Outlining of Talk

- Ricky, Sally & Jimmie.
- What is the “underlying event” (UE)?
- CMS UE Tunes: Two PYTHIA 6 tunes, three PYTHIA 8 tunes, and one HERWIG++ tune from the CMS “Physics Comparisons & Generator Tunes” subgroup.
- The Energy Dependence of the UE: Detailed look at the energy dependence of the UE and the extrapolation to 13 TeV.
- Predictions at 13 TeV: Compare the CMS PYTHIA 8 tunes with the Skands Monash tune and the PYTHIA 6 Tune Z2* at 13 TeV.
- MB & UE Data 13 TeV: Look at the early MB data from CMS and ATLAS and the early UE data from ATLAS.
My mother was born on May 10, 1922, in Houston Texas. She died on Sunday November 6, 2011 in Malibu, California at age 89.
Margaret Field in “The Man From Planet X” (1951)

http://www.youtube.com/watch?v=896jnOb1fcI

Sally Field - Actress
The Berkeley Years

R. D. Field
University of California, Berkeley, 1962-66 (undergraduate)
University of California, Berkeley, 1966-71 (graduate student)

Rick Field 1964

Rick & Jimmie 1968
The Berkeley Years

R. D. Field
University of California, Berkeley, 1962-66 (undergraduate)
University of California, Berkeley, 1966-71 (graduate student)

Rick Field 1964

me

My sister Sally!

Rick & Jimmie 1968

Rick & Jimmie 1968
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

Proton Proton Proton Proton + + …

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

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

The "underlying-event" (UE)!

Multiple-parton interactions (MPI)!

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

$p_{T0}(E_{cm}) = p_{T0Ref} \times (E_{cm}/E_{cmRef})^{ecmPow}$
Traditional Approach

Look at charged particle correlations in the azimuthal angle $\Delta \phi$ relative to a leading object (i.e., CaloJet#1, ChgJet#1, PTmax, Z-boson). For CDF PTmin = 0.5 GeV/c $\eta_{\text{cut}} = 1.0$ or 0.8.

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.
Early Studies of the UE

DPF 2000: My first presentation on the “underlying event”!

First CDF UE Studies
Rick Field Wine & Cheese Talk
October 4, 2002
My First Talk on the UE

DiJet: Charged Multiplicity versus PT(chgjet#1)

The Underlying Event: Summary & Conclusions

Need to “tune” the QCD MC models!

My first look at the “underlying event plateau”!

"Underlying Event" Publications


- Many LHC UE Studies
  - HERWIG++ UE Tune, M. Seymour and A. Siódmok!
  - Monash Tune, Peter Skands!
  - Perugia Tunes, Peter Skands!
  - Gavin Salam!
The goal is to produce data (corrected to the particle level) that can be used by the theorists to tune and improve the QCD Monte-Carlo models that are used to simulate hadron-hadron collisions.

http://arxiv.org/abs/1508.05340
**UE Observables**

- **“Transverse” Charged Particle Density**: Number of charged particles ($p_T > 0.5 \text{ GeV/c}, |\eta| < \eta_{\text{cut}}$) in the “transverse” region as defined by the leading charged particle, $P_{T\text{max}}$, divided by the area in $\eta$-$\phi$ space, $2\eta_{\text{cut}} \times 2\pi/3$, averaged over all events with at least one particle with $p_T > 0.5 \text{ GeV/c}, |\eta| < \eta_{\text{cut}}$.

- **“Transverse” Charged PTsum Density**: Scalar $p_T$ sum of the charged particles ($p_T > 0.5 \text{ GeV/c}, |\eta| < \eta_{\text{cut}}$) in the “transverse” region as defined by the leading charged particle, $P_{T\text{max}}$, divided by the area in $\eta$-$\phi$ space, $2\eta_{\text{cut}} \times 2\pi/3$, averaged over all events with at least one particle with $p_T > 0.5 \text{ GeV/c}, |\eta| < \eta_{\text{cut}}$.

- **“Transverse” Charged Particle Average $P_T$**: Event-by-event $<p_T> = \text{PTsum}/\text{Nchg}$ for charged particles ($p_T > 0.5 \text{ GeV/c}, |\eta| < \eta_{\text{cut}}$) in the “transverse” region as defined by the leading charged particle, $P_{T\text{max}}$, averaged over all events with at least one particle in the “transverse” region with $p_T > 0.5 \text{ GeV/c}, |\eta| < \eta_{\text{cut}}$.

- **Zero “Transverse” Charged Particles**: If there are no charged particles in the “transverse” region then $\text{Nchg}$ and $\text{PTsum}$ are zero and one includes these zeros in the average over all events with at least one particle with $p_T > 0.5 \text{ GeV/c}, |\eta| < \eta_{\text{cut}}$. However, if there are no charged particles in the “transverse” region then the event is not used in constructing the “transverse” average $p_T$. 

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*Durham, September 8, 2015*  
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“transMAX” and “transMIN” Charged Particle Density: Number of charged particles ($p_T > 0.5$ GeV/c, $|\eta| < 0.8$) in the the maximum (minimum) of the two “transverse” regions as defined by the leading charged particle, $p_T$max, divided by the area in $\eta$-$\phi$ space, $2\eta_{cut} \times 2\pi/6$, averaged over all events with at least one particle with $p_T > 0.5$ GeV/c, $|\eta| < \eta_{cut}$.

“transMAX” and “transMIN” Charged PTsum Density: Scalar $p_T$ sum of charged particles ($p_T > 0.5$ GeV/c, $|\eta| < 0.8$) in the the maximum (minimum) of the two “transverse” regions as defined by the leading charged particle, $p_T$max, divided by the area in $\eta$-$\phi$ space, $2\eta_{cut} \times 2\pi/6$, averaged over all events with at least one particle with $p_T > 0.5$ GeV/c, $|\eta| < \eta_{cut}$.

Note: The overall “transverse” density is equal to the average of the “transMAX” and “transMIN” densities. The “TransDIF” Density is the “transMAX” Density minus the “transMIN” Density.

\[
\text{“Transverse” Density} = \text{“transAVE” Density} = \frac{\text{“transMAX” Density} + \text{“transMIN” Density}}{2}
\]

\[
\text{“TransDIF” Density} = \text{“transMAX” Density} - \text{“transMIN” Density}
\]
The “toward” region contains the leading “jet”, while the “away” region, on the average, contains the “away-side” “jet”. The “transverse” region is perpendicular to the plane of the hard 2-to-2 scattering and is very sensitive to the “underlying event”. For events with large initial or final-state radiation the “transMAX” region defined contains the third jet while both the “transMAX” and “transMIN” regions receive contributions from the MPI and beam-beam remnants. Thus, the “transMIN” region is very sensitive to the multiple parton interactions (MPI) and beam-beam remnants (BBR), while the “transMAX” minus the “transMIN” (i.e. “transDIF”) is very sensitive to initial-state radiation (ISR) and final-state radiation (FSR).

- “TransMIN” density more sensitive to MPI & BBR.
- “TransDIF” density more sensitive to ISR & FSR.

\[ 0 \leq \text{“TransDIF”} \leq 2 \times \text{“TransAVE”} \]

“TransDIF” = “TransAVE” if “TransMIX” = 3 \times “TransMIN”
Corrected CMS data at 7 TeV and CDF data at 1.96 TeV, 900 GeV, and 300 GeV on the charged particle density in the “transMAX”, “transMIN”, and “transDIF” regions 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 to the particle level with errors that include both the statistical error and the systematic uncertainty.
Corrected CDF data at 1.96 TeV, 900 GeV, and 300 GeV on the charged PTsum density in the “transMAX”, “transMIN”, and “transDIF” regions 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 to the particle level with errors that include both the statistical error and the systematic uncertainty.
Corrected CMS data at 7 TeV and CDF data at 1.96 TeV, 900 GeV, and 300 GeV on the charged particle density in the “transMAX” region 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 to the particle level with errors that include both the statistical error and the systematic uncertainty.

Corrected CMS and CDF data on the charged particle density in the “transMAX” region as defined by the leading charged particle (PTmax) for charged particles with p_T > 0.5 GeV/c and |η| < 0.8 with 5 < PTmax < 6 GeV/c. The data are plotted versus the center-of-mass energy (log scale).
Corrected CMS data at 7 TeV and CDF data at 1.96 TeV, 900 GeV, and 300 GeV on the charged particle density in the “transMIN” region 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 to the particle level with errors that include both the statistical error and the systematic uncertainty.

Corrected CMS and CDF data on the charged particle density in the “transMIN” region as defined by the leading charged particle (PTmax) for charged particles with p_T > 0.5 GeV/c and |η| < 0.8 with 5 < PTmax < 6 GeV/c. The data are plotted versus the center-of-mass energy (log scale).
Corrected CMS data at 7 TeV and CDF data at 1.96 TeV, 900 GeV, and 300 GeV on the charged particle density in the “transMAX” and “transMIN” regions as defined by the leading charged particle (PTmax) for charged particles with p_T > 0.5 GeV/c and |η| < 0.8 with 5 < PTmax < 6 GeV/c. The data are plotted versus the center-of-mass energy (log scale).

Ratio of CMS data at 7 TeV and CDF data at 1.96 TeV, 900 GeV, and 300 GeV to the value at 300 GeV for the charged particle density in the “transMAX” and “transMIN” regions as defined by the leading charged particle (PTmax) for charged particles with p_T > 0.5 GeV/c and |η| < 0.8 with 5 < PTmax < 6 GeV/c. The data are plotted versus the center-of-mass energy (log scale).
**Corrected CMS data at 7 TeV and CDF data at 1.96 TeV, 900 GeV, and 300 GeV** on the charged particle density in the “transAVE” and “transDIF” regions as defined by the leading charged particle (PTmax) for charged particles with p_T > 0.5 GeV/c and |η| < 0.8 with 5 < PTmax < 6 GeV/c. The data are plotted versus the center-of-mass energy (log scale).

**Ratio of CMS data at 7 TeV and CDF data at 1.96 TeV, 900 GeV, and 300 GeV to the value at 300 GeV** for the charged particle density in the “transAVE” and “transDIF” regions as defined by the leading charged particle (PTmax) for charged particles with p_T > 0.5 GeV/c and |η| < 0.8 with 5 < PTmax < 6 GeV/c. The data are plotted versus the center-of-mass energy (log scale).
**“TransMIN/DIF” vs $E_{cm}$**

- **Ratio of CMS data at 7 TeV and CDF data at 1.96 TeV, 900 GeV, and 300 GeV to the value at 300 GeV for the charged particle density in the “transMIN”, and “transDIF” regions as defined by the leading charged particle ($p_T$) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$ with $5 < p_T < 6$ GeV/c. The data are plotted versus the center-of-mass energy (log scale).**

- **Ratio of CMS data at 7 TeV and CDF data at 1.96 TeV, 900 GeV, and 300 GeV to the value at 300 GeV for the charged PTsum density in the “transMIN”, and “transDIF” regions as defined by the leading charged particle ($p_T$) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$ with $5 < p_T < 6$ GeV/c. The data are plotted versus the center-of-mass energy (log scale).**
First Time Seen

The “transMIN” (MPI-BBR component) increases much faster with center-of-mass energy than the “transDIF” (ISR-FSR component)!

- Ratio of CMS data at 7 TeV and CDF data at 1.96 TeV, 900 GeV, and 300 GeV to the value at 300 GeV of the charged PTsum density in the “transMIN” and “transDIF” regions as defined by the leading charged particle (PTmax) for charged particles with p_T > 0.5 GeV/c and |η| < 0.8 with 5 < PTmax < 6 GeV/c. The data are plotted versus the center-of-mass energy (log scale).

- Transverse Charged Particle Density Ratio
  - RDF Preliminary Corrected Data
  - Divided by 300 GeV Value

- Transverse Charged PTsum Density Ratio
  - RDF Preliminary Corrected Data
  - Divided by 300 GeV Value

Durham, September 8, 2015
CMS at the LHC
900 GeV, 2.96 TeV, 7 TeV, 8 TeV, 13 TeV

Sorry to be so slow!!

http://arxiv.org/abs/soon!

Three new PYTHIA-8 underlying event (UE) tunes are constructed, one using the CTEQ6.6L parton distribution function (PDF), one using HERAPDF 1.5 leading order (LO), and one using the NNPDF3.0 LO PDF; two new PYTHIA-8 UE tunes, one for the CTEQ6.6L PDF and one for the HERAPDF 1.5 LO, and one new HERWIG++ UE tune for the CTEQ6.6L PDF are also available. Simultaneous fits to CDF UE data at 300 GeV, 900 GeV, and 1.96 TeV, together with CMS UE data at 7 TeV, check the UE models and constrain their parameters, providing thereby more precise predictions for proton-proton collisions at 13 TeV. In addition, several new double-parton scattering (DPS) tunes are investigated when the values of the UE parameters from fits to observables are consistent with the values determined from fitting DPS-sensitive observables. Also examined is how well the new UE tunes predict “minimum bias” (MB) events, jet and Drell-Yan (gg → Z/γ* → lepton-antilepton+jets) observables, as well as the MB and UE observables at 13 TeV.
Fit the “underlying event” in a hard scattering process.

“Underlying Event”

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

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

1/(p_T)^4 \rightarrow 1/(p_T^2 + p_{T_0}^2)^2

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

Predict MB (ND)!

Predict MB (IN)!

UE Tunes and MB

“Underlying Event”

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

I/PP Seminar
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Most of the time MPI are much “softer” than the primary “hard” scattering, however, occasionally two “hard” 2-to-2 parton scatterings can occur within the same hadron-hadron. This is referred to as double parton scattering (DPS).

\[
\frac{1}{(p_T)^4} \rightarrow \frac{1}{(p_T^2 + p_{T_0}^2)^2}
\]
PYTHIA 6.4 Tune CUETP6S1-CTEQ6L: Start with Tune Z2*-lep and tune to the CDF PTmax “transMAX” and “transMIN” UE data at 300 GeV, 900 GeV, and 1.96 TeV and the CMS PTmax “transMAX” and “transMIN” UE data at 7 TeV.

PYTHIA 6.4 Tune CUETP6S1-HERAPDF1.5LO: Start with Tune Z2*-lep and tune to the CDF PTmax “transMAX” and “transMIN” UE data at 300 GeV, 900 GeV, and 1.96 TeV and the CMS PTmax “transMAX” and “transMIN” UE data at 7 TeV.

PYTHIA 8 Tune CUETP8S1-CTEQ6L: Start with Corke & Sjöstrand Tune 4C and tune to the CDF PTmax “transMAX” and “transMIN” UE data at 900 GeV, and 1.96 TeV and the CMS PTmax “transMAX” and “transMIN” UE data at 7 TeV. Exclude 300 GeV data.

PYTHIA 8 Tune CUETP8S1-HERAPDF1.5LO: Start with Corke & Sjöstrand Tune 4C and tune to the CDF PTmax “transMAX” and “transMIN” UE data at 900 GeV, and 1.96 TeV and the CMS PTmax “transMAX” and “transMIN” UE data at 7 TeV. Exclude 300 GeV data.

PYTHIA 8 Tune CUETP8M1-NNPDF2.3LO: Start with the Skands Monash-NNPDF2.3LO tune and tune to the CDF PTmax “transMAX” and “transMIN” UE data at 900 GeV, and 1.96 TeV and the CMS PTmax “transMAX” and “transMIN” UE data at 7 TeV. Exclude 300 GeV data.

HERWIG++ Tune CUETHS1-CTEQ6L: Start with the Seymour & Siódmok UE-EE-5C tune and tune to the CDF PTmax “transMAX” and “transMIN” UE data at 900 GeV, and 1.96 TeV and the CMS PTmax “transMAX” and “transMIN” UE data at 7 TeV.
CMS data at 7 TeV and CDF data at 1.96 TeV, 900 GeV, and 300 GeV on the charged particle density in the “transAVE” region as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5 \text{ GeV}/c$ and $|\eta| < 0.8$. The data are compared with PYTHIA 6.4 Tune Z2*. 

CMS data at 7 TeV and CDF data at 1.96 TeV, 900 GeV, and 300 GeV on the charged particle density in the “transAVE” region as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5 \text{ GeV}/c$ and $|\eta| < 0.8$. The data are compared with PYTHIA 8 Tune CUETP8S1-CTEQ6L (excludes 300 GeV in fit).
CMS data at 7 TeV and CDF data at 1.96 TeV, 900 GeV, and 300 GeV on the charged particle density in the “transAVE” region 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 compared with the PYTHIA 8 Tune Monash-NNPDF2.3LO.

CMS data at 7 TeV and CDF data at 1.96 TeV, 900 GeV, and 300 GeV on the charged particle density in the “transAVE” region 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 compared with the PYTHIA 8 Tune CUETP8M1-NNPDF2.3LO (excludes 300 GeV in fit).
CMS data at 7 TeV and CDF data at 1.96 TeV, 900 GeV, and 300 GeV on the charged particle density in the “transAVE” region 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 compared with the PYTHIA 8 Tune Monash-NNPDF2.3LO.

CMS data at 7 TeV and CDF data at 1.96 TeV, 900 GeV, and 300 GeV on the charged particle density in the “transAVE” region 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 compared with the PYTHIA 8 Tune CUETP8M1-NNPDF2.3LO (excludes 300 GeV in fit).
Energy Dependence

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

- CMS solid dots
- CDF solid squares
- Tune Z2*-CTEQ6L (solid line)

Center-of-Mass Energy (GeV)

- Charged Particles ($|\eta|<0.8$, $P_T>0.5$ GeV/c)
- $5.0 < P_{T\text{max}} < 6.0$ GeV/c

13 TeV

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

- CMS solid dots
- CDF solid squares
- CUETP8M1-NNPDF2.3LO (solid line)

Center-of-Mass Energy (GeV)

- Charged Particles ($|\eta|<0.8$, $P_T>0.5$ GeV/c)
Energy Dependence

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

<table>
<thead>
<tr>
<th>Center-of-Mass Energy (GeV)</th>
<th>Charged Particle Density</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1</td>
<td>0.2</td>
</tr>
<tr>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>10.0</td>
<td>10.0</td>
</tr>
<tr>
<td>100.0</td>
<td>100.0</td>
</tr>
</tbody>
</table>

CMS solid dots
CDF solid squares

5.0 < \( PT_{\text{max}} \) < 6.0 GeV/c

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

Monash-NNPDF2.3LO (red line)
CUETP8M1-NNPDF2.3LO (blue line)

13 TeV
"TransMAX" Charged Particle Density

13 TeV

Tune Z2*-CTEQ6L (green line)
CUETP8S1-CTEQ6L (black line)
Monash-NNPDF2.3LO (red line)
CUETP8M1-NNPDF2.3LO (blue line)

Average Density
Charged Particles (|η|<0.8, PT>0.5 GeV/c)

0.0 0.7 1.4 2.1 0 5 10 15 20 25 30
PTmax (GeV/c)

"TransMIN" Charged Particle Density

13 TeV

Tune Z2*-CTEQ6L (green line)
CUETP8S1-CTEQ6L (black line)
Monash-NNPDF2.3LO (red line)
CUETP8M1-NNPDF2.3LO (blue line)

Average Density
Charged Particles (|η|<0.8, PT>0.5 GeV/c)

0.0 0.3 0.6 0.9 0 5 10 15 20 25 30
PTmax (GeV/c)

"TransMAX" Charged PTsum Density

13 TeV

Tune Z2*-CTEQ6L (green line)
CUETP8S1-CTEQ6L (black line)
Monash-NNPDF2.3LO (red line)
CUETP8M1-NNPDF2.3LO (blue line)

Average Density (GeV/c)
Charged Particles (|η|<0.8, PT>0.5 GeV/c)

0.0 1.0 2.0 3.0 0 5 10 15 20 25 30
PTmax (GeV/c)

"TransMIN" Charged PTsum Density

13 TeV

Tune Z2*-CTEQ6L (green line)
CUETP8S1-CTEQ6L (black line)
Monash-NNPDF2.3LO (red line)
CUETP8M1-NNPDF2.3LO (blue line)

Average Density (GeV/c)
Charged Particles (|η|<0.8, PT>0.5 GeV/c)

0.0 0.3 0.6 0.9 0 5 10 15 20 25 30
PTmax (GeV/c)
Predictions at 13 TeV

**"TransAVE" Charged Particle Density**

13 TeV

- Tune Z2*-CTEQ6L (green line)
- CUETP8S1-CTEQ6L (black line)
- Monash-NNPDF2.3LO (red line)
- CUETP8M1-NNPDF2.3LO (blue line)

**"TransDIF" Charged Particle Density**

13 TeV

- Tune Z2*-CTEQ6L (green line)
- CUETP8S1-CTEQ6L (black line)
- Monash-NNPDF2.3LO (red line)
- CUETP8M1-NNPDF2.3LO (blue line)
CMS and CDF data on the charged particle density in the “transAVE” region as defined by the leading charged particle (PTmax) for charged particles with p_T > 0.5 GeV/c and |η| < 0.8 with 5 < PTmax < 6 GeV/c. The data are plotted versus the center-of-mass energy (log scale). The data are compared with PYTHIA 6 Tune Z2* and PYTHIA 8 Tune CUETP8S1, Tune Monash, and Tune CUETP8M1.

CMS data at 7 TeV and CDF data at 1.96 TeV, 900 GeV, and 300 GeV on the charged particle density in the “transAVE” region 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 compared with PYTHIA 6 Tune Z2* and PYTHIA 8 Tune CUETP8S1, Tune Monash, and Tune CUETP8M1.
**Predictions at 13 TeV**

CMS and CDF data on the charged PTsum density in the “transAVE” region as defined by the leading charged particle (PTmax) for charged particles with \( p_T > 0.5 \text{ GeV/c} \) and \( \abs{\eta} < 0.8 \) with \( 5 < \text{PTmax} < 6 \text{ GeV/c} \). The data are plotted versus the center-of-mass energy (log scale). The data are compared with PYTHIA 6 Tune Z2* and PYTHIA 8 Tune CUETP8S1, Tune Monash, and Tune CUETP8M1.

CMS data at 7 TeV and CDF data at 1.96 TeV, 900 GeV, and 300 GeV on the charged PTsum density in the “transAVE” region as defined by the leading charged particle (PTmax) for charged particles with \( p_T > 0.5 \text{ GeV/c} \) and \( \abs{\eta} < 0.8 \). The data are compared with PYTHIA 6 Tune Z2* and PYTHIA 8 Tune CUETP8S1, Tune Monash, and Tune CUETP8M1.
Predicting DPS

CMS data at 7 TeV on the normalized distributions of the correlation observables $\Delta S$ (top row) and $\Delta^{rel}_{p_T}$ (bottom row) measured in 4-jet production compared with (left column) the CMS PYTHIA 8 DPS tune CDPSP8S2-4j and with MADGRAPH (MG) interfaced with tune CDPSP8S2-4j; and with (right column) the CMS PYTHIA 8 UE tune CUETP8M1-NNPDF2.3LO.

IPPP Seminar
Durham, September 8, 2015

Rick Field – Florida/CDF/CMS
MB at 13 TeV: $dN/d\eta$

CMS UE Tune CUETP8S1-HERAPDF1.5LO.

EPOS LHC

HERWIG++

$pp, \sqrt{s} = 13$ TeV inelastic

$1/N_{ch} \cdot dN_{ch}/d\eta$

$n_{ch} \geq 1, \rho_T > 500$ MeV, $|\eta| < 2.5$

ATLAS Preliminary $\sqrt{s} = 13$ TeV
The UE tune do a fairly good job predicting the MB data. 
Do not need separate MB tunes!
**ATLAS data at 13 TeV** on the charged particle density (keft) and charged PTsum density in the “transAVE” region as defined by the leading charged particle for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 2.5$. The data are uncorrected and compared with the MC models after detector simulation.
ATLAS data at 13 TeV on the charged particle density (keft) and charged PTsum density in the "transAVE" region as defined by the leading charged particle for charged particles with \( p_T > 0.5 \text{ GeV/c} \) and \( |\eta| < 2.5 \). The data are uncorrected and compared with the MC models after detector simulation.

\( p_T > 0.5 \text{ GeV}, |\eta| < 2.5 \)

\( p_T^\text{lead} > 1 \text{ GeV} \)

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**EPOS does a poor job on the UE!**

**Monash doing well except the turn on region!**

**Very strange behavior by HERWIG++ in the turn on region!**
More 13 TeV Predictions

"TransAVE" Charged Particle Density

13 TeV (generator level)

Average Density

Charged Particles (|\(\eta\)|<2.0, PT>0.5 GeV/c)

PT\(_{\text{max}}\) (GeV/c)

Monash-NNPDF2.3LO (red line)
CUETP8M1-NNPDF2.3LO (blue line)
CUETHS1-CTEQ6L (brown line)

Monash-NNPDF2.3LO (red line)
CUETHS1-CTEQ6L (brown line)

Monash-NNPDF2.3LO (red line)
CUETP8M1-NNPDF2.3LO (blue line)
CUETHS1-CTEQ6L (brown line)

Very strange behavior by CUETHS1 in the turn on region!
"TransAVE" Charged Particle Density: dN/dηdφ

Mapping out the Energy Dependence of the UE

(300 GeV, 900 GeV, 1.96 TeV, 7 TeV, 13 TeV)
"TransAVE" Charged Particle Density: $dN/d\eta d\phi$

**Mapping out the Energy Dependence of the UE**

(300 GeV, 900 GeV, 1.96 TeV, 7 TeV, 13 TeV)

Fake data generated by Rick using the Monash tune with the statistics we currently have at CMS!
Mapping out the Energy Dependence of the UE

(300 GeV, 900 GeV, 1.96 TeV, 7 TeV, 13 TeV)
Measure the “Underlying Event” at 13 TeV at CMS

Measure the UE observables as defined by the leading charged particle jet, chgjet#1, for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 2.0$.

Measure the UE observables as defined by the leading charged particle, PTmax, for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 2.0$ and $|\eta| < 0.8$.

Livio & Rick were part of the CMS Run 1 UE&MB team!
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Proton Proton

Initial-State Radiation

Final-State Radiation

UE@CMS 13 TeV

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UE&MB@CMS

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Sorry to be slow! We hope to have the CMS “Common Plots” finished for the LPCC UE&MB meeting on November 19 and 20!