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

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

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

Do we need separate fragmentation tunes for $e^+e^-$ and hadron-hadron collisions?

I will talk about this in my “tuning” talk on Thursday in the soft QCD session.
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 any 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/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).
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).
CDF data at 1.96 TeV on the density of charged particles, dN/dηdφ, with p_T > 0.5 GeV/c and |η| < 1 for Drell-Yan production as a function of P_T(Z) for the “toward”, “away”, and “transverse” regions compared with PYTHIA Tune DW.

CMS data at 7 TeV on the density of charged particles, dN/dηdφ, with p_T > 0.5 GeV/c and |η| < 2 for Drell-Yan production as a function of P_T(Z) for the “toward”, “away”, and “transverse” regions compared with PYTHIA Tune DW.
CDF: Proton-Antiproton Collisions at 1.96 TeV
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 TeV
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: Proton-Antiproton Collisions at 1.96 GeV
Lepton Cuts: $p_T > 20 \text{ GeV} \ |\eta| < 1.0$
Mass Cut: $70 < M(\text{lepton-pair}) < 110 \text{ GeV}$
Charged Particles: $p_T > 0.5 \text{ GeV/c} \ |\eta| < 1.0$

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

- **CDF data at 1.96 TeV** on the density of charged particles, $dN/d\eta d\phi$, with $p_T > 0.5 \text{ GeV/c}$ 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 DW.

- **CMS data at 7 TeV** on the density of charged particles, $dN/d\eta d\phi$, 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 DW.
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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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.

CMS data at 7 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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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 jet (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 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 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.
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)
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!
## 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>
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<tr>
<td>PARP(89) – Reference energy, E0</td>
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<tr>
<td>PARP(90) – MPI Energy Extrapolation</td>
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<tr>
<td>PARP(77) – CR Suppression</td>
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<tr>
<td>PARP(78) – CR Strength</td>
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<tr>
<td>PARP(80) – Probability colored parton from BBR</td>
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<td>0.1</td>
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<tr>
<td>PARP(83) – Matter fraction in core</td>
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<td>0.356</td>
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<tr>
<td>PARP(84) – Core of matter overlap</td>
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<td>0.651</td>
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<tr>
<td>PARP(62) – ISR Cut-off</td>
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<td>1.025</td>
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<tr>
<td>PARP(93) – primordial kT-max</td>
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<td>10.0</td>
</tr>
<tr>
<td>MSTP(81) – MPI, ISR, FSR, BBR model</td>
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<td>21</td>
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<tr>
<td>MSTP(82) – Double gaussian matter distribution</td>
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<tr>
<td>MSTP(91) – Gaussian primordial kT</td>
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<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!**
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 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 (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 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.
CMS data at 900 GeV on the “transverse” charged particle density, $dN/d\eta d\phi$, as defined by the leading charged particle jet (chgjet#1) for charged particles with $p_T >$ 0.5 GeV/c and $|\eta| < 2.0$. The data are corrected and compared with PYTHIA Tune Z1 at the generator level.

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

CDF data at 1.96 TeV on the “transverse” charged PTsum density, dPT/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.
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.
PYTHIA Tune Z1

Tune Z1 describes the energy dependence fairly well!

- 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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**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 $P_T(Z)$ for the “toward”, “away”, and “transverse” regions compared with PYTHIA Tune Z1.

**CMS data at 7 TeV** on the charged PTsum density, $dP_T/d\eta d\phi$, 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.
PYTHIA Tune Z1

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

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

CDF 1.96 TeV
CMS 7 TeV
CMS 900 GeV

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

- Charged Particles (PT>0.5 GeV/c)

CDF 1.96 TeV
CMS 7 TeV

Drell-Yan Production
Chgjet Production

RDF Preliminary data corrected pyZ1 generator level

QCD@LHC, St. Andrews, Scotland
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PYTHIA Tune Z1

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

- CDF 1.96 TeV
- CMS 900 GeV
- CMS 7 TeV
- RDF Preliminary

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

- CDF 1.96 TeV
- CMS 7 TeV
- Charged Particles ($|\eta|<2.0$, $PT>0.5$ GeV/c)
- Drell-Yan Production
- Charged Particles ($PT>0.5$ GeV/c)
- Tune Z1

Charged Particles (PT>0.5 GeV/c)

Drell-Yan Production

Cms Preliminary

RDF Preliminary

pyZ1 generator level

7 TeV

Chgjet Production

Charged Particles (|\eta|<2.0, PT>0.5 GeV/c)
Overall amazingly good agreement with the LHC and Tevatron Jet production and Drell-Yan! (although not perfect yet)

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

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

Majority of “min-bias” events!

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

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

The "underlying-event" (UE)!

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

"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".

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

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

Model of the inelastic non-diffractive cross section!

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

“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”

1/(p_T)^4 \rightarrow 1/(p_T^2 + p_T^0)^2

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

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

Predict MB (ND)!

Predict MB (IN)!

Single Diffraction

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

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

“Minimum Bias” Collisions

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

“Minimum Bias” Collisions

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

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

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

QCD@LHC, St. Andrews, Scotland
August 22, 2011

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MB versus UE

**ATLAS data** on the density of charged particles in the “transverse” region as a function of PTmax for charged particles (pT > 0.1 GeV/c, |\(\eta\)| < 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 \(\eta-\phi\), \((1/N_{\text{NSD}}) \, dN/d\eta d\phi\).
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.

“Minimum Bias” Collisions

Okay not perfect, but remember we do not know if the SD & DD are correct!
Generator level charged multiplicity distribution (all pT, |η| < 2) at 900 GeV and 7 TeV. Shows the NSD = HC + DD prediction for Tune Z1. Also shows the CMS NSD data.

“Minimum Bias” Collisions

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

CMS corrected data at 900 GeV and 7 TeV on the charged particle multiplicity distribution in the "transverse" region for charged particles (\( p_T > 0.5 \text{ GeV/c}, |\eta| < 2 \)) as defined by the leading charged particle jet with \( p_T(\text{chgjet#1}) > 3 \text{ GeV/c} \) compared with PYTHIA Tune Z1 at the generator level.

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