Energy Dependence of the UE

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Outline of Talk

- CDF PYTHIA 6.2 Tevatron Tune DW predictions.
- CMS PYTHIA 6.4 LHC Tune Z1.
- LPCC MB&UE working group “common plots”.
- New UE data at 300 GeV, 900 GeV, and 1.96 TeV from the Tevatron Energy-Scan.
- New comparisons with PYTHIA 6.2 Tune DW and PYTHIA 6.4 Tune Z1.
- Much more coming soon!

CDF Run 2
300 GeV, 900 GeV, 1.96 TeV

CMS at the LHC
900 GeV, 7 & 8 TeV

ICHEP 2012
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Rick Field – Florida/CDF/CMS
Page 1
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 the “underlying event”.

The “underlying event” is an unavoidable background to most collider observables and having good understand of it leads to more precise collider measurements!
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Default</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>PARP(83)</td>
<td>0.5</td>
<td>Double-Gaussian: Fraction of total hadronic matter within PARP(84)</td>
</tr>
<tr>
<td>PARP(84)</td>
<td>0.2</td>
<td>Double-Gaussian: Fraction of the overall hadron radius containing the fraction PARP(83) of the total hadronic matter.</td>
</tr>
<tr>
<td>PARP(85)</td>
<td>0.33</td>
<td>Produces two gluons with color connections to the &quot;nearest neighbors.&quot;</td>
</tr>
<tr>
<td>PARP(86)</td>
<td>0.66</td>
<td>Probability that the MPI produces two gluons either as described by PARP(85) or as a closed gluon loop. The remaining fraction consists of quark-antiquark pairs.</td>
</tr>
<tr>
<td>PARP(89)</td>
<td>1 TeV</td>
<td>Determines the reference energy $E_0$.</td>
</tr>
<tr>
<td>PARP(82)</td>
<td>1.09 GeV/c</td>
<td>The cut-off $P_{T0}$ that regulates the 2-to-2 scattering divergence $1/PT^4 \rightarrow 1/(PT^2 + P_{T0}^2)^2$</td>
</tr>
<tr>
<td>PARP(90)</td>
<td>0.16</td>
<td>Determines the energy dependence of the cut-off $P_{T0}$ as follows $P_{T0}(E_{cm}) = P_{T0}(E_{cm}/E_0)\varepsilon$ with $\varepsilon = PARP(90)$</td>
</tr>
<tr>
<td>PARP(67)</td>
<td>1.0</td>
<td>A scale factor that determines the maximum parton virtuality for space-like showers. The larger the value of PARP(67) the more initial-state radiation.</td>
</tr>
</tbody>
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**Determines the energy dependence of the MPI!**

**Multiple Parton Interaction Parameters**

- **Determines the energy dependence of the cut-off $P_{T0}$**
- **A scale factor that determines the maximum parton virtuality for space-like showers.**
- **Take $E_0 = 1.8$ TeV**
- **Determine by comparing with 630 GeV data!**
- **Reference point at 1.8 TeV**
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 $P_T \text{min} = 0.5 \text{ GeV}/c \eta_{\text{cut}} = 1$.

Define $|\Delta \phi| < 60^0$ as “Toward”, $60^0 < |\Delta \phi| < 120^0$ as “Transverse”, and $|\Delta \phi| > 120^0$ as “Away”.

All three regions have the same area in $\eta$-$\phi$ space, $\Delta \eta \times \Delta \phi = 2\eta_{\text{cut}} \times 120^0 = 2\eta_{\text{cut}} \times 2\pi/3$. 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, |η| < 1) at 7 TeV as defined by PTmax, PT(chgjet#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.
Min-Bias “Associated” Charged Particle Density

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) 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).

RHIC 0.2 TeV → 1.96 TeV (UE increase ~2.7 times) → Tevatron 1.96 TeV → 14 TeV (UE increase ~1.9 times) → LHC

Linear scale!
Min-Bias “Associated” Charged Particle Density

 Shows the “associated” charged particle density in the “transverse” region as a function of PTmax for charged particles ($p_T > 0.5$ GeV/c, $|\eta| < 1$, 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).
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 p_T > 0.5 GeV/c and |η| < 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.
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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 \( p_T > 0.5 \text{ GeV/c} \) and \( |\eta| < 2 \). The data are uncorrected and compared with PYTHIA Tune DW after detector simulation.
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 Nchgl ≥ 6 and to fit the PT_{max} UE data with PT_{max} > 10 GeV/c. Tune AMBT1 is primarily a min-bias tune, while Tune Z1 is a UE tune!
### PYTHIA Tune Z1

<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>

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!

CMS UE Data

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ATLAS published 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 published 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.

ATLAS publication – arXiv:1012.0791
December 3, 2010
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.
"Transverse" Charged Particle Density: $dN/d\eta d\phi$

RDF Preliminary
Tune Z1 generator level

ALICE (red)
ATLAS (blue)

7 TeV Charged Particles ($|\eta| < 0.8$, $PT > 0.5$ GeV/c)

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

RDF Preliminary
Tune Z1 generator level

ALICE (red)
ATLAS (blue)

7 TeV Charged Particles ($|\eta| < 0.8$, $PT > 0.5$ GeV/c)

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

RDF Preliminary
Tune Z1 generator level

ALICE (red)
ATLAS (blue)

900 GeV Charged Particles ($|\eta| < 0.8$, $PT > 0.5$ GeV/c)

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

RDF Preliminary
Tune Z1 generator level

ALICE (red)
ATLAS (blue)

900 GeV Charged Particles ($|\eta| < 0.8$, $PT > 0.5$ GeV/c)
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 ($P_{T\text{max}}$) 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.

Very nice agreement!

CMS corrected data!
New CMS UE Data

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 (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.

RT: Very nice agreement!

CMS corrected data!
UE Common Plots

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

RDF Preliminary corrected data

CMS (solid red)
ATLAS (solid blue)
ALICE (open black)
Charged Particles ($|\eta| < 0.8$, $PT > 0.5$ GeV/c)

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

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Charged Particles ($|\eta| < 0.8$, $PT > 0.5$ GeV/c)
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 Corrected CDF data at 300 GeV, 900 GeV, and 1.96 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| < 1.0.
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Ratio of the CDF data at 300 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 $|\eta| < 1.0$. Shows 1.96 TeV divided by 300 GeV.
New Corrected 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.

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Ratio of the CDF data at 900 GeV and 1.96 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| < 1.0. Shows 1.96 TeV divided by 900 GeV.
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“Transverse” Charged Particle Density: $dN/d\eta d\phi$

CDF Preliminary
Corrected Data
Tune DW Generator Level

1.96 TeV
900 GeV
300 GeV

PYTHIA Tune DW

Charged Particles ($|\eta|<1.0$, $PT>0.5$ GeV/c)

PTmax (GeV/c)

Ratio

1.96 TeV divided by 300 GeV
900 GeV divided by 300 GeV

Region

1.0
1.5
2.0

1.0
1.2
1.4
1.6

CDF Preliminary
Corrected Data
Tune DW Generator Level

1.96 TeV divided by 900 GeV

Panels show the comparison of different energy scales with PYTHIA Tune DW generator level.
"Transverse" Charged Particle Density: $dN/d\eta d\phi$

CDF Preliminary Corrected Data
Tune Z1 Generator Level

1.96 TeV
900 GeV
300 GeV

PYTHIA Tune Z1

Charged Particles ($|\eta|<1.0$, $PT>0.5$ GeV/c)

PTmax (GeV/c)

"Transverse" Charged Density

Center-of-Mass Energy (TeV)

PYTHIA Tune Z1

5.0 < PTmax < 6.0 GeV/c
Charged Particles ($|\eta|<1.0$, $PT>0.5$ GeV/c)
PYTHIA 6.4 Tune Z1

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

CDF Preliminary Corrected Data
Tune Z1 Generator Level

1.96 TeV
900 GeV
300 GeV

Charged Particles ($|\eta|<1.0$, $P_T>0.5$ GeV/c)

PTmax (GeV/c)

Ratio

CDF Preliminary Corrected Data
Tune Z1 Generator Level

1.96 TeV divided by 300 GeV
900 GeV divided by 300 GeV

Charged Particles ($|\eta|<1.0$, $P_T>0.5$ GeV/c)

PTmax (GeV/c)
PYTHIA 6.4 Tune Z1

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

CDF Preliminary Corrected Data
Tune Z1 Generator Level

Charged Particles ($|\eta|<1.0, PT>0.5$ GeV/c)

1.96 TeV

300 GeV

900 GeV

PYTHIA Tune Z1

ATLAS

CMS

ALICE

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Published CDF Run 2 data at 1.96 TeV on the “transverse” charged particle density, \( \frac{dN}{d\eta d\phi} \), as defined by the leading calorimeter jet (jet#1) for charged particles with \( p_T > 0.5 \text{ GeV/c} \) and \( |\eta| < 1.0 \) compared with PYTHIA Tune Z1.

New CDF data 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 \( p_T > 0.5 \text{ GeV/c} \) and \( |\eta| < 1.0 \) compared with PYTHIA Tune Z1.
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Okay
No inconsistency
But need to understand!

CDF - Two $\eta$ Ranges: Must do $(p_T > 0.5 \text{ GeV/c}, |\eta| < 0.8)$ as well as $(p_T > 0.5 \text{ GeV}, |\eta| < 1)$.

CDF - Min-Bias: Many MB observables: Multiplicity, $dN/d\eta$, $p_T$ distribution, $<p_T>$ versus Nchg, etc.

Soon we will have MB & UE data at 300 GeV, 900 GeV, 1.96 TeV, 7 TeV, and 8 TeV! We can study the energy dependence more precisely than ever before!

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CDF - Min-Bias: Many MB observables: Multiplicity, \(dN/d\eta\), pt distribution, \(<p_T>\) versus Nchg, etc.

Soon we will have MB & UE data at 300 GeV, 900 GeV, 1.96 TeV, 7 TeV, and 8 TeV! We can study the energy dependence more precisely than ever before!

What we are learning should allow for more precise predictions at the future LHC energy of 13 TeV!