GeV/c compared with PYTHIA Tune DW and Tune D6T at the detector level (i.e. Theory + SIM).

CMS uncorrected data at 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 and $p_T(chgjet#1) > 20$ GeV/c compared with PYTHIA Tune Z1 at the detector level (i.e. Theory + SIM).
CMS uncorrected data at 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, chgjet#1, with $PT(chgjet#1) > 3$ GeV/c and $PT(chgjet#1) > 20$ GeV/c compared with PYTHIA Tune Z1 at the detector level (i.e. Theory + SIM).

Difficult to produce enough events with large “transverse” multiplicity at low hard scale!
CMS uncorrected data at 7 TeV on the charged PTsum 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 and $PT(chgjet#1) > 20$ GeV/c compared with PYTHIA Tune DW and Tune D6T at the detector level (i.e. Theory + SIM).
CMS uncorrected data at 7 TeV on the charged PTsum distribution in the “transverse” region for charged particles ($p_T > 0.5$ GeV/c, $|\eta| < 2$) as defined by the leading charged particle jet, chgjet#1, with PT(chgjet#1) > 3 GeV/c and PT(chgjet#1) > 20 GeV/c compared with PYTHIA Tune Z1 at the detector level (i.e. Theory + SIM).

Difficult to produce enough events with large “transverse” PTsum at low hard scale!
Generator level $dN/d\eta$ (all pT). Shows the NSD = HC + DD and the HC = ND contributions for Tune Z1. Also shows the CMS NSD data.

Generator level $dN/d\eta$ (all pT). Shows the NSD = HC + DD prediction for Tune Z1 and Tune X2. Also shows the CMS NSD data.

Okay not perfect, but remember we do not know if the DD is correct!
ALICE inelastic data at 900 GeV on the $dN/d\eta$ distribution for charged particles ($p_T > PT_{\text{min}}$) for events with at least one charged particle with $p_T > PT_{\text{min}}$ and $|\eta| < 0.8$ for $PT_{\text{min}} = 0.15 \text{ GeV/c}, 0.5 \text{ GeV/c}$, and $1.0 \text{ GeV/c}$ compared with PYTHIA Tune Z1 at the generator level.

Okay not perfect, but remember we do not know if the SD & DD are correct!
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.

Okay not perfect! But not that bad!
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.

CMS uncorrected 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 detector level (i.e. Theory + SIM).
CMS uncorrected data at 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 $PT(chgjet#1) > 20$ GeV/c compared with PYTHIA Tune Z1 at the detector level (i.e. Theory + SIM). Also shows the CMS corrected NSD multiplicity distribution (all pT, $|\eta| < 2$) compared with Tune Z1 at the generator.

Amazing what we are asking the Monte-Carlo models to fit!
CMS uncorrected data at 7 TeV on the charged particle multiplicity distribution in the “transverse” region for charged particles \((p_T > 0.5 \text{ GeV}/c, |\eta| < 2)\) as defined by the leading charged particle jet with \(PT(\text{chgjet}\#1) > 20 \text{ GeV}/c\) compared with PYTHIA Tune Z1 at the detector level (\textit{i.e.} Theory + SIM). Also shows the CMS corrected NSD multiplicity distribution (all \(p_T, |\eta| < 2\)) compared with Tune Z1 at the generator.

Amazing what we are asking the Monte-Carlo models to fit!
Strange Particle Production

A lot more strange mesons at large $p_T$ than predicted by the Monte-Carlo Models!

$K/\pi$ ratio fairly independent of the center-of-mass energy.

$\Rightarrow$ A lot more strange mesons at large $p_T$ than predicted by the Monte-Carlo Models!

$\Rightarrow$ $K/\pi$ ratio fairly independent of the center-of-mass energy.
Signal, $S$, is two particles in the same event. Background, $B$, is two particles in two different events.

Correlation, $R$, is $(S-B)/B$. 
Bose-Einstein

CMS “min-bias” 7 TeV
Two Particle Angular Correlations

CMS “min-bias” 7 TeV

Two Particles in Same Jet

Jet#1

Jet#2
Two Particle Angular Correlations

CMS “min-bias” 7 TeV
A dedicated high multiplicity trigger was implemented in the two levels of the CMS trigger system. Level 1 (L1): Sum of the total ET (ECAL, HCAL, and HF) > 60 GeV.

High-level trigger (HLT): number of online tracks built from the three layers of pixel detectors >70 (85).
Two Particle Angular Correlations

Average “Min-Bias”

High Multiplicity “Min-Bias”

Lots of jets at high multiplicity!
Two Particle Angular Correlations

Average “Min-Bias”
(a) MinBias, $p_T > 0.1\text{GeV/c}$

High Multiplicity “Min-Bias”
(c) $N > 110$, $p_T > 0.1\text{GeV/c}$

Back-to-back jet correlations: enhanced in high multiplicity
Two Particles in Two Jets
Two Particle Angular Correlations

Average “Min-Bias”

(b) MinBias, 1.0GeV/c<p_{T}<3.0GeV/c

High Multiplicity “Min-Bias”

(d) N>110, 1.0GeV/c<p_{T}<3.0GeV/c

Striking “ridge” structure extending to large Δη at Δφ ~ 0

➔ Long range (in Δη) same side correlations! What is this?
Long range correlations expected in “collective flow” in heavy ion collisions.
Long-range “Ridge”-like structure in $\Delta \eta$ at $\Delta \phi \approx 0!$
Long-Range Same-Side Correlations

High Multiplicity “Min-Bias”
(d) N>110, 1.0GeV/c<p_{\text{T}}<3.0GeV/c

→ Observation of a Long-Range, Near-Side angular correlations at high multiplicity in pp events at intermediate p_{\text{T}} (Ridge at \Delta \phi \sim 0)

Not there in PYTHIA8! Also not there in PYTHIA 6 and HERWIG++!
Proton-Proton Collisions 7 TeV

(d) \( N>110, \ 1.0\text{GeV/c}<p_T<3.0\text{GeV/c} \)

Gold-Gold Collisions 200 GeV

- I am not ready to jump on the quark-gluon plasma bandwagon quite yet!

Similar “ridge” in high multiplicity pp
(even similar \( p_T \) dependence)
Jet-Jet Correlations

Are the “leading-log” or “modified leading-log” QCD Monte-Carlo Models missing an important QCD correlation?

The leading jet and the incident protons form a plane (yz-plane in the figure). This is the plane of the hard scattering.

Initial & final-state radiation prefers to lie in this plane. This is a higher order effect that you can see in the $2\to3$ or $2\to4$ matrix elements, but it is not there if you do $2\to2$ matrix elements and then add radiation using a naïve leading log approximation (i.e. independent emission).

I do not know to what extent this higher order jet-jet correlation is incorporated in the QCD Monte-Carlo models.

I would think that this jet-jet correlation would produce a long range (in $\Delta\eta$) correlation with $\Delta\phi \approx 0$ from two particles with one in the leading jet and one in the radiated jet. Why don’t we see this in the Monte-Carlo models?
Jet-Jet Correlations

- **Initial & Final-State Radiation:** There should be more particles “in-the-plane” of the hard scattering (yz-plane in the figure) than “out-of –the-plane”.

- I do not understand why this does not result in a long-range same-side correlation?
We are a long way from having a Monte-Carlo model that will fit all the features of the LHC min-bias data! There are more soft particles that expected!

We need a better understanding and modeling of diffraction!

It is difficult for the Monte-Carlo models to produce a soft event (i.e. no large hard scale) with a large multiplicity. There seems to be more “min-bias” high multiplicity soft events at 7 TeV than predicted by the models!

The models do not produce enough strange particles! I have no idea what is going on here! The Monte-Carlo models are constrained by LEP data.